INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19-22, 2008.

DESIGN 2008

MODELLING DECISION-MAKING IN COMPLEX PRODUCT DEVELOPMENT

J. Eriksson, S. Johnsson and R. Olsson

Keywords: decision-making, uncertainty, performance, complex product development, PDOPM

1. Introduction

The need for shorter lead time, trends with outsourcing, complex product requirements, and shorter product life cycles requires increased knowledge and advanced skills in the design of complex products. The ability to manage such complexities is seen as a competitive advantage for technologically advanced industry, and the global market places greater demands on industry to continuously increase its performance. One challenge today for companies lies in finding the right approach to measuring and continuously improving the current state of a company's product development process. Integrated product development focuses on the aspect that complex product development puts demands on managing interdependent systems of products and processes with high numbers of elements, thus making it necessary to maintain an overall view in order not to sub-optimise [Malvius 2007]. Integrated product development advocates the integration of work procedures, information management and support tools so the complexity can be managed in an effective and efficient way [Norell 1992]. The task of continuously improving the performance of integrated product development demands the successful management of information, communication, cooperation and decision-making in a context of uncertainty, which is a highly complex task in itself. The research question to which this research ultimately will try to contribute is the following: How can performance in product development be improved? However, in this paper, the research question focused upon is: How can decision-making be modelled in an organizational context, in relation to performance?
To be able to manage a complex product development system in an appropriate way, the authors have identified three important aspects of product development. These aspects are decision-making, uncertainty and performance. These aspects form the foundation for the suggested Product Development Organization Performance Model (PDOPM) which is intended to be used by engineering design researchers and, when further developed, product development managers. This initial paper elaborates on the aspect of decision-making and performance.

2. Methodology

This paper is the first in a series of several, aimed at describing the ongoing development of PDOPM. Blessing and Chakrabarti's [2002] Design Research Methodology (DRM) is the foundation for the research, and this paper is a result of the DRM's research clarification stage.
To deal with the complexity of product development, a systems theory has been used in this study, in accordance with Arbnor and Bjerke [1997]. Increased complexity stresses the need for models that could be used for teams to develop a shared understanding [Katz and Kahn 1978]. Systems theory is a promising effort to deal with this complexity. There, an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts.

The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [Senge 1990]. Instead of adopting a rational approach, where only one correct explanation for how data is connected to theory exists, a systems approach is adopted. In it, knowledge is built up from the studied indicator effects. This means that the forces influencing the system are important. Further, the relationships can be either deterministic or stochastic. It is also important to see the processes of change for the system, rather than taking snapshots.

A foundation for this research is several extensive studies on uncertainty management, which resulted in one of the authors' PhD (see Olsson [2006]). The basis of this research was first developed through a workshop together with senior managers within product development in seven different high-tech industrial companies. The companies are all international companies, based in Sweden. They all have extensive experience in developing complex products within telecommunications, automotive and automation. This formed the initial ideas and problem statements regarding product development, including factors affecting performance. This research then continued with the identification of gaps in literature by conducting reviews within decision-making theory, uncertainty management, and product development performance. A total of twenty semi-structured and open interviews were held at four companies in order to identify the need for change within the management of product development at different levels in the organisations. These results were then incorporated into the PDOPM. Further, the authors' professional work experience within complex product development was also applied to the development of the PDOPM. The initial results of the research of the PDOPM are presented in this paper.

3. Decision-making in complex product development

What makes a product development process go forward? The fundamental answer is decisions. If no decision is made, the process remains at a halt. So the process may be viewed as a system of decisions that influence each other in a complex way. This view has been discussed in literature in relation to product development organizations and resulted in the concept of Decision-based Design [Herrman and Schmidt 2002]. It discusses the gap between design research and practise, which could be bridged by moving from a problem-solving approach to a decision-based approach. Using this view of complex product development as a decision system, the consideration of the whole becomes even more important.

One important question is how this type of decision system is supported. Much attention has been spent on decision-making support systems (DSS) in research to support improvements in decision-making performance in complex product development organizations. Even though the frontier of intelligent decision-making support systems (i-DSS) lies in the ability to incorporate the complex nature of decision-making into computerised analysis and decision-making, the human being is still considered to be the most important part of the systems for making successful decisions [Jatinder et al. 2006]. Studies have shown that designers use their memory to a large extent when retrieving information and tend to seek information and expertise among their colleagues instead of in information systems (documents and reports) [Court et al. 1996, Marsh 1997, Saeema 2000]. It has also been shown that decision-making output quality does not increase if standardization of decision-making procedures and control functions are introduced [Sutcliffe 2001]. This in turn puts even more pressure on supporting and improving the decision-making skill of people in an organisation for increased decision-making performance. The process of learning [Saeema 2000] and evaluation [Nutt 1998] becomes central in order to make high quality decisions in a complex environment. Further, management of aspects such as information, communication, uncertainty, and cooperation has a direct impact on the quality of decisions.

Hansen and Andreasen [2004] and Gidel et al. [2005] argue for a change in designers' mindsets regarding decision-making and have developed support for amplified cognitive capacity. Both articles present models for better understanding of decision-making in engineering design. Hansen and Andreasen's approach presents a model of a Decision Node and Decision Map, which has a base in actual decision-making practice. Gidel et al. focus on the connection between decision-making and project management. Both authors support improvements in the human problem-solving capacity in complex situations, i.e. non-programmed decision-making situations. Another example of support of

non-programmed decision-making situations is Saeema's C-QuARK method [2000], which amplifies a novice engineer's ability to retrieve information for the basis of design decisions. It seems that focusing on, and supporting, the human decision-making capacity can achieve improvements in design and project performance. The question is which aspects of decision-making are important to focus on to better support product development projects? Cooke-Davis [2002] describes different performance aspects of a project as Project Success and Project Management Success. The aspects relate to success criteria and factors, and depend on which of the following three questions is asked: (1) What factors are critical to project management success?; (2) What factors are critical to success on an individual project?; and (3) What factors lead to consistently successful projects? [Cooke-Davis 2002]. This research aims at developing support for reasoning regarding all three questions.
When reviewing literature of decision-making in product development, including its influencing factors, three categorizations can be distinguished and several authors argue the importance of these categories: Decision-making procedures (activities) [Gidel et al. 2005, Ullman 2006,]; decision-making uncertainty [Busby 2001]; and decision-making environment [Simon 1997].

3.1 Decision-making context and generic factors

Decisions are attempts to create value, and this can only be done through committing resources to actions. However, when committing resources to actions, consequences will occur, and at best, they add to the created value. Thus, it is vital to be able to foresee factors and uncertainties impacting the decision. When studying to what extent these factors are identified and managed when making a decision, it is necessary to use clear definitions of input, output, goal, resources and uncertainty. This research has adopted the viewpoints of O'Donnell and Duffy's performance framework [O' Donnell and Duffy 2002], based on the IDEFO model [Colquhoun et al. 1993]. An organizational function, activity, or decision has input, output, a goal and resources. If output is compared to goal, effectiveness (π) is determined. If the relation between output and input are compared with used resources, efficiency (η) is determined. However, both effectiveness and efficiency are influenced by uncertainty (μ) in decision-making. This could be present as uncertainty in the basis on which a decision is taken, goal or input. If input and goal are compared, it is possible to understand the impact of uncertainty in decisions, actions and consequences. Further, uncertainty can affect the purpose of the decision, i.e. the created value. With the influence of uncertainty, effectiveness and efficiency combined constitute performance (See Figure 1).

3.2 Decision-making and project organisations

In each generic level of an organization, function, activity, or decision can be studied. Each of them is influenced by two kinds of factors: inner factors, e.g. group dynamics; and surrounding factors, e.g. imposed goals. According to Krishnan and Ulrich [2001], generic decisions are made in these levels. When looking at the product strategy level, five generic decisions are made: What is the market and product strategy to maximize probability of economic success?, What portfolio of product opportunities will be pursued?, What is the timing of product development projects?, What assets (e.g. platforms), if any, will be shared across which products?, and which technologies will be employed in the product(s)? When looking at a project management level, five generic decisions are made: What is the relative priority of development objectives?, What is the planned timing and sequence of development activities?, What are the major project milestones and planned prototypes?, What will be the communication mechanisms among team members?, and how will the project be monitored and controlled? Further, when looking at the product activity level, eighteen generic decisions, divided into five categories, are made. The categories are: Concept development, Supply chain design, Product design, Performance testing and validation, and Production ramp-up and launch [Krishnan and Ulrich 2001]. These generic decisions are guided by requirements and constraints, i.e. input, from the project organization. The output at different levels is a subdivision of the goals, requirements and constraints. These are further translated into decisions to serve as goals for activities at the next sub-level. The project organization provides resources to support product strategy, project management, and product activities. It is also suggested that all these generic decisions in Product strategy, Project management, and Product activities have a major impact on all other important decisions within a product development process. The question is then how to be able to identify and measure the performance of decisions?

4. A new model of product development organization performance

One of the objectives of developing the PDOPM is to increase the ability to focus on the right aspect of product development performance and to support the development of performance metrics in order to increase decision-making performance over time.

During interviews and the workshop, certain aspects have shown to be powerful viewpoints in industry when discussing decision-making performance in a project organizational context. These aspects are: (1) division of performance (metrics, effectiveness and efficiency), (2) uncertainty, and (3) division of decision-making procedure and environment (decision activity and decision-making organization). The categorization at the end of section 3 and these aspects have been incorporated into the PDOPM through the separation of performance into effectiveness and efficiency, uncertainty, decision-making procedure and decision environment.

It is suggested here that an increased awareness and understanding of a simplified whole system, and its relevant influencing factors, will increase product development performance. Hansen and Andreasen [2000] argue that by making people more aware of the decision-making process, their decision-making practice will improve. The intent of the model is to emphasize three identified generic organizational levels. The three generic levels in a project organization have been identified during this research as: (1) Product Strategy, (2) Project Management, and (3) Product Activity. The generic levels are suggested as important in order to understand product development performance. The developed model is primarily intended to provide an understanding of the interaction between performance, uncertainty and decision-making in an organizational system. This will enable researchers as well as product development participants to understand the structure of the decision-making process as part of the development process in an organizational context.

4.1 A decision structure

Hansen and Andreasen [2004] propose that designers, acting in the way they do, may impose negative effects on their designs. Hansen and Andreasen also suggest that designers ought to change their mindset to a more structured approach of decision-making. The process of design is about learning about a problem or an opportunity. Therefore, the process of learning is central and can be incorporated into the approach of Hansen and Andreasen.

One suggestion is the importance of incorporating the learning cycle into the decision activity. This is because the goal and specifying of requirements of the decision impact how designers retrieve and search for information in order to build knowledge. This information, albeit influenced by uncertainty, serves as a basis for the decision itself. Several authors argue the importance of learning in product development, and have proposed models of the learning cycle [Agris & Schön 1978, Kolb 1984]. In this research, the model of IDEO's method cards [Kelly and Littman 2005] is used to enhance the emphasis on the relationship between the product development process and learning (see Figure 2). The decision-making process, as proposed by Hansen and Andreasen [2004], includes specifying, evaluating, validating, navigating, and unifying. If IDEO's learning cycle and Hansen and Andreasen's decision node are combined, the result constitutes a decision activity. The question is how to improve performance in such a decision-making activity?

In a design project, decision activities create a complex network of decisions, and the sheer amount of decisions is too numerous to map. Even if it were possible to map all decision activities, it would be meaningless for reuse in future project due to the innovative, non-repetitive nature of design projects [Gidel et al. 2005]. Studying the nature of decision-making, factors such as the mindset, structuring, input, goal and resources plays a crucial role for performance, and can be illustrated with inspiration from O'Donnell and Duffy's [2002] performance model (see Figure 1).

If IDEO's learning cycle and Hansen and Andreasen's decision node are combined, they become an illustration of how decision-making relates to effectiveness, efficiency, and uncertainty, as shown in Figure 2. The combination provides a foundation for a discussion regarding surrounding factors, e.g.

current knowledge of customer needs, imposed goals for activity performance, given platforms to use for the product, and provided resources for the execution of the activity. Further, it also illustrates how a decision-making activity is impacted by inner factors.

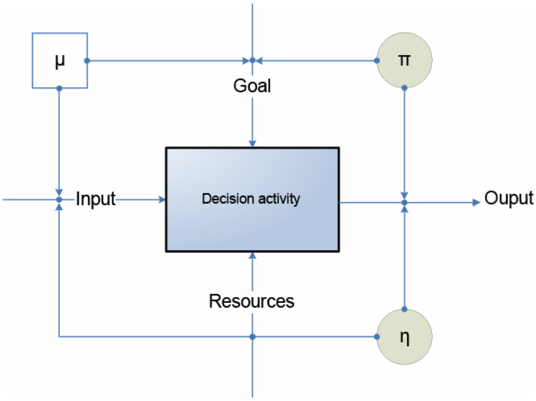

Figure 1. An illustration of how decision-making relates to effectiveness, efficiency and uncertainty

Examples of those factors include methods used for creating understanding of the situation, the generation of one or many alternatives, and the approach when selecting an alternative. The combination of the inner and surrounding factors illustrates how a decision-making activity relates to performance. The illustration also provides a foundation for modelling decision-making. It also shows how a decision-making procedure (structure), combined with performance factors, i.e. input, goal, and resources, can be used for reasoning about decision-making activity performance improvements.

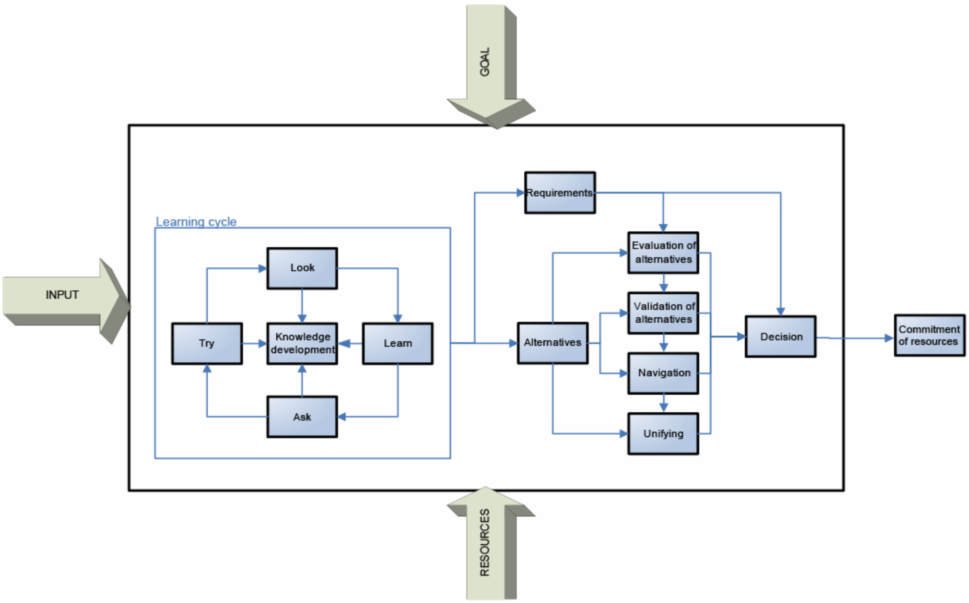

Figure 2. An illustration of the decision-making structure, with inner and surrounding factors

4.2 A holistic Product Development Organization Performance Model (PDOPM)

Product development projects are inevitably linked to an organisation. Thus, it is important to create a visual representation of an organisation, linking decision-making and performance in an organizational context. If one lever is pulled to improve an organization, something elsewhere is changed in the system and must therefore be looked upon as a whole in an organizational context [Rummler and Brache 1990]. The performance of product development can be argued to be the accuracy and rate by which an organisation translates a market opportunity into a successful product on the market. This means that if there is a change in the market, performance will be influenced by how accurately and rapidly the company identifies the change and translates it into goal and input for the project organisation, and how accurately and rapidly the project organisation uses it to create a product that corresponds to the market need. The market need is the overall goal for a product-developing organisation. It is also where the final output (product) ultimately is judged. In a business strategy context, market needs are assessed and translated into goal and input to the project organisation. The three identified generic organizational levels are viewed as levels of decision-making activity systems, which interact with one another. They interact by transforming input and goals into output, which in turn serve as goals for sub-levels (See Figure 3). Further, they interact by verification and validation cycles where communication upward in the organisation is enabled. Resources must be provided for the activities to work properly. It is suggested that if these theories are combined in a model of an organisation and its surroundings, performance in product development can be discussed in an organizational context. The suggested model, PDOPM, describes the rationale behind communication, uncertainty and performance (See Figure 3). The market is the primary source when setting the goal for product strategies on a business strategy level. Product strategy includes product portfolio, design briefs and pre-studies, which serve as goals for the project management level. The project management level is responsible for the subversion and communion of the design goal and activity goal to the product activity level. It is also the project management's responsibility to align design and activity goals with strategic goals in order to achieve coherence in performance. Through the combination of Figure 2 and the PDOPM, it is possible to holistically reason about factors related to communication, uncertainty and product development performance influencing decision-making performance in a complex organizational context.

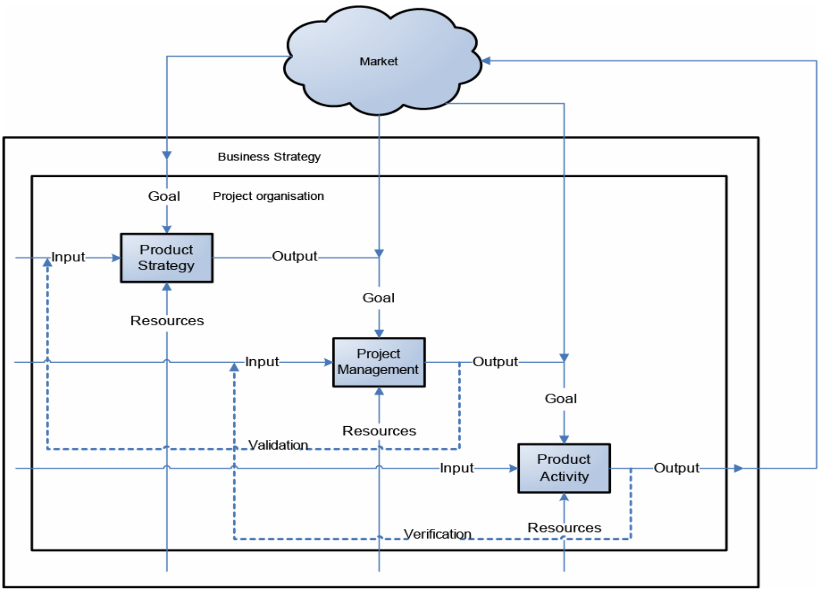

Figure 3. Product Development Organisation Performance Model (PDOPM)

4.3 Assessing product development performance with PDOPM

Performance in product development is seldom clearly defined and there is often no consensus about what performance is [O' Donnell and Duffy 2002]. The proposed PDOPM makes it possible to reason about, and assess, efficiency, effectiveness and uncertainty of decision-making within the three generic levels of activity: *product strategy, project management and product activities*.

Product strategy effectiveness describes how the output of the activity meets the defined goal. On the strategy level the goal is to fulfil the business strategy and consequently it is vital that the output correspond to the business strategy. *Product strategy efficiency* is dependent upon making good use of the input and resources in order to create an output. It is vital that the output of the product strategy is delivered in time, at the right quality, to the right people. It is vital in order to transform the identified market opportunity into an initialized project at the right time in order to capture the market window. *Product strategy uncertainty* is strongly related to project portfolio management and the timing of the projects in order to maximize probability of economic success for the company as a whole. A mix of different levels of uncertainty is often sought and the maturity of technology introduced into the projects greatly impacts decision-making uncertainty.

Project management effectiveness is e.g. how well the overall needs of a selected customer group, identified at the product strategy level, are translated into a product specification. The identified needs can change over time and is the main focus for the management of the project to fulfil. Effectiveness of the project management is for that reason a measure of how well the project is realizing the dynamic scope of the project. This emphasises the importance of communication between product management and project management. *Project management efficiency* is related to project planning and is often seen as the main task of project management. Low efficiency in project management activities is shown in high costs and time overruns. Project managers have a propensity to focus on the efficiency aspect during project execution and it is for that reason important to remember that if the effectiveness of the project management activity cannot be assured, everything else is of minor importance. *Project management uncertainty* is strongly related to project planning which, if strictly enforced, will guide the project in a too inflexible way. Uncertainty in, and deviation from, planning of people, budget and time is the nature of projects and is the primary task of a project manager and needs to be managed in a dynamic way during execution of projects.

Product activity effectiveness is an important measure and too often forgotten due to unclear goals, directions, or specifications. It is vital that a project manager always focus on the whole of the project in order to communicate a clear and well defined goal for activities. *Product activity efficiency* is defined as the difference between output and input divided by the resources used to realize the output. The resource of time is often seen as the most important at this level but impacts cost in the product life cycle to a great extent and constitute a trade-off between how much time is required to achieve appropriate quality of the decision, or solution, and still make the deadline. Product activity uncertainty is crucial to manage and measuring the product activity uncertainty enables discovery of potential problems early in the project when there still is time for changes without risking any substantial costs.

The factor of time is not explicitly shown in the PDOPM, but there is time dependency in the model by the *verification* and *validation loop*, see Figure 3. The two feedback loops also represents the communication and learning cycle of the organization. It is also a way to manage activities and the different outputs that is supposed to match the specified goals. *The validation loop* represents the feedback from the output from project management and it is modelled as an input to the product strategy. The validation represents the possibility for product management to see the progress of the product development project. *The verification loop* is modelled as the feedback from product activities to project management. By representing it in this way, it shows the possibility for the project manager to view the progress and the output from product activities.

5. Future work of verifying the new model

The presented PDOPM has shown promising initial results in conducted research studies in an industrial setting. It enables the identification of inner, surrounding factors and uncertainties relevant to the management of product development. However, there still remains work to be done, developing the model and an appropriate method to map different aspects of the decision-making process in product development. A literature review and discussions with management and product development project managers at several large companies in Sweden has resulted in the creation of six performance categories to focus on when analyzing a project organization's decision-making performance. They are: (1) Information management; (2) Communication; (3) Co-operation management; (4) Decision management; (5) Uncertainty management; and (6) Product development performance metrics. The categories will be studied in future research for the development of mapping methods linked to performance, and are not discussed further here. Several case studies are planned to verify the model and for further development.

6. Discussion and conclusion

The need for improvements in product development led the authors to study the combination of three important aspects of the product development process. The aspects are decision-making, uncertainty, and performance within product development. The need for management of such aspects has been shown in industry as well as literature. However, the aspects are rarely combined. To combine them, the authors suggest a change of view of the product development process: they argue for a holistic view of the decision activity system related to product development performance.

The first contribution is an illustration of how decision-making relates to effectiveness, efficiency, and uncertainty. The illustration links performance and uncertainty into a model-based theory of what factors influence decision-making performance. The second contribution is an illustration of a decision activity. It shows the separation of inner and surrounding factors that influence a decision activity. It enables a discussion of which factors influence decision-making as a whole.

In this paper, we have suggested a Product Development Organizational Performance Model, PDOPM, which is intended to support the discussion of decision-making performance in an organizational context. Together with the illustrations, it is possible to separates influencing factors in decision-making into input, goal, resources, organizational levels, communication, and organizational context. It can be used for research studies of product development and support the identification of relevant factors influencing product development performance on different organisational levels in an industrial setting. It can also be used by project managers for understanding and reasoning about product development performance improvements in the context of the whole company.

When we tested PDOPM with empirical studies, PDOPM constituted a powerful model for the identification of factors influencing decision-making in a product development organisation. However, the authors see a need for the further development of the model, which can serve as a basis for the development of a holistic approach to product development process improvements.

References

Agyris, C., Schön, D.A., Organizational Learning – A Theory of Action Perspective, Addison-Wesley, Reading MA, USA, 1978.

Arbnor, I., Bjerke, B., Methodology for Creating Business Knowledge, 2nd ed. Sage Publications, USA, 1997.

Blessing L.T.M., Chakrabarti, A., DRM: A Design Research Methodology. Proceedings of the Conférence Internationale Les Sciences de la Conception, INSA-Lyon, March 2002.

Busby, J.S., Error and Distributed Cognition in Design. Design Studies, Vol. 22, No. 3, May, 2001.

Colquhoun, G.J., Baines, R.W., Crossley, R., A State of the Art Review of IDEFO. International Journal of Computer Integrated Manufacturing, Vol. 6, No. 4, pp. 252-64, 1993.

Cooke-Davis, T., The "Real" Success Factors on Projects. International Journal of Project Management,Vol. 20, pp. 185-190, 2002.

Court, A.., Cully, S., McMahon, C., Information Access Diagrams: A Technique for Analyzing the Useage of Design Information. Journal of Engineering Design, 7 (No 1): p. 55-75, 1996.

Gidel, T., Gautier, R., Duchamp, R., Decision-making Framework Methodology: An Original Approach to Project Risk Management in New Product Design. Journal of Engineering Design, Vol. 16, No. 1, Feb, 2005, 1-23.

Hansen,C.T., Andreasen, M.M., A Mapping of Design Decision-making. International Design Conference – Design 2004, Dubrovnik, May, 2004.
Herrman, J.W., Schmidt, L.C., Viewing Product Development as a Decision Production System. Proceedings of DETC 2002, ASME 2002, Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Montreal, Canada, 2002.
Jatinder N.D. Gupta (Editor), Guisseppi A. Forgionne (Editor), Manuel Mora (Editor).
Intelligent Decision-making Support Systems: Foundations, Applications and Challenges, Springer, 2006.
Katz, D. and Kahn, R.L., The Social Psychology of Organizations (2 ed.). John-Wiley & Sons, New York, 1978.
Kelly, T., Littman, J., The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate & Driving Creativity throughout Your Organization. Doubleday, USA, 2005.
Kolb, D.A., Experimental Learning. Prentice-Hall, NJ, USA, 1984.
Krishnan, V., Ulrich, K.T., Product Development Decisions: A Review of the Literature. Management Science, Jan. 2001, 47, 1; ABI/INFORM Global, 2001.
Malvius, D., Information Management for Complex Product Development. Licentiate Thesis, KTH, 2007.
Marsh, J.R., The Capture and Utilisation of Experience in Engineering Design. Ph.D., Cambridge, 1997.
Norell, M., Stödmetoder och samverkan i produktutveckling: Advisory Tools and Co-operation in Product Development. Stockholm, Sweden, 1992.
Nutt, T.P.C., Surprising But True: Half the Decisions in Organizations Fail. Academy of Management Executive, 13, 75–90, 1999.
O' Donnell, F.J., Duffy, A.H.B., Design Performance, Springer Verlag, 2005.
O'Donnell, F.J., Duffy, A.H.B., Modelling design development performance. International Journal of Operations & Production Management; 2002; 22, 11; ABI/INFORM Global pg. 1198
Olsson, R., Managing Project Uncertainty by Using An Enhanced Risk Management Process. Doctoral Dissertation, Mälardalen University Press, Västerås, Sweden, 2006.
Rummler, G.A., Brache, A.P., How to Manage the White Space on the Organization Chart. Jossey-Bass Inc., California, USA, 1990.
Saeema, A., Understanding the Use and Reuse of Experience in Engineering Design. Ph.D, Clare Hall, Cambridge, 2000.
Senge, P.M., The Fifth Dicipline, the Art & Practice of Learning Organizations. Currency Doubleday, NY, 1990.
Simon, H., Administrative Behaviour: A Study of Decision-making Processes in Administrative Organizations. The Free Press, NY, USA, 1997 .
Sutcliffe, K.M., McNamara, G., Controlling Decision-making Practice in Organizations. Organization Science, Vol. 12, No. 4. Jul-Aug., pp. 484-501, 2001.
Ullman, D.G., Making Robust Decisions: Decision Management for Technical, Business, & Service Teams. Trafford Publishing, Oxford, UK, 2006.

Joakim Eriksson, Ph.D student
Department of Innovation, Design and Product Development
Section of Product and Process Development
Mälardalen University
P.O. Box 325
E-631 05 Eskilstuna, Sweden
Tel.: +46 16 15 34 87
Email: joakim.eriksson@mdh.se