Decision Process in One-of-a-kind Production

Authors:
Agnar Johansen, SINTEF Technology and Society, Trondheim, Norway
Asbjørn Rolstadås, Norwegian University of Science and Technology, Trondheim Norway

Corresponding author:
Professor Asbjørn Rolstadås
Department of Production and Quality Engineering
Norwegian University of Science and Technology
Trondheim, Norway
E-mail: asbjorn.rolstadas@ntnu.no
Phone: +47-90793707
Fax: +47-73597117

Decision Process in One-of-a-kind Production

Abstract

One-of-a-kind production is project business. In any project, the decision process is of importance for a successful outcome. However, there is a need for a more formal approach to decision making in projects. We have therefore developed a model of the decision process. It uses three types of decisions: selection, authorization, and plan decisions. Enterprise models together with the project life cycle form a platform for developing a decision model. The life cycle enables a decision chain whereas the enterprise models allow decisions at different levels. The horizontal decision chain is linked to physical flow of documents and materials. Vertically, decision making is hierarchically decomposed into levels of different planning horizons and time periods.

Keywords:

Project Management, One-of-a-kind Production, Decision Making, Enterprise models, Project Risk Management.

1. Introduction

Traditionally there are three types of manufacturing:

- Mass production
- Batch production
- One-of-kind production (OKP)

The main difference is in the batch size. This classical view is considered insufficient and has been replaced by a thinking where the customer order is followed backwards into the enterprise along the production chain. The question is at what stage in this chain the customer order releases activity. We denote this stage as the *customer order decoupling point*. Different alternatives are shown in Figure 1 (Wortmann et al. 1997; Rolstadås 2008). As it can be seen, OKP is always released by the acceptance of a customer order.

The above applies to a single factory. If several suppliers are involved, we have a *supply chain*. Supply chain management (SCM) is the process of managing relationships, information, and materials flow across enterprise borders to deliver enhanced customer service and economic value (Mentzer 2001; Gourdin 2001). Asbjørnslett (2003) has taken the SCM concept from the manufacturing industry and applied it to projects. He refers to this as project supply chain management.

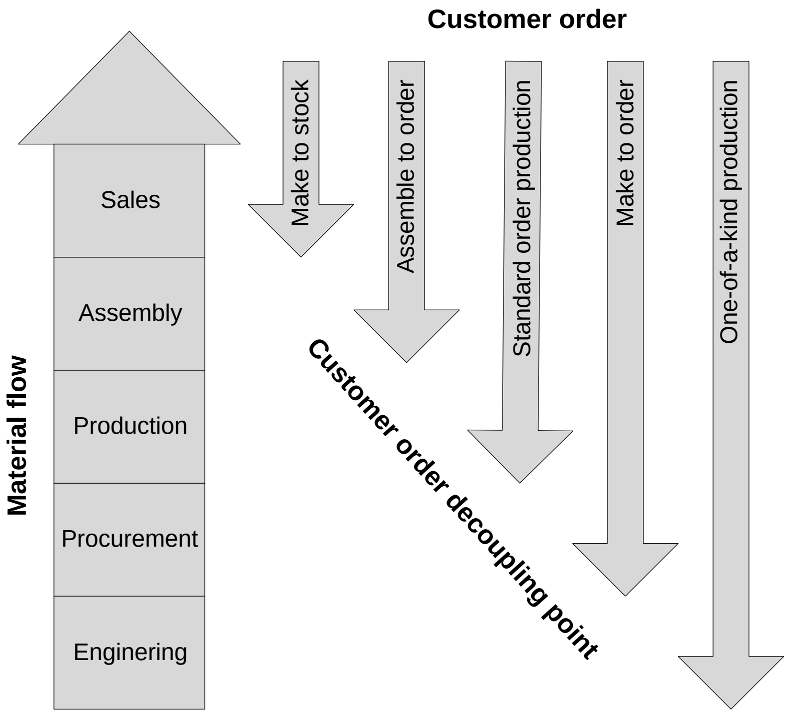


Figure 1 Production typology based on customer order decoupling point.

A *project* is another term for OKP. The Project Management Institute (PMI) defines a project as (PMI 2013):

> *"A temporary endeavor undertaken to create a unique product or service"*

The one-of-a-kind (uniqueness) aspect is the main characteristic of a project.

The result of the project is often some type of facilities or products. To achieve the results normally requires application of technology. The execution of the project is handled by a temporary organization. This requires organizational competence in order to succeed.

The project results and the process of making the results are *technical* aspects of a project. The *organizational* aspects are leadership and management of the personnel involved. This combination of technical and organizational aspects is important for the understanding of what leads to a successful project. In addition, there are of course financial aspects to be considered in any project. Project management includes management of the personnel involved (organizational aspects) as well as management of the process of making the project results (technical aspects).

The distinction between the technical and organizational aspects of the project is supported by several authors in literature (Doumeingts et al. 1995; Rolstadås 2008). Some of these refer to what they call different schools of thought (Bredillet 2007; Söderlund 2010).

Many think of decision making as one of the core activities of a project manager. Thus, competence in decision-making and tools to aid the decision process is of crucial importance for project success. But, how formalized is the decision making process in projects?

Fischer and Adams (2011) have studied engineering-based decisions in construction and claimed that the (construction) industry has a crying need for engineers to ensure that field decisions are made using the required level of technical analysis. They also point to the fact that decisions must be made “in the heat of the battle”; every minute counts, and there is no place to “hide”. Arroyo (2014) has done interviews and case studies and found that:

- Decisions are rarely documented
- Rationale is not clear
- Formal decision-making methods are seldom used
- Decision-making process usually lacks transparency and does not help in building consensus or continuous learning
- Multiple stakeholders with different perspective and conflict of interests are involved

Our literature review has uncovered a large number of decision framework that have been developed over the last 20 years. Some of these have their focus on levels of decision-making in organizations depending on the purpose of the management activity, i.e. strategic decisions, tactical decisions, and operational decisions (Anthony 1965). Other scholars have had focus on computational decision support technology (Tu et al. 2006). Some have studied standardization of phase, steps and the gate keeping process (Morris 2004) involved in OKP, and others has focused decision making in daily meetings (Stray et al. 2012).

We will argue that a more formal and rigorous approach to decision-making is needed. This will improve the quality of the decision and develop commitment and understanding in the project organization. We believe that the model we present in this paper is a contribution to obtaining better decisions. We have not found much research documenting the consequences of wrong decisions. However, Flyvbjerg et al. (2003) have found that in nine out of ten cases, cost of megaprojects are underestimated. He claims that the reason is “misinformation” and says that this destabilizes the decision-making in a project. This view is supported by two Norwegian case studies in 2009 and 2013 (Krane et al. 2014) where risks and opportunities were analyzed. This research revealed that there are more risks than opportunities focused in both the private and the public sector.

Short and Kopp (2005) have studied transport infrastructure projects and argued the need for improved planning and decision-making. They point to better explanation of decision methods as a solution to the problem.

Marques et al. (2010) are looking at projects as complex systems. They claim that when complexity becomes sufficiently large, the possibilities and interrelations become so fuzzy that decision-making has to be assisted by appropriate tools and skills. They argue for the need for a modelling approach to decision making. Brady and Davies (2014) also support this view.

Virine and Trumper (2008) also see decision-making as complicated and give the following reasons for this: (1) most problems involve multiple objectives, (2) project managers deal with uncertainties, (3) project management problems can be complex, and (4) most projects include multiple stakeholders.

In our view, the decision making process is of crucial importance for successfully managing projects (OKP). Decisions are taken at various levels and at different time in the project life cycle. Thus, we distinguish between a *decision chain* and *decision levels*. This paper will explore this further and will present a model for decision making in OKP.

We will start by defining our research approach (Section 2), and proceed with some background on decision-making in projects based on recently published research (Section 3). Then (Section 4) we will review the research literature. Finally (Section 5), we will present our model for the decision process in OKP and illustrate this with an example.

2. Research approach

The work reported in this paper utilized several approaches and research methods. First, a literature review was conducted on existing decision frameworks and models in order to understand what aspects they encompass. A search for sources that have proposed different relevant frameworks was conducted through relevant library and science databases covering journals that we considered relevant (e.g., *Production Planning and Control*, *International Journal of Project Management*, *Journal of Engineering Design*, *International Journal of Computer Integrated Manufacturing, Computers in Industry*, *Production & Manufacturing Research* and other academic journals that covers decisions in OKP (projects).

Next, the principles of design science (March and Smith 1995, Hevner et al. 2004, Dresch et al. 2014, Eekels 1991)) were applied to develop an alternative decisions framework. The design process was initiated from the gap not covered by existing frameworks. However, the strengths of existing frameworks were used as guidelines for the design of the alternative model. As prescribed by proponents of design science, the development was carried out through an iterative process of identifying requirements, developing conceptual solutions, evaluating these, and further refining the most promising ones until a final design was reached. Ultimately, a new decision framework was developed that built on existing ones.

Finally, a simple example was used to demonstrate how the new decisions framework could be applied to actual projects. As described by Siggelkow (2007), the purpose of an illustrative example is not an attempt to verify empirically the proposed framework as this would require further research, in which the framework would be applied to a larger set of case projects and systematically evaluated, something we intend to do in the future. Rather, as in our case, the purpose of an example is to provide a description of how the framework can be applied in practice, thus both aiding readers in understanding how the framework has been composed and what the different aspects of the framework entail in practice.

3. Decision process in projects

In any project, there are three control variables (Kerzner 2012; Meredith and Mantel 2012; Rolstadås 2008):

- Scope of work
- Time
- Cost

A project plan thus includes three documents referred to as *WBS* (Work Breakdown Structure), *schedule*, and *cost estimate*. These three documents comprise the *project control baseline*. Management of risk is important in all projects and uncertainty could thus comprise a fourth control variable. However, most of the literature embeds uncertainty into the three control variables listed.

Major project oriented enterprises have developed a *project execution model* splitting the project into a number of *phases* and defining the major decision points. An example is shown in Figure 2. Such decision points are referred to as *decision gates*. The idea behind this is that there are certain conditions for being allowed to enter through the gate. A gatekeeper is responsible for checking whether the conditions are met and then authorizes passing the gate.

Figure 2 shows the three typical phases a project is running through and some associated decision gates (DG). The sequence of project phases is usually referred to as the *project life cycle*. Our life cycle ends when the project is handed over to the owner. There are, however, life cycle models that include the use and demolition of the project delivery. Some models also include the preparation of the business case. They are referred to as the *capital value process* (Rolstadås 2008).

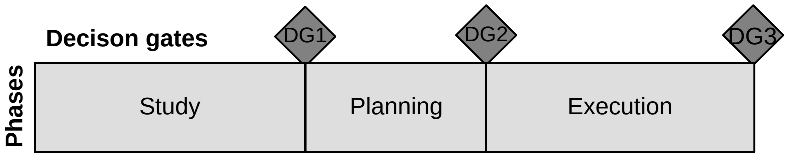


Figure 2 Project execution model

Traditionally, decision-making is about identifying problems, analyzing, developing and choosing between alternative courses of action to achieve a desired objective. However, as we shall see, our scope is broader: we will suggest that decision-making is more than the selection from alternatives. Several models for decision-making exist. Simon (1960) proposed a model that has three steps:

1. Intelligence activity
2. Design activity
3. Choice activity

Drucker (1955) defined a model with six steps by adding an action and follow-up activity to Simon's model:

1. Define the Problem
2. Analyze the Problem
3. Develop Alternative Solutions
4. Decide on the Best Solution
5. Convert decisions into Effective Actions
6. Follow-up on actions taken

Rolstadås et al. (2014) have published a model of the decision process. They extended this to include feedback as shown in Figure 3. A core part of this is the decision preparation, taking input from results achieved, future plans, problems identified, and policies deployed. This is the state for the decision. The preparation uses decision factors, which are variables to take into account. It is facilitated by application of decision methods. The decision will produce some action leading to a result.

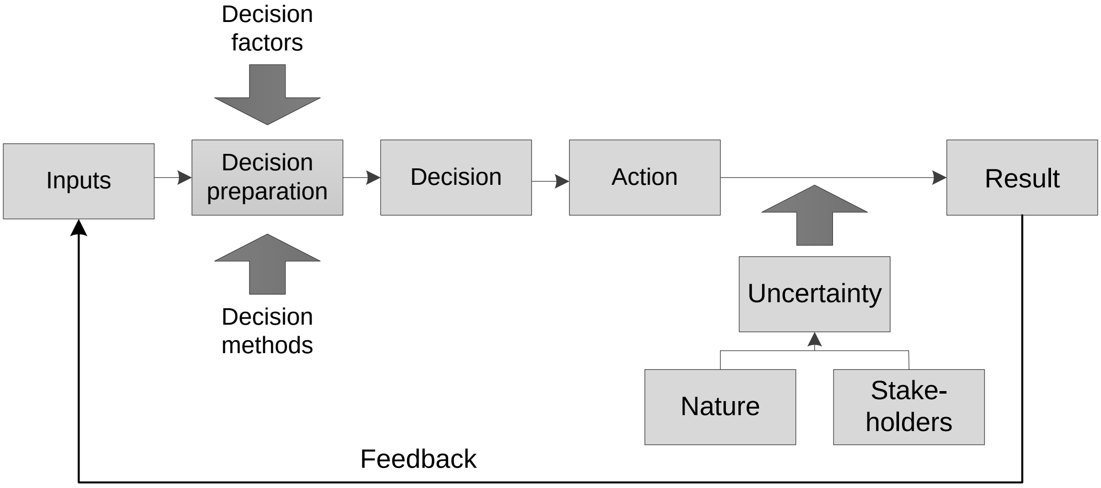


Figure 3 Decision-making process.

This model corresponds to the model published by Drucker (1955). Decision preparation corresponds to step 1, 2 and 3, decision corresponds to 4, and action corresponds to 5 and 6.

Rolstadås et al. (2014) defines three types of decisions:

- Selection decisions
- Authorization decisions
- Plan decisions

Selection decisions are the selection of one (or more) alternative(s) from a list of options. Typically, they are concerned with finding “the best” solutions from a number of potential alternatives. Often a selection decision includes ranking the alternatives as well. This decision is fundamentally what is discussed and covered by the rational decision making model developed by Simon (1960) and Drucker (1955).

Authorization decisions are go/no-go, yes/no, go/stop decisions. Some decision background data are developed and used for the decision-making. An example could be the investor looking at a prospect and reviewing its capital exposure, payback time, net present value (NPV), and internal rate of return (IRR) before saying yes or no.

Plan decisions are the approval of plans that establish what to do, how, and when. Other details may also be included, for example a budget or the preferred choice of a contractor. Inherent in a plan decision is an authorization to initiate the plan. In this way, it differs from the authorization decision, which is merely a go/no-go decision. Plan decisions initiate activity that will accomplish the project objectives and deliver the results by synchronization of products and resources. Plans are also used to monitor work progress and to decide on necessary corrective actions. Plans may be changed according to a range of factors: requests from the owner (changed authorization); decisions to correct errors (for example, a design that proves to be infeasible); to improve the project results (for example, taking advantage of new technology); or to reduce costs. Plan decisions also include decisions to initiate corrective actions and incorporate approved changes in the plans, and in addition to initiate and monitor any actions following from these changes. The formal approval of a single change order is a go/no-go decision (authorization decision).

All projects carry risk. Risk is closely connected to the decision making process (Rolstadås et al. 2011). Any decision introduces some risk or opens some opportunity. At the same time, decisions are often made to mitigate risk or to capitalize on an opportunity. Managing risks may lead to changes in plans. Such decisions require a higher level of understanding and creative thought than the original plan did (Fischer and Adams 2011).

Decisions in a project are linked to risk and uncertainty in two ways:

- Decisions are taken to mitigate risk
- Decisions taken introduce uncertainty

With reference to Figure 3, we see that actions from a decision are influenced by uncertainty, which means that the result could differ from what we want to achieve. There are two main sources of this uncertainty:

- Nature
- Stakeholders

Nature means that any person or organization cannot influence it. It is beyond human control. It spans a range from extreme forces with low frequency such as major earthquakes to normal forces of high frequency such as bad weather conditions.

Any person or organization that can influence the project and its results or can be affected by the project and its result is called a *stakeholder*. Consequently, stakeholders introduce risk, as their reactions cannot be fully predicted.

There are three fundamental categories of decision problems:

- The results are known with certainty. Such problems are called *decision under certainty*.
- The probability distribution of the result is known. Such problems are called *decision under risk*.
- The probability distribution of the results is unknown. Such problems are called *decision under uncertainty*.

The first type represents a deterministic decision where we assume none of the decision factors carry uncertainty. Although we can argue that such situations hardly exist, decisions are taken without considering uncertainty or risk. The latter two decision types are stochastic decisions as they consider uncertainty and risk. There are a large number of available tools and methods to aid the decision process. However, it is beyond the scope of this paper to discuss this further. We will concentrate on the decision process (independent of the applied decision method) and see how this can be modelled.

4. Literature review

We have developed a model for the decision process in OKP. We have studied the literature on OKP, decision support, and enterprise modelling. Although there is a rich literature, we have not found literature that focuses on the decision process in OKP directly based on the physical production process.

4.1 One-of-a-kind production

Up to the late 1980ies, production management research in the manufacturing domain was mainly focused on repetitive production. However, the European Union initiated research on theory for OKP in its ESPRIT research program. The editorial of the PPC journal 3(2) discussed OKP and argued that the market pull for customized products was a major driving force (Rolstadås 1992). Wortmann (1991) claimed that OKP was the future of the European industry and introduced terms such as *customer driven engineering and manufacturing*. Rolstadås (1991) published a framework for managing OKP and suggested a scheme for changing the production resource structure to meet the changes of product structure.

The allocation of resources to the product being produced, is a central problem in OKP. It is closely linked to the scheduling activity. A number of authors have discussed scheduling in OKP. Choi and You (2006) presents an extensive performance analysis of dispatching rules for dynamic scheduling in OKP where each job has its own due-date and multilevel routing structure. A framework of dynamic dispatching rules is proposed together with a simulation framework to identify five dispatching rules.

Liu and Tu (2008) discuss a dynamic capacitated production planning problem in small to medium-sized enterprises who base their businesses based on the OKP manufacturing paradigm. They specifically look at outsourcing. Herroelen and Leus (2005) look at project scheduling taking uncertainty into account. They claim that project activities are subject to considerable uncertainty, and have performed a survey where they review the fundamental approaches for scheduling under uncertainty such as reactive scheduling, stochastic project scheduling, fuzzy project scheduling, robust (proactive) scheduling and sensitivity analysis.

Grabenstetter and Usher (2015) are looking at sequencing of jobs in an engineer-to-order engineering environment. They present a framework to solve the problem of determination of an accurate schedule within a complex transactional process for jobs which have not been designed.

Gosling et al. (2015) discuss principles for the design and operation of engineer-to-order supply chains in the construction sector. A set of five design principles are identified and provide a foundation for sound supply chain design.

Because of the extra complexity introduced with OKP, knowledge management competence is crucial. Xie et al. (2003) have worked with rapid OKP product development and published a literature review of the state-of-the-art. They discuss future trends of Internet-based collaborative design, decision support, manufacturing support, supply chain management, workflow management, Internet techniques for product design and manufacturing, product modelling, STEP-based data environment, concurrent engineering, etc.

Xie et al. (2005) propose an Internet-based reconfigurable platform for rapid OKP product development that has been prototyped to serve as a substrate for integrating innovative tools and systems for OKP companies in New Zealand. They investigated how to build such a platform and to design appropriate intelligent tools and systems for the purpose of rapidly and economically producing OKP products in the global environment.

4.2 **Enterprise modelling**

Modelling of decision processes is different depending on whether we consider a single decision problem or a set of decisions. There is a rich literature on decision theory showing, different modelling approaches. However, our scope is to look at chains of decisions in managing projects (OKP). To model this, we have to study the enterprise architecture and the project life cycle. In other words, we have to consider both the organization of the resources (in a hierarchy) and the flow of documents and materials in a chain.

The European EU project FOF (Factory of the Future) was one of the first attempts to model both the resources and material flow (Wortmann et al. 1997). FOF was looking at design and redesign of a production system. It used performance indicators to illustrate the effect of different design choices. It had an intermediate level to handle the relationship between design choices and performance indicators. The FOF project also showed that the model may be viewed through different lenses. It looked at a workflow view, a resource view, and an organizational/decisional view.

The Finnish scientist Lauro Koskela (2000) further developed the conceptual model of the FOF project to the TFV (transformation-flow-value) theory of production.

Partly in parallel with the FOF project, another large EU project, CIMOSA, developed an enterprise model (Kosanke et al. 1999). CIMOSA uses a reference architecture with three modelling levels:

- Generic model
- Partial model
- Particular model

At each level, four different views are supported:

- Function view
- Information view
- Resource view
- Organization view

CIMOSA also supports the complete life cycle of the enterprise operations. It distinguishes between:

- Requirements definition model
- Design specification model
- Implementation description model

The *GRAI method* developed at the University in Bordeaux is an enterprise modeling tool originally developed for production management (Doumeingts et al. 1995). It is a tool for designing or redesigning a decisional system. The papers written by Ridgway (1992) and Wortmann et al. (1997) demonstrate that this tool can also be used to analyze decision centers and information and decision flow in the management of a large project.

The GRAI model splits the production management and the project management system into three subsystems: the physical system, the information system and the decisional system.

The *physical* system consists of all the activities related to realization of the physical production of a product. The physical system comprises both the flow of technical documents and the material flow.

The *information* system collects and stores information on the physical and decisional activities and provides information to these activities.

The *decisional* system is composed of all the control *decision centers* aimed at managing the physical system. The control decisions are based on period decisions respectively event-driven decisions. Period-decisions are top-down activated and event-driven are bottom-up activated by the feedback, for example when an activity is finished.

GRAI uses the $IDEF_0$ formalism. IDEF modelling languages arose in the 1970ies from the US AirForce computer integrated manufacturing program, and can be used to model decisions, actions, and activities of an organizational system (Gastinger and Szegheo 2000).

Enterprise modelling attracted a lot of research interest during the 1990ies, but later lost momentum as it was not a priority research topic in the research framework of the European Union. It has gained some interest later, but then with a slightly different focus on integration and interoperability. As an example, Chen et al. (2008) discuss basic concepts of enterprise architecture and argue for integration and interoperability. They refer to architectures such as CIMOSA, PERA (Williams 1994, Scheer 1994) and discuss how these architectures could be harmonized to operate together.

Vernadat (2002) recalls challenges and rationale for enterprise modelling and integration, and points out substantial results achieved so far as well as potential difficulties and pitfalls to make enterprise modelling and integration a reality.

Doumeingts et al. (2000) demonstrate the usefulness of enterprise modelling to implement enterprise resource planning software. They review the evolution of production management in the new enterprise and present the status of enterprise modelling methodology (particularly the GRAI methodology), and discuss the difficulties to implement ERP and the role of enterprise modelling methodology in this implementation.

Enterprise modelling is closely connected to organizational performance and different organizational models. The pioneer work on organizational models was published by Minztberg (1980). He describes five basic organizational configurations: (1) simple structure, (2) machine bureaucracy, (3) professional bureaucracy, (4) divisionalized form, and (5) adhocracy. The professional bureaucracy is in our context of special relevance. Mintzberg says that the professional bureaucracy relies on the standardization of skills in its operating core for coordination; jobs are highly specialized but minimally formalized, training is extensive and grouping is on a concurrent functional and market basis, with large sized operating units, and decentralization is extensive in both the vertical and horizontal dimensions.

4.3 Decision support

The literature on decision support is vast. We will here focus on a few papers that are relevant for decision support related to management of OKP.

The PPC journal published a special issue in 2014 on collaborative decision-making and decision support systems for enhancing operations management in industrial environments. Boza et al. (2014) published a model-driven decision support system architecture for delivery management in collaborative supply chains with lack of homogeneity in products. It is intended to help the person in charge of delivery management to reallocate the available real inventory to orders to satisfy homogenous customer requirements in a collaborative supply chain of a ceramic tile collaborative. Maheut et al. (2014) have developed a decision support system for modelling and implementing solutions to the supply network configuration and operations scheduling problems in the machine tool industry. They present a decision support system to simultaneously solve the supply network configuration problem and the operations scheduling problem for the machine tool industry. It contains a novel database structure capable of considering alternative operations and alternative bills of material. They demonstrate their approach through a case study from a Spanish company that assembles highly customised machines and tools in several European plants.

There is also some work published on decision support in rapid product development. Xie (2006) has developed a decision support system for rapid one-of-a-kind product development. He claims that a decision support system is a specific class of computerized information systems that support decision-making activities, and that such a system has become paramount in supporting manufacturing activities with the development of World Wide Web technology in recent years. The underlying architecture of the proposed system is a system that manages and optimizes data, information and knowledge in the product development process.

Viciens et al. (2001) have developed a methodology for decision support in hierarchical production planning in an enterprise integration context. They use the GRAI method and describe a physical, information and decision system.

Mafakheri et al. (2008) propose a decision aid model using *fuzzy set theory* for assessment of project agility. It considers multiple dimensions for *agileness* and the proposed model provides an opportunity for using a range of aggregation operators to determine the *index of agility*.

Based on the Simon's (1960) principles of bounded rationality to decision-making, Gidel et al. (2005) develop a *decision-making framework methodology* for *project risk* management in new product design. The decision-making framework facilitates the process of deciding whether to take risks, take action to reduce the causes of risks, take action to reduce the consequences of risk or take action to improve the detection of risks.

Barton and Love (2000) use the idea of *decision chains* to argue that product design decisions are part of a chain of decisions that extend to the design and operation of the 'downstream' processes that ultimately manufacture and support the product. The decision process moves from the abstract to the concrete with the solution on one level becoming part of the requirements and constraints on the next level.

5. Decision process model for OKP

Decision making in production management is a multi-dimensional problem. Decisions can be structured according to several dimensions:

- A production view – products and resources
- A decisional level view – decisional and information links
- An organizational view – decisional centers
- A management function view – to manage product, to manage resources, to plan
- A time view – time-independent (static) and time dependent (dynamic)
- A deterministic and stochastic view;

Several mathematical representations are in use, acyclic and cyclic networks and nesting. There exist deterministic or stochastic tools to analyze and simulate systems.

As shown in the literature review (Section 4), there are several enterprise modelling architectures available. They all have their main focus on describing activities of the enterprise (the physical, information and organizational systems), some to a degree allowing simulation of operations. The GRAI model has its main focus on modelling the decision system. As our objective is to formalize the decision process in one-of-a-kind production, we find that GRAI suits best for modeling of the decision process.

The physical system and the decision system are supported by the information system as shown in Figure 4. The decision system is really the control system and includes three elementary control functions:

- Product management (flow management decisions)
- Planning (decisions on synchronization and co-ordination between product flows and resource capacities)
- Resource management (capacity management decisions)

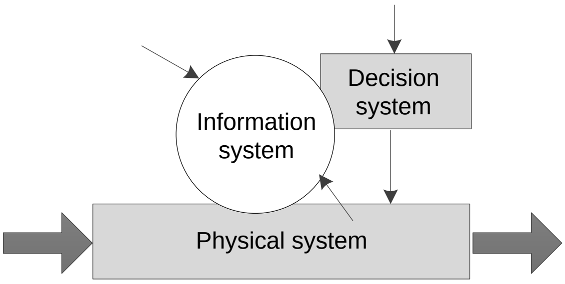


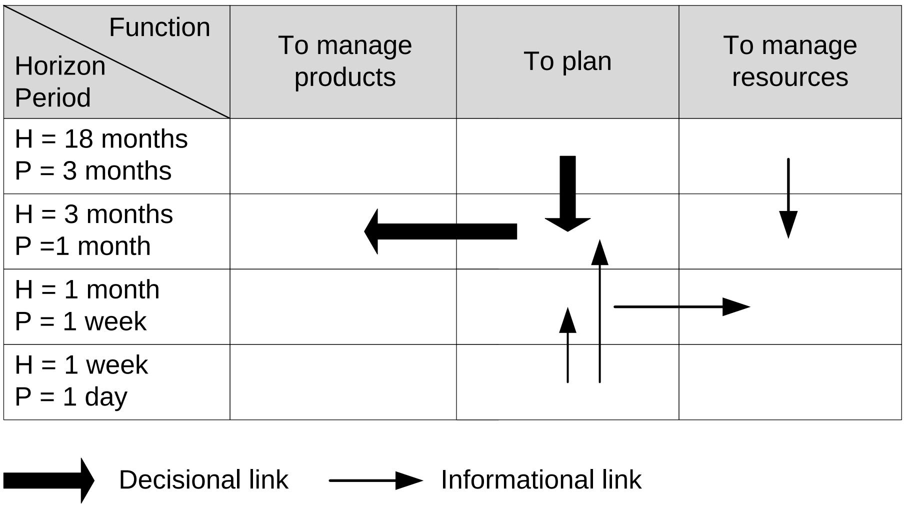
Figure 4 GRAI conceptual model

The GRAI model builds on two formalisms for the decision-making (Doumeingts et.al.,1995;Wortmann et al.,1997): the GRAI grid and the GRAI net. The GRAI net is the micro-model of the decisional structure and was developed as a graphic tool for representing decisions made in the decisional centers. It falls beyond the purpose of this paper to discuss this further.

The GRAI grid is a macro-model of the decisional structure representing the hierarchical and horizontal structure of the decision centers. The grid comprises a matrix of rows and columns, where the columns are the three elementary functions whereas the rows are different levels of decision-making. Thus, a decision needs to be taken with reference to a horizon of time. Therefore, the criterion of decomposition and structuring of decisions is based on time, with two related concepts - the decision horizon and the decision period. The decision horizon refers to the length of time which the decision maker is looking ahead and expects the decision to be valid for (the horizon usually depends on activity lead times). The decision period relates to the interval of time after which the validity of the decision is reconsidered.

Accordingly, the grid serves as a map on which the decisional activities within a business entity can be mapped (Figure 5). Each cell in the grid is a *decision center.* The solid arrows show flow of decisions frames. A decision frame represents a set of conditions for the decision-making such as constraints, criteria, etc. The thin arrows shows flow of information.

Figure 5 is a simplified illustration only focusing on the essential elements explained. The grid can be extended with more columns.



Function Horizon Period	To manage products	To plan	To manage resources
H = 18 months P = 3 months			
H = 3 months P =1 month			
H = 1 month P = 1 week			
H = 1 week P = 1 day			

Figure 5 The basic GRAI grid with Decisional and Information feedback links

Each of the decisional centers is connected to a project control review process. The project control review is hierarchically structured according to the GRAI grid (Figure 5). It is by analyzing the GRAI grids (and nets) and its information and decisional links, a full understanding of how the review process is operated. The review assesses the progress of the project and identifies factors, that may cause the project to miss its target, and thus needs corrective action. For example, the one month horizon represents the decisions taken and activities performed at the monthly progress review. The one week review period represents a week review assessing the progress of the decisions taken at the monthly review (Ridgway 1992).

Decisions are taken at different levels of the organization. If we look at the interface between two adjacent decisional levels, it is proposed to break the modelling process into more manageable parts by dividing it into two principal steps (Franksen 1972):

1. Design of a technique (re-engineering)
2. Operation of a technique

The first step is one of *synthesis* in which we *specify* a system configuration by stating its structural properties. This step describes uniquely the inter-relationships between resources and the decision processes. Design of a technique is an open-ended problem in which we establish, heuristically, a production and decisional system in terms of its causal logic-physical and temporal relationships. The second step is one of *analysis* in which we *investigate* a specified system configuration in order to operate it more efficiently or economically. This decomposition is also in agreement with the concept of time-horizons in economic theory and production planning. Operation of a technique is a *short-run* situation where it is only possible to increase/decrease the services of certain resources such as purchase of raw material. Design of a technique is a *long-run* situation where it is possible to vary the structure of the production method by substitution of system configurations implying time-consuming processes. Thus, all factors and technical coefficients can be made variable. These two steps can be generalized and nested to several levels of decision making as it is also represented by the GRAI grid.

Rolstadås et al. (2015) introduce the concept of a decision chain for projects. The idea is to define a chain of decisions during the project life cycle. It uses the classification of decisions into authorization, selection and plan decisions (Rolstadås et al. 2014). The chain is built from a number of *primitive decision elements*. Each element is triggered by an authorization decision, which is typically a decision gate. The element contains a process selection (selection decision) and task execution (plan decision).

The decision chain and more precisely, the OKP project activity network, express the ordered sequence of decisions ordered on a time line. This is one aspect of time. The other aspect of time is expressed by the GRAI grid where decision-making of planning and control is hierarchically decomposed into levels of different horizons and time periods. A primitive decision element can therefore be represented by a grid for each of the phases of the project life cycle as illustrated in Figure 6.

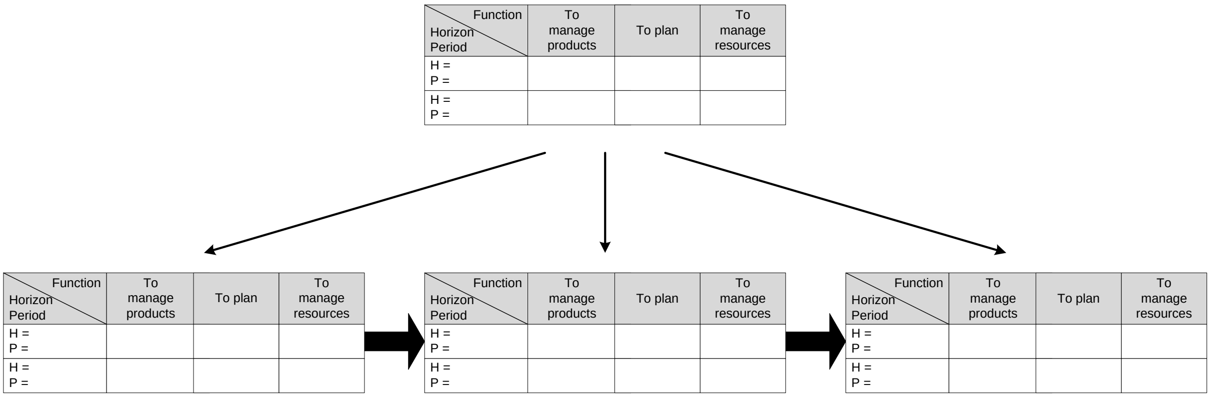


Figure 6 Decision chain with project life cycle and overall management structure.

To summarize, we have structured the decisions according to two aspects of time: horizontal into a causal *decision chain,* and vertical into *decision levels*. The purpose of this is to formalize the decision process in OKP projects. This will contribute to reducing the problems described by Fischer and Adams (2011) and highlighted in Section 1. Once the decisions have been identified and classified (authorization, selection or plan), then appropriate decision methods can be identified.

We will illustrate our method with a brief example from the oil and gas industry. Offshore oil and gas exploration today uses to a large extent subsea facilities rather than platforms (floating or gravity based). This involves installing equipment on the seafloor at water depths hardly accessible by divers. However, this equipment needs to be protected from damage from other businesses such as fisheries. For this reason, a steel frame cover is placed over the equipment.

In our example, such a steel frame cover is ordered from a steel erection yard through a contract with the operating oil company. The physical process for the yard includes both a material flow and a document flow. The document flow represents the development of the specifications for the fabrication process whilst the material flow is the fabrication process itself. The involved steps in the two flows are depicted in Figure 7.

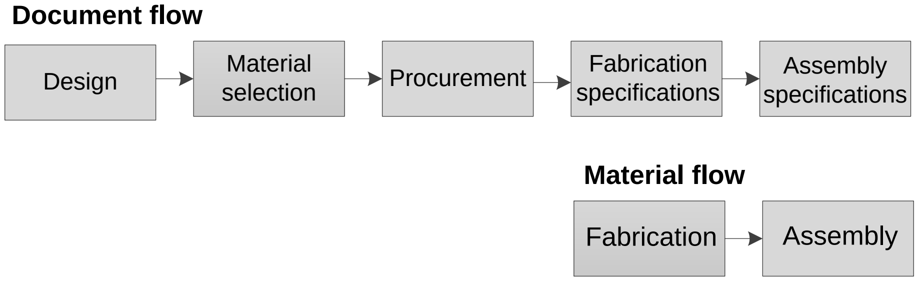


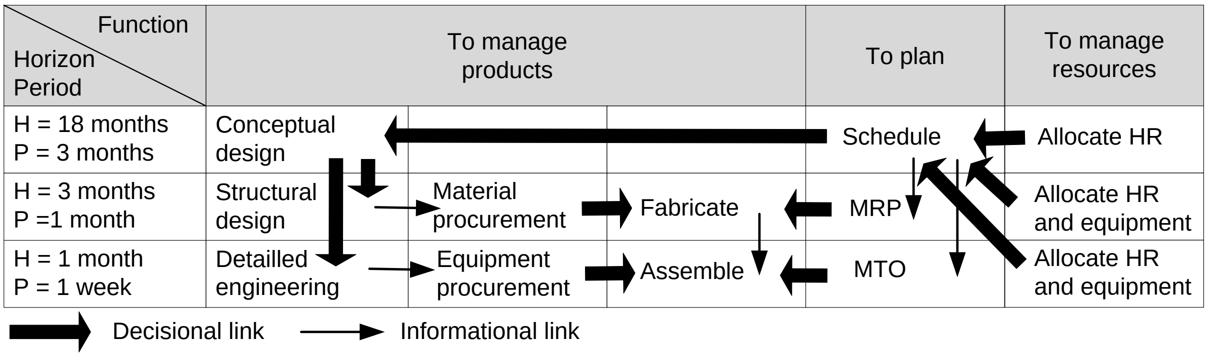
Figure 7 Physical process for example.

The physical process is used to develop the GRAI grid for this project (Figure 8). There are 7 decision centers involved to manage the product (decide on conceptual design, initiate structural design, initiate detailed design, start procurement of materials, start procurement of equipment, initiate fabrication, and initiate assembly).

As an example, we will look closer at the decision center “material procurement”. The scope of this is to start and execute the process of procuring (steel) materials. If we look at this as a primitive decision element, then we need to define the three types of decisions involved. The authorization decision is obviously the order to procure materials (the trigger). The selection decision is to find the best supplier, and the plan decision is to decide on the procurement contract. In summary, this involves the following steps:

- Develop bidders list (based on market availability, track record, and capacity)
- Evaluate bids (based on price, quality and risk assessment)
- Place order (based on contract negotiations, project schedule, and risk level)

This primitive element can subsequently be expanded to a more detailed level as indicated in Figure 6.



Function Horizon Period	To manage products			To plan	To manage resources
H = 18 months P = 3 months	Conceptual design			Schedule	Allocate HR
H = 3 months P =1 month	Structural design	Material procurement	Fabricate	MRP	Allocate HR and equipment
H = 1 month P = 1 week	Detailled engineering	Equipment procurement	Assemble	MTO	Allocate HR and equipment

Figure 8 GRAI grid for example.

The uncertainty found in a project can be one of three different types (Rolstadås & Johansen, 2008):

1. Operational uncertainty (internal uncertainty). This can be related to the choice of concepts in the planning phase and technical uncertainties in the implementation phase.

2. Strategic uncertainty (external uncertainty). This can be related to the project owner’s changing strategic considerations of the project. However, it is also related to how the owner perceives achieving the best possible business profile at the completion of the project.
3. Contextual uncertainty (external uncertainty). This is related to the external environment that the project is a part of.

All of the different decisions centers in our example (Figure 8) takes their decisions under uncertainty based on imperfect information of needs, volume, price, market conditions, and technical requirements that will change as the project evolve.

The grids provide a "map over of the process" that procurement of steel relies on obtaining input from, and that presents how the review process is operated as the project evolves. Decisions made in "Schedule" by the owner or the project manager makes the timeframe for the whole operation, and it allocates human resources on short and long term. "Schedule" gives the constraints to the "Conceptual design" and it creates a flow of information to MRP and MTO. The "Conceptual design" center makes decisions on the overall concept that gives criteria and constrains for "Structural design" and "Detailed Engineering" decisions, and this again creates a flow of information to material and equipment procurement. This means that start and execution of procuring (steel) rely on decisions made in three different decision centers, and these decisions needs to be reliable and correct before the bids and orders can be placed in the market. All decision centers will work on the operational solution with different timeframes and they will deal with operational and strategic uncertainties seen from decision center view over different time horizons. "Schedule" and "Conceptual design" need to focus on long term risk and "Detailed Engineering" needs to focus more on risk in short term horizon.

6. Conclusion

In this paper, we have proposed a decision structure model for OKP decision processes that will ensure that decisions made at each stage and level of the project lifecycle add value to overall project performance.

On the one hand, we have the *structural relationships or linking of the decisions* expressed directly by the horizontal *decision chain* corresponding to the physical flow of work documents and materials in an OKP project network. On the other hand, we have an indirect linking by the vertical decisional system (the GRAI Grid) with the decision levels and feedback represented by the information and decisional links.

The horizontal decisions are decisions connected to the project network plan that defines the *structural relationships of the activitie*s (activities and their precedence relationships).

The vertical decisions are connected to the GRAI method and the method explicitly exposes the decisional structure at all levels (by grid and net) such that we can analyze the decision centers, their consequences, and can correct/repair information and decisional flow.

Thus, the aim of this paper has not only been to establish a model to analyze the project decision processes, but also to apply the model for design of the decisional processes, horizontal as well as vertical.

A structured and well defined way of making decisions in projects is a key success factor. In a real project situation, decisions **have to be made.** If not, the project execution may stop. Most of the decisions in a OKP are taken under uncertainty as the project evolves– and it can be argued that none of the stakeholders have perfect information available when the decisions are made. The question is then: have we made a good or bad decision based on the information that is available? Have the decisions that control center suggested strengthened or weakened the probability to meet the project goals and the business objectives?

OKP is often a complex system consisting of several sub systems (*physical, information* and *decisional*) that all need to function together. A structured decisions process is vital so that good decisions are made at the right level in the chain, at the right time based on the information available, of experts that know their part of the system and have the authorization to make the decisions.

Fischer and Adams (2011) point to the fact that decisions must be made “in the heat of the battle”; every minute counts, and there is no place to “hide”. However, does this mean that we should rely on decisions only based on gut feeling made of the project managers as the project evolves?

We believe that a more formalized decision process will reduce the risk of making bad decisions. The GRAI grid provides an important link to the project execution model presented in figure 2. It gives project owner and project manager information about who is producing what at different level of the process, and it gives important information about what kind of information that the different decision centers build on. Understanding this "flow" of decisions is important for the owner and project manager – they need to understand the level and details of each part of the process and be sure that all of the decision centers add value to the overall project performance.

A structured approach increases the probability of taking good decisions at all levels and thus contributing to project success.

7. References

Anthony, R. N. 1965. *Planning and Control Systems: A Framework for Analysis*, Harvard University, Boston.

Arroyo, P. 2014. *Exploring Decision-Making for Sustainable Design in Commercial Buildings*. Dissertation, University of California, Berkeley.

Asbjørnslett, B. E.. 2003. *Project supply chain management: From agile to lean.* Dissertation, Norwegian University of Science and Technology.

Barton, J. A. and D. M. Love. 2000. “Design decision chains as a basis for design analysis.” *Journal of Engineering Design* 11(3): 283 – 297.

Boza, A., M. M. E. Alemany, F. Alarcón, , and L. Cuenca. 2014. “A model-driven DSS architecture for delivery management in collaborative supply chains with lack of homogeneity in products.” *Production Planning and Control* 25(8): 650 – 661.

Brady, T. and A. Davies. 2014. “Managing Structural and Dynamic Complexity: A Tale of Two Projects.” *Project Management Journal* 45(4): 21 – 38.

Bredillet, C. 2007. “Exploring Research in Project Management: Nine Schools of Project Management Research.” *Project Management Journal* 38/4: 2 – 4.

Chen, D., G. Doumeingts and F. Vernadat. 2008. “Architectures for enterprise integration and interoperability: Past, present and future.” *Computers in Industry* 59: 647 – 659.

Choi, B. K. and N. K. You,. 2006. “Dispatching rules for dynamic scheduling of one-of- a-kind production.” *International Journal of Computer Integrated Manufacturing* 19(4): 383 – 392.

Doumeingts, G., F. Marcotte, and H. Rojas. 1995. “GRAI-Approach: A Methodology for Re-Engineering the Manufacturing Enterprise.” In Browne, J. and D. O’Sullivan (eds) Re-engineering the enterprise: proceedings of the IFIP TC5/WG5.7 Working Conference on Re-engineering the Enterprise, Galway.

Doumeingts, G., Y. Ducq, B. Vallespir, and S. Kleinhans. 2000. “Production management and enterprise modelling.” *Computers in Industry* 42: 245 – 263.

Dresch, A., D. P. Lacerda , and J. A. V. Antunes. 2014. Design science research: a method for science and technology advancement.

Drucker, P. 1955. The practice of management. Heinemann, London.

Eekels, J. 1991. "A methodological comparison of the structures of scientific research and engineering design: their similarities and differences," *Design Studies Design Studies,* 12: 197 – 203.

Fischer, M. and H. Adams. 2011. “Engineering-Based Decisions in Construction.” *Journal of Construction Engineering and Management*: 751 – 754.

Flyvbjerg, B., M. K. Skamris Holm, and S. L. Buhl. 2003. «What Causes Cost Overrun in Transport Infrastructure Projects.” *Transport Reviews* 24(1): 3 – 18.

Franksen, O. I. 1972. “Introducing Diakoptical Simulation in Engineering Education.” *The Matrix and Tensor Quarterly* Sept: 1 – 16.

Gastinger. A. and O. Szegheo. 2000. “Enterprise Modeling Approaches.” In Rolstadås, A. and B. Andersen (eds) Enterprise Modeling – Improving Global Industrial Competitiveness. Kluwer Academic Press, London, pp 55 – 69.

Gidel, T., R. Gautier, and R. Duchamp. 2005. “Decision-making framework methodology: an original approach to project risk management in new product design.” *Journal of Engineering Design* 16(1): 1 – 23.

Gosling, J., D. R. Towill, M. M. Naim, and A. R. Dainty. 2015. “Principles for the design and operation of engineer-to-order supply chains in the construction sector.” *Production Planning and Control* 26(3): 203 – 218.

Gourdin, K. N. 2001. Global Logistics Management: A competitive advantage for the new millennium. Blackwell Publishers, Oxford.

Grabenstetter, D., and J. M. Usher. 2015. “Sequencing jobs in an engineer-to-order engineering environment.” *Production & Manufacturing Research* 3(1): 201 – 217.

Herroelen W., R. Leus. 2005. “Project scheduling under uncertainty: Survey and research potentials.” *European Journal of Operational Research* 165 (2): 289-306.

Hevner, A. R., S. T. March, J. Park, and S. Ram. 2004. "Design Science in Information Systems Research," *misquarterly MIS Quarterly,* 28: 75 – 105.

Kerzner, H. 2012. Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 11th ed. John Wiley & Sons, Hoboken.

Kosanke, K., F. Vernadat, and M. Zelm. 1999. «CIMOSA: enterprise engineering and integration.” *Computers in Industry* 40(1-2): 83 – 97.

Koskela, L. 2000. An exploration towards a production theory and its application to construction. VTT publication 408. Technical Research Centre of Finland, Helsinki University of Technology, Espoo.

Krane, H. P., A. Johansen, and R. Alstad. 2014. «Exploiting Opportunities in the Uncertainty Management.” *Procedia-Social and Behavioral Sciences*, 119: 615 – 624.

Liu, X., and Y. L. Tu. 2008. “Capacitated production planning with outsourcing in an OKP company.” *International Journal of Production Research* 46(20): 5781–5795.

Mafakheri, F., F. Nasiri, and M. Mousavi. 2008. “Project agility assessment: an integrated decision analysis approach.” *Production Planning and Control* 19(6): 567 – 576.

Maheut, J., J. M. Besgab, J. Uribetxebarriab, and J. P. Garcia-Sabatera. 2014. “A decision support system for modelling and implementing the supply network configuration and operations scheduling problem in the machine tool industry”. *Production Planning and Control* 25(8): 679 – 697.

March, S. T., and G. F. Smith. 1995. "Design and natural science research on information technology," *Decision Support Systems,* 15: 251 – 266.

Marques, G., D. Gourc, and M. Lauras. 2010. “Multi-criteria performance analysis for decision making in project management.” *International Journal of Project Management* 29: 1057 – 1069.

Mentzer, J. T. 2001. Supply Chain Management. Sage Publications, Thousand Oaks.

Meredith. J. R. and S. J. Mantel. 2012. Project management: a managerial approach, 8th ed. John Wiley & Sons, Hoboken.

Mintzberg, H. 1980. “Structure in 5's: A Synthesis of the Research on Organization Design”. *Management Science* 26(3): 322 - 341.

Morris, P. W. 2004. “Science, objective knowledge and the theory of project management.” *Civil Engineering*, 150(2): 82 – 90.

PMI. 2013. A Guide to the Project Management Body of Knowledge, 5th ed. Project Management Institute, Newtown Square.

Ridgway, K. 1992. “Analysis of decision centres and information flow in project management.” *International Journal of Project Management* 10(3): 145 – 152.

Rolstadås, A. 1991. “FOF Production Theory.” *Computers in Industry* 16: 129 – 139.

Rolstadås, A. 1992. “One-of-a-kind Production.” *Production Planning and Control”* 3(2): 117.

Rolstadås, A. and A. Johansen. 2008. “From protective to offensive project management.” Paper presented at the PMI EMEA congress, Malta, May 19 – 21.

Rolstadås, A. 2008. Applied Project Management – How to Organize, Plan and Control Projects. Tapir Academic Press, Trondheim.

Rolstadås, A., P. W. Hetland, G. Jergeas, and R. Westney. 2011. Risk Navigation Strategies for Major Capital Projects – Beyond the Myth of Predictability. Springer, London.

Rolstadås, A., J. K. Pinto, P. Falster, and R. Venkataraman. 2014. Decision Making in Project Management. Akademika, Trondheim.

Rolstadås, A., J. K. Pinto, P. Falster, and R. Venkataraman. 2015. “Project Decision Chain.” *Project Management Journal* 46(4): 6 - 19.

Scheer, A. W. 1994. Business Process Engineering – Reference Models for Industrial Enterprises, 2nd edition. Springer-Verlag, Berlin.

Short, J., and A. Kopp. 2005. “Transport infrastructure: Investment and planning. Policy and research aspects.” Transport Policy 12(4): 360 – 367.

Siggelkow, N. 2007. "Persuasion with Case Studies," *The Academy of Management Journal,* 50: 20 – 24.

Simon, H. A. 1960. The new Science of Management Decision. Harper and Row, New York.

Stray, V. G., N. B. Moe, and A. Aurum. 2012. “Investigating daily team meetings in agile software projects” in 38th Euromicro Conference on Software Engineering and Advanced Applications: 274 – 281, IEEE.

Söderlund, J. 2010. “Pluralism in Project Management: Navigating the Crossroads of Specialization and Fragmentation.” *International Journal of Management Reviews* 13: 153 – 176.

Tu, Y. L., S. Q. Xie, and J. J. Kam. 2006. «Rapid one-of-a-kind production.” *The International Journal of Advanced Manufacturing Technology,* 29(5-6): 499 – 510.

Vernadat, F. B. (2002) 2002. “Enterprise Modelling and Integration: Current Status and Research Perspectives.” *Annual Reviews in Control* 26: 15 – 25.

Viciens, E., M. E. Alemany, C. Andrés, and J. J. Guarch. 2001. “A design and application methodology for hierarchical production planning decision support systems in an enterprise integration context.” *International Journal of Production Economics* 74: 5 – 20.

Virine, L., and M. Trumper. 2008. Project Decisions – The Art and Science. Management Concepts, Vienna, VA.

Williams, T. J. 1994. “The Purdue enterprise reference architecture.” *Computers in Industry* 24 (2/3): 141 – 158.

Wortmann, J. C. 1991. “Towards One-Of-A-Kind Production: The Future of European Industry” in Eloranta, E (ed) Advances in Production Management Systems. Elsevier.

Wortmann, J. C., D. R. Muntslag, and P. J. M. Timmermans. 1997. Customer-driven manufacturing. Chapman & Hall, London.

Xie, S. Q., Y. L. Tu,R. Y. K. Fung, and Z. D. Zhou. 2003. “Rapid one-of-a-kind product development via the Internet: a literature review of the state-of-the-art and a proposed platform” *International Journal of Production Research* 41(18): 4257 – 4298.

Xie, S. Q., X. Xu, and Y. L. Tu. 2005. “A reconfigurable platform in support of one-of-a-kind product development.” *International Journal of Production Research* 43(9): 1889 – 1910.

Xie, S. Q. 2006. “A decision support system for rapid one-of-a-kind product development.” *International Journal of Advanced Manufacturing Technology* 28(7-8): 643-652.