# Take the knowledge path to support knowledge management in product service systems

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**Abstract**

Product/Service-Systems (PSS) strategies are a part of an overall movement towards a service-based society that is increasingly knowledge and information based. Knowledge sharing for cross-company innovation and development projects has been recognized as troublesome, since disparate knowledge domains must be brought together in a cohesive way to support both creativity and innovations. Stage-Gate process models are widely used in collaborative development projects but they do not suggest how to assess the degree of understanding of the produced information and the results in projects. A successful assessment of knowledge should be used for designing the next development steps in form of work methods and tools. This paper describes an approach for supporting Knowledge Management and Knowledge Sharing in the development of PSS. Finally, a concept for supporting knowledge assessment is proposed, based on designing and visualizing knowledge paths.

**Keywords**

Knowledge Management, Product Development Process, Knowledge path, Knowledge maturity, Technology Readiness Level

## 1 INTRODUCTION

Globalization, increased competition, dynamic and constantly changing business demands are some of the factors that industrial manufacturing companies have to deal with. These demands require the companies to improve the performance in their product development, which primarily are achieved by focusing on reduction of cost, reduction of lead-time and improvement of quality [1]. The activities to follow during product development can be formalized in a Product Development Process (PDP) wherein work methods, tools and practices can be described. The results when following the PDP depends on the methods and tools that are prescribed, as well as on the knowledge and skills of the people doing the work.

To achieve an improved performance many industrial manufacturing companies have adopted a Stage-gate process [2, 3] as the foundation of their Product Development Process, and the benefits of using such a model have been well documented. Johansson [4] explains this choice with *'In industry, a popular way of formulating a process based on the gate-milestone model, because it makes the process more natural to manage and you have natural decision points in the gates where everyone converges to take decisions about the process'*. Stage-Gate is a process that moves projects from idea to launch of product. It is based on a process model called Phased Review [3] implemented by NASA during the 1960s to manage the development projects by breaking the process into clearly defined stages with reporting in-between them.

The main structure of Stage-Gate is that you have a series of Stage and Gates, typically named Scoping, Business Case, Development, Testing and Launch. The Stage (see Figure 1) is where the development work takes place and within each Stage, activities are normally undertaken in parallel. The Stage can also be seen as information gathering activities that after an integrated analysis produce deliverables as input to the Gate [3]. After a Stage there is a Gate (also known as a decision point). The role of the Gate is to assess results, evaluate what has been done in the previous Stage and to decide the way forward; what should be done in the next Stage, how that path forward should be undertaken and how much resources should be allocated for creating new deliverables during the next Stage [3].

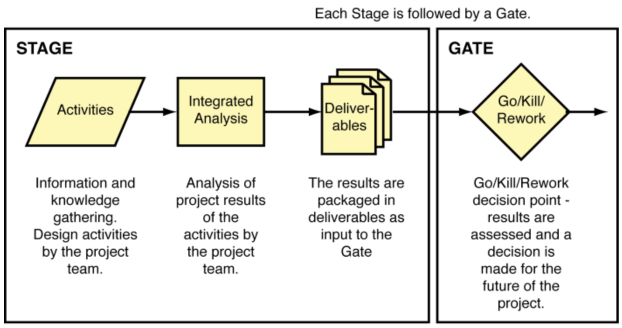


Figure 1: Stage-Gate structure with a Stage followed by a Gate (adapted from Cooper [3])

Stage-Gate models prescribe that the gate keeping team focuses their reviews on the results that has been developed during the Stage. Particularly, Stage-Gate models do not provide any solutions for assessing the degree of understanding of the produced information in the process. Furthermore, it is not apparent how such solutions should support the assessment of infomation in the PDP in the existing Stage-Gate context of industrial manufacturing companies. A successful assessment of knowledge should be at the centre of support methods and tools to be used by the project team.

Moving towards a development of a Product/Service Service system, depicting an integration of a diverse set of knowledge areas with the integration of hardware and services in a total offer with a lifecycle perspective [5], managing uncertainties and ambiguities by assessing knowledge and information [6] will be even more important to be able to deliver a PSS that the manufacturer can "live with" for the duration of the its life cycle.

Thus, the purpose of this paper is to describe different views on knowledge assessment in the Product Development Process in industrial manufacturing companies and to suggest how this can be supported in the development of PSS.

Following this introduction, a theoretical framework within the area of Knowledge Management is summarized. The data generation and results of the case study are presented in the following chapters and finally, a concept for supporting knowledge assessment in the Product Development Process is proposed, based on designing and visualizing knowledge paths.

## 2 THEORETICAL FRAMEWORK

### 2.1 Knowledge and Knowledge Management

There are many ways to define Knowledge Management. One of them is *'…the systematic processes by which knowledge needed for an organization to succeed is created, captured, shared and leveraged.'* [7]. Knowledge Management greatly focuses on organizational aspects and how knowledge can be managed for the benefit of the organization, stopping it from leaving with i.e. employee turnover [8].

As with Knowledge Management, there are also many ways to define knowledge. Knowledge can be distinguished from information and data by using the knowledge hierarchy (also known as the DIKW-hierarchy reflecting the terms Data, Information, Knowledge, and Wisdom), see Figure 2.

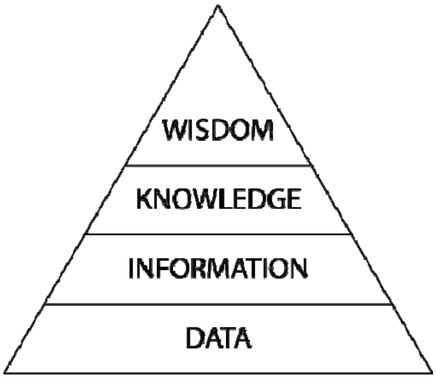


Figure 2: Knowledge hierarchy, relating data, information, knowledge and wisdom (adopted from [9])

Johansson [4] summarizes the knowledge pyramid as:

- Data is about the raw numbers.
- Information is about adding meaning to the data, for instance by relating it to other sets of data.
- Knowledge is when predictions can be made and actions can be taken, you start to see patterns in the data and information. You no longer look back in the past on what has been, but can start to look ahead and take decisions and act for the future, based on what you know, in real time.
- Wisdom is yet one more step forward, where you forecast implications of decisions and actions.

Understanding and context aids the transition from one stage of the hierarchy to the next. Clark [10] states that *"one gains knowledge through context (experiences) and understanding'*.

Knowledge can also be broken down into tacit and explicit knowledge [11]. Tacit knowledge is the type of knowledge that is residing in people's minds [12] and cannot be written down and codified in an easy manner. In contrary, explicit knowledge is the knowledge that can be communicated with others.

### 2.2 Technology Readiness Level

TRL is developed by NASA [13] and prescribes the development of a technology that, in the case of NASA, will feature on products that are used for space missions. The TRL is a 9-level scale that has criterions that describes necessary developments for every step, see Figure 3. TRL is intended to be used as a flight of stairs that are climbed one by one as the technology is developed and thus matured. It begins, on the first level (TRL 1), with basic principles being observed often in research or laboratory environments. At this stage the technology is as far away from implementation as is possible. Thereafter the developers can develop and mature the technology, through different stages of validation and integration in larger systems. At the end of the scale (TRL 9) the technology and its systems are 'flight proven' in space environments and various bugs have been ironed out. The further up the scale the technology matures, the more expensive it is to move to the next level. Therefore, technologies and systems that are not 'mission critical' will not move through the whole scale. TRL has been widely adopted in the aerospace community and is now a feature in many companies to measure technology maturity.

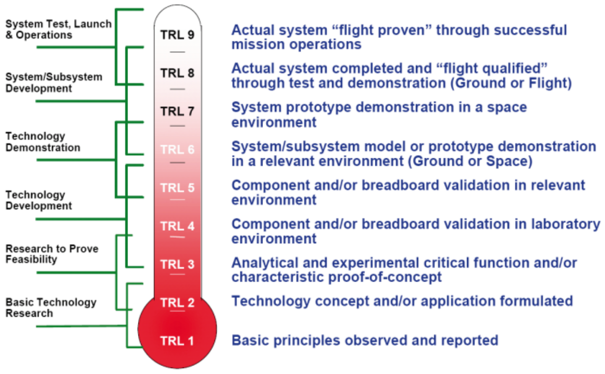


Figure 3: Technology Readiness Level (TRL) chart with criterion descriptions (from Mankins [13])

### 2.3 Knowledge Maturity

Knowledge Maturity [4] is an approach based on the idea of assessing the state of the current knowledge at any point in a development project. Essentially, it is about comparing the amount of knowledge that a company considers to be needed to feel confident (i.e. good enough) that a product or service will perform as intended, with the knowledge that is available to the company about that product or service at any time in a project. Based on maturity and readiness ideas borrowed from the Technology Readiness Level [13] concept and the Capability Maturity Model (CMM/CMMI) [14, 15] concept from software engineering, the Knowledge Maturity idea was born as a way to assess knowledge in a similar way as performance measures and indicators are assessed at decision points (i.e. gates). It is developed to support a gated process where there is a prescriptive dimension to it as well as the gate-assessment dimension. The maturity of the knowledge is assessed on three dimensions; input data, methods/tools used, and experience/expertise of the people doing the work. A generic scale of the criterion is presented in Figure 3 below.

| | | |
|---|---|---|
| 5 | EXCELLENT | *The content and rationale is tested and proven. It reflects a known confidence regarding, for instance, risks.<br>*The procedure to produce the content and rationale reflects an approach where tried out methods are used and where workers continually reflect and improve.<br>*Lessons learned is an important element. |
| 4 | GOOD (between 3&5) | |
| 3 | ACCEPTABLE | *The content and rationale is more standardised and defined.<br>*There is a greater extent of detailing and definition.<br>*The procedure to produce the content and rationale is more stable with an element of standardisation and repeatability. |
| 2 | DUBIOUS (between 1&3) | |
| 1 | INFERIOR | *Content and rationale is characterised by instability.<br>*The procedure to produce the content and rationale is dependant on individuals and formalised methods are non-existent. |

Figure 4: Knowledge Maturity criterion
(adopted from Johansson et al [4])

Input data is a label for all information and data that flows into the process (mainly from outside the company). How well can the company trust that the information is accurate? Is further research and development into the subject needed? Such questions should this dimension be able to address. The method/tool dimension is basically about assessing the refinement and development (of the input data) that goes on in a project. How good are the processes and methods used? How accurate are the simulation models that are used? And so on. These types of questions should be taken care of by this dimension of the Knowledge Maturity concept. Experience and expertise is about people, it is about the people who do the work, the experts that contribute, etc. Who has delivered this result? Which experts were involved? What experience from similar projects can be utilised? Such questions could be answered by addressing this dimension.

Since sharing tacit knowledge is one of the basics for enabling knowledge creation [16], knowing what experience and expertise conclusions can be based upon can be the deciding factor of whether a project is a success or a failure.

This concept with the criterion scales is also working in a prescriptive manner, where project leaders can assess what areas of knowledge creation and acquisition efforts should be focused on.

### 2.4 Lessons Learned

There are many different definitions of Lessons Learned. Secchi et al [17] provides a definition that is used by American, European and Japanese space agencies:

*'A lesson learned is a knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered sources of lessons learned. A lesson must be significant in that it has a real or assumed impact on operations; valid in that is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.'*

## 3 DATA GENERATION

The data presented in this paper has been gathered during both formal workshops and semi-structured follow-up interviews with some of the participants of these workshops.

Three workshops where held between April and September 2008 with development teams of three different product development projects in the aerospace sector. The participants were introduced to the workshop method with this information:

*'For many corporations, 'thinking-outside-the-box' means detaching yourself from current market needs and demands, and the term is often filled with frustration for the development teams that are supposed to turn these unconventional ideas into engineered reality. In a two-day immersive workshop format, we are using visual facilitation methods to enable highly cross-functional teams to explore a wide range of critical issues concerning product and service innovation, to create new ideas for how to address these issues, and to develop practical solution proposals for how to bring these ideas to market.'*

In these workshops, the development teams consisted of competencies representing all phases of the product lifecycle. Researchers who actively have participated and thus influenced both process and results have facilitated the workshops. The workshop process and the results have been thoroughly documented in internal reports.

In addition, to follow-up the workshops, semi-structured interviews were held with a selection of the participants. Based on the results from the workshops, the following themes were discussed during the interviews;

Application of:

- Stage-Gate processes
- Knowledge Management
- Knowledge Maturity
- Technology Readiness Level
- Lessons Learned

The intention to focus on different views on knowledge assessment in the Product Development Process have evolved during of the implicit analysis of the workshops and interviews, which have highlighted specific challenges about the current practice, thus evolving to become a main focus of this paper.

Given the use case driven nature of this study, the research can be seen as case study oriented.

## 4 KNOWLEDGE ASSESSMENT CHALLENGES IN THE PRODUCT DEVELOPMENT PROCESS – 'AS-IS'

The three development projects are described as:

- Project A: Process Development – Development of the company's PDP
- Project B: Product Development – Developing a new physical aerospace component
- Project C: Technology Development – Developing a new technology in order to be able to take on new product development projects

In all of the three development projects a company-specific version of the Stage-Gate is implemented. During the workshops we find that this process is well communicated and understood amongst the participants.

However, in both project A and B the gate reviews are seen as very important, but poorly used as an opportunity of knowledge assessment.

*'…they (the gate reviews) are important but why aren't we using them for educational purposes? Why aren't other development projects participating in order to learn something new?'*

Another participant comment was:

*'…and our review process isn't that good today. A lot of deliverables (between 40-50 reports) and a total of 6000 pages. Everything wasn't read or understood by the gate keeping team…'*

In project A, knowledge is primarily identified as a resource challenge. As one respondent puts it:

*'We only have a limited amount of staff with a certain competence. This implies that the number of experts isn't enough to cover the total needs of the company's project portfolio.'*

In project C, two companies are involved; the first is an experienced actor within the aerospace community; the other has no previous knowledge of aerospace development projects. Several times during the workshop communication issues are discussed. Lack of communication and lack of usage of tacit knowledge are seen as some of the major risks for this project.

*'…things that we (the experienced company) take for granted, is news for the others in the project…'*

*'We should immediately start a knowledge exchange program where we continuously send people to each others offices'*

The idea of the exchange program was developed in order to assess new and tacit knowledge to and from both organizations.

In all three projects, participants are comfortable with using the TRL scale. Especially in project A is it obvious that the intense focus on reaching a higher TRL is seen as an important challenge.

*'…our focus on TRL is always of highest priority. It doesn't work – we will reach TRL9 and go bankrupt at the same time…'*

In project B, Lessons Learned is the topic of the workshop. During the workshop, 8 positive and 12 negative Lessons are identified as the most important.

In all projects, Lessons Learned are prescribed in the Stage-Gate process description. They are supposed to be identified and documented (as a deliverable) at the end of the project.

*'…we should identify other development projects that can use the lessons we have learned – and then arrange a road show and 'push' the lessons to them…'*

All projects also mentioned the challenge of finding relevant Lessons Learned from other development projects.

In none of the three projects are the term knowledge maturity discussed or related to during the workshops.

In Table 1 below, some of the main points from the workshops and interviews are summarized to enable the reader to get an overview of the results from the case study.

## 5 KNOWLEDGE PATHS IN THE PRODUCT DEVELOPMENT PROCESS

The concept is based on the knowledge path framework introduced by Murray [18]. The term knowledge path is defined as the path a firm takes to explore the knowledge that expands and add value to its current knowledge base and product offerings. A knowledge path has two dimensions; the first part is how the firm searches for new knowledge and the second part is the assembly of the new knowledge with the existing knowledge base.

Murray [18] suggests that a firm's decision about where to search for knowledge and how to assemble it should be based on cost of search and assembly, organizational requirements, and likelihood of success. Further, Murray [18] states that a better understanding of the knowledge paths and their underlying processes will be at the heart for sustainable competitive advantage for knowledge-based firms.

### 5.1 The concept idea

As found in the in the results section there seems to be a need to better support knowledge assessment in the PDP. In the context of the PDP, the Stage-Gate models prescribes a way of performing product development activities, as well as prescribing the search and assembly of information in order to meet both the deliverables during the Stages and make correct decisions at the Gates. However, the knowledge assessment dimension is still missing in Stage-Gate models, as the main focus is about delivering and reviewing the results, not on a learning perspective. Engwall [19] concludes that Stage-Gate needs to be applied correctly, to allow for both flexibility and learning.

The main idea behind the concept presented here is to combine the approaches of TRL and Knowledge Maturity and relate them to the Stage-Gate process. See Figure 6

| | **Project A** | **Project B** | **Project C** |
|---|---|---|---|
| **Type of project** | Process Development – Development of the company's PDP | Product Development – Developing a new physical aerospace component | Technology Development – Developing a new technology in order to be able to take on new product development projects |
| **Workshop focus** | PDP Development | Lessons Learned | Risk Management |
| **Usage of Stage-Gate processes** | Yes. The Gate reviews aren't used to assess or distribute knowledge. | | |
| **Usage of Knowledge Management** | Resource planning is a knowledge challenge | - | Lack of usage of tacit knowledge is an identified risk for this project |
| **Usage of Technology Readiness Level** | Yes | | |
| **Usage of Knowledge Maturity** | No | | |
| **Usage of Lessons Learned** | Hard to find usable from other projects. | Hard to find usable from other projects. Pushing their own lessons to other development projects. | Hard to find usable from other projects. |

Table 1: Summary of workshop and interview results

for a schematic overview of the idea. Work in the PDP is aimed at and governed by increasing the TRL of the product. Knowledge maturity is about supporting the learning and knowledge utilization in the PDP. High knowledge maturity reflects a high level of knowledge about the product and the process. The use of a scale depicts that it is an evolutionary process, where you climb the scale while developing and learning about the product and process.

The knowledge path can be seen in this figure as the journey that the development team needs to make in terms of knowledge acquisition and technological evolution to meet the objective with the product, depicted as an increase in Knowledge Maturity and TRL respectively.

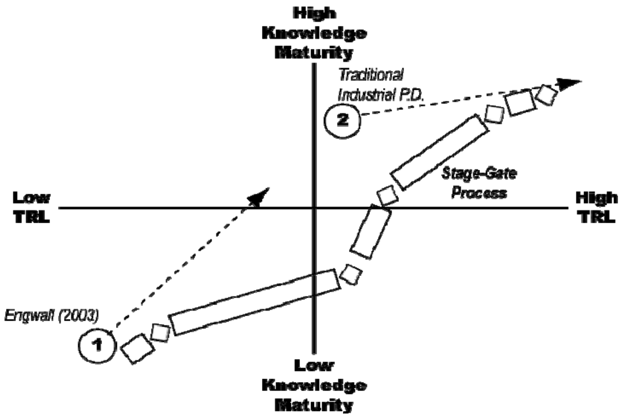


Figure 6: 2-by-2 that show the Knowledge Maturity in relation to TRL.

The knowledge path looks different for different product development projects, depending on the amount of learning. As the team learns, the amount of knowledge is improved and therefore the maturity of the knowledge in the project improves. This learning is depicted as moving along the y-axis in this figure. As a consequence of the learning, the technology is also developed. For instance, testing and simulating materials moves it closer to being ready for implementation in a product. This technological development is depicted as moving along the x-axis in the figure.

Figure 6 also depicts two examples, where the dashed arrows indicate the knowledge paths taken in the respective cases. The first has been described by Engwall [19], where the project team discarded the standardized Stage-Gate based process that the companies usually work by, in favor of processes that are more flexible and allows for uncertainty and learning. In this case there were essentially no prior knowledge about the problem they were solving and therefore the knowledge maturity began at a low level. Discarding the Stage-Gate did not only bring positive results as the integration with the organization and industrialization of the project proved difficult.

The second example depicts a more traditional product development project in the aerospace industry. There is very little uncertainty as contracts have been written with customers before the development effort begins, as well are their demands clearly defined in the contracts. This means that little learning takes place and the TRL level of the technologies is relatively high when beginning the project.

### 5.2 Designing the process

This line of thinking will also make it possible to design the process and knowledge path that should be taken. When will leaps in knowledge be made during the project? When will more staffing and resources be needed to make these leaps? And naturally, when can these resources be afforded to some other projects? Further, adding a time dimension to this reasoning could also help in planning of utilization of resources, such as when external consultants or experts are necessary to bring the project forward. In Figure 7 below, the dashed line exemplifies a typical knowledge path developed in advance of a project as a part of the resource allocation plan. Here stages with high workload can be identified and thus knowledge-intensive resource can be allocated. Conversely, Stages with need for less knowledge-intensive resources can also be planned for, so that they can be released to other projects in the organization. The same approach can be made for the gate keeping team who probably needs to invest more time and effort into Gate five due to the high increase in knowledge maturity during the Stage leading up to Gate five.

In a PSS scenario it is about making sure that you can deliver and be profitable for the duration of a product's lifecycle. Signing up for the risk that a total offer contain, means that a company cannot take any risks in terms of not knowing how the product will perform or that the business case will not hold. Therefore, being able to balance the technological leaps that need to be made from time to time to have an attractive PSS offering, with knowing about the unknowns will be imperative. The idea is to "design" this with this kind of representation.

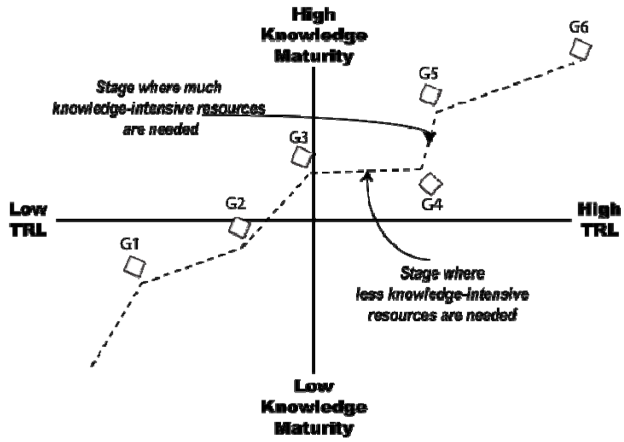


Figure 7: 2-by-2 that show the planning of a knowledge path.

### 5.3 Visualizing the progress

Cooper [3] says that the role of the gate meeting is, apart from deciding if the project should be allowed to pass, to decide how the path forward should look and how many resources should be allocated for the next Stage. The example in Figure 8 reflects one arbitrary gate in a product development project, where the dashed line depicts the knowledge path that should be taken during the stage. However, in this case the actual result of the work during the stage is similar in terms of TRL but too low in terms of the progress made in the knowledge maturity dimension. Therefore, more learning is needed in the following Stage to take the knowledge base to the correct level.

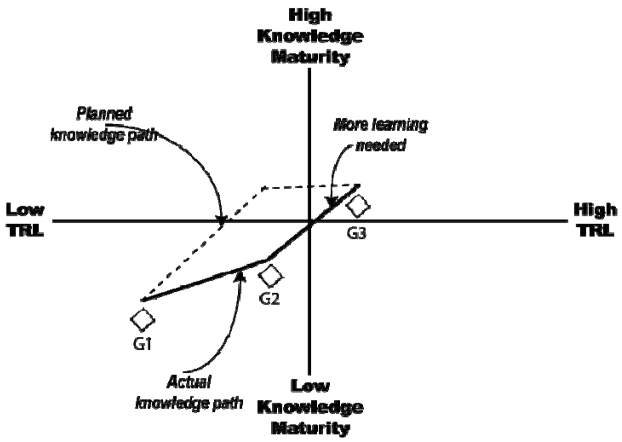


*Figure 8: 2-by-2 that shows progress made in relation to what was prescribed in terms of learning and technological maturity.*

## 6 CONCLUSIONS

The purpose of this paper was to describe different views on knowledge assessment in the PDP in industrial manufacturing companies. The result from the case study shows that both Stage-Gate process and TRL is already used in several types of development projects. However, there is an identified need of developing knowledge assessment methods, as learning and knowledge is not a focus in today's Stage-Gate driven development projects.

From a PSS perspective, the dimensions of learning and managing ambiguities and uncertainties will be even more important for successful executions of development projects.

Our conclusions are that the area of knowledge assessment in the PDP in industrial manufacturing companies is an interesting approach to facilitate learning in the development process. It is in need of further research and initially with a focus on the descriptive part in order to gain a better understanding. Thereafter, the intention is to move on with a prescriptive study, where and intervention, i.e. tool, method or other form of support, will be designed to aid in overcoming the problems identified.

The presented concept of creating knowledge paths in the PDP can be a valuable contribution as it combines two existing and implemented concepts (Stage-Gate and TRL) with a new method of assessing knowledge, the knowledge maturity approach. This concepts also fits very well into the development of PSS with the focus on managing a disperse knowledge base.


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