DEVELOPMENT OF ENGINEERING KNOWLEDGE MODELS TO ACHIEVE PRODUCT INNOVATION

Anna Karlsson[1,2] and Peter Törlind[1]
[1] Luleå University of Technology, [2] Sandvik Coromant

ABSTRACT
To pursue the understanding of governing principles, observations of phenomena and simulation of processes instead of relying purely on trial-and-error, is becoming more and more important in product development activities. This suggests that use of engineering knowledge models is an important part of future innovations. The purpose of this study is therefore to gain insight into the development and use of engineering knowledge models in the innovation process. Based on interviews with originators of such models within a manufacturing company, this descriptive study emphasizes the following aspects: the ambivalent aspect of reuse, multi-use of existing models and increased interactivity provided by engineering knowledge models.

Keywords: Engineering knowledge models, product innovation

1. INTRODUCTION
In innovation activities an important aspect is the learning of new things, particularly when it comes to achieving more successful innovations faster. Furthermore, an important approach of learning is reviewing information captured by fellow team members [1]. Innovation activities are therefore dependent on utilization of existing knowledge in a company, especially in highly technological companies where deep knowledge within the areas of technology, process and material are such important information assets in product development activities. To acquire the appropriate knowledge to perform a certain task a project group within a company has four possibilities:
1. Find who knows, ask individual or group within the company (implicit)
2. Revise corporate knowledge e.g. databases, models, current offer etc. (explicit)
3. Search externally (explicit)
4. Develop gaps in knowledge internally e.g. observations, tests, simulations (implicit, explicit)

Internal sources that imply collaboration with others seems to be preferred [2]. This holds true especially when the person or group stands before a complex or innovative problem where access to experts is preferred over static documents [3]. In the Community Innovation Survey 2008, table 1, information sources important for innovation were identified.

Table 1: Highly important sources of information for innovation among innovative firms in different European countries, 2006-2008 (% of sources rated as "highly important" for the completion of new or existing innovation projects.)

Sources of information for innovation	Belgium	Bulgaria	Germany	Spain	France	Luxemburg	Hungary	Netherlands	Poland	Finland	Average
Sources within the enterprise	32	22	32	34	44	26	26	35	29	40	32
Clients or customers	16	20	26	15	17	19	20	22	16	24	20
Suppliers of equipment	19	18	10	20	13	13	14	17	11	11	15
Competitors	6	11	10	8	6	9	11	7	10	7	9
Conferences, trade fairs, exhibitions	8	10	8	3	6	12	7	5	11	6	8
Scientific journals	4	7	5	7	5	8	4	4	8	2	5
Consultants	4	4	3	5	3	4	8	3	4	3	4
Professional and industry associations	5	4	3	3	3	7	3	3	4	1	4
Universities	3	3	3	3	2	1	5	3	3	3	3
Government or public research institutes	2	2	1	2	1	1	2	2	5	1	2

Source: Eurostat, statistics, search database, Sources of information for innovation

The most important sources according to the survey, were sources within the enterprise, although, the accessibility to sources of information can also explain this preference. An internal source for both information and learning in a company is engineering knowledge models describing either empiric data or analytic relationships between quantities. This study intends to answer how such models are used in the innovation process and why they were developed in the first place. According to Arora and Gambardella most prior innovations and productivity improvements have resulted from empirical procedures based on trial-and-error. But there seems to be a change in this state-of-affairs. The tendency is towards attempting to understand governing principles, to observe phenomena and to simulate processes on computers instead of relying purely on trial-and-error to find out what may work [4]. This change suggests that development and use of engineering knowledge models is an important part of future innovations. The purpose of this study is therefore to gain insight into the development and use of engineering models in the innovation process.

1.2 Delimitation

This study is limited to the point of view of originators of selected models within a manufacturing company. The reason for this is that originators should have the best insight in both the past (reason for development) and the present i.e. current use of the models. All models are computer based and come from the product development department of a leading manufacturer of tools for the metal cutting industry. Therefore models developed for manufacturing, service or marketing purposes are not included in this study.

2. THEORETICAL FRAMEWORK

2.1 Types of knowledge and innovation

The distinction between tacit and explicit knowledge is the key for understanding organizational knowledge. Explicit knowledge is formal and systematic and can consequently be communicated and shared. Tacit (implicit) knowledge on the other hand is hard to formalize and, therefore, difficult to communicate to others. Another aspect of tacit knowledge is that it is highly personal and deeply rooted in action [5]. One way to make knowledge explicit is to write it down and in doing so the knowledge is codified [6]. Where to draw the line between codifiable and non-codifiable knowledge is, according to Johnson et al, highly problematic since any body of knowledge might be codified to a certain extent [7]. But people don’t just passively receive new knowledge, codified or not, it is necessary for people to actively interpret the knowledge to fit their own situation and perspective [6]. This holds true also on a group level, i.e. between departments in a company. The departments constitute different “thought worlds” which each have an important insight into the product or market that is essential to achieve successful innovations. But these interpretive differences between departments also hinder collaboration [8].
Innovations can be of different types:

- *Technological innovations* can be a product, a process or a service and consists of the knowledge of components, methods, processes and techniques that go into a product or a service.
- *Market innovation* is an improvement of the components of the marketing-mix, that is, product, price, promotion and place.
- *Administrative innovations* are related to strategies, structure, systems, or people in the organization and therefore pertain to the organizational structure and the administrative processes [9].

The newness of a product innovation can be framed either at a) a macrolevel where the characteristics of product innovation are measured against newness to the world, the market or an industry or b) a microlevel where product innovativeness is identified as new to the firm or the customer. Measuring newness at a microlevel results in difficulties to compare results from different studies [10]. The focus of a firm’s innovation activity is often connected to the nature of the enterprise and in its market. Other innovation types are therefore focused on impacts of innovations as opposed to their novelty. Radical or disruptive innovation can be defined as an innovation that has a significant impact on market and on the economic activity of the firm in that market, whereas incremental innovation continuously advances the process of change and is more focused on production efficiency, product differentiation and marketing [11].

2.2 A model, one way to codify knowledge

Progress in design projects is measured by deliverables such as drawings, prototypes, results of analysis, and other representations of generated information. These deliverables can all be seen as models of the final product [12]. A model is consequently an artifact, which reproduces the properties of an object, used to answer queries during the design process. Engineering design can therefore be seen as propagation from model to model [13]. The simplicity of models, compared to real life, derives from the fact that only relevant information is included i.e. models are idealized.

- *Iconic models* are enlarged or reduced renderings of reality. Iconic models look like the reality it is intended to portray; it is the scale that differs i.e. maps, photos and CAD-models.
- *Analogy models* use a property to provide information of another. Examples of analog models are a slide-rule or using a hydraulic system to symbolize an electric system. These type of models are easier to manipulate in order to indicate an effect but also more abstract and general than iconic models.
- *Symbolic models* express the real condition, object or occurrences in a symbolic form. An example of a symbolic model is mathematical models where symbols stand for quantities. Symbolic models are the most abstract and general form of models, but at the same time they are easier to handle (e.g. conduct parametric studies) compared to iconic and analog models [14].

2.3 Codified knowledge in Innovation

According to Senker the codification of knowledge increases as a technology matures. There are three main routes to achieve this codification namely science push (theoretic underpinning of procedures, filling identified knowledge gaps or a result from blue-sky research), technology pull (exploration of phenomena and problems arising in industry) or the introduction of automation (machine tool instructions such as NC-code) [15]. There are two different ways of accessing explicit technological, codified knowledge; those being generating the knowledge internally or acquiring it in the markets. Licenses represent a means of acquiring explicit knowledge developed by other organizations. When it comes to explicit knowledge generated internally, a representative variable that is used to measure the effect of technological knowledge assets on innovation is intellectual property rights (patents, utility models) [16]. Codified and disclosed knowledge such as patent disclosures and computer-based information networks, are seen by firms as relatively unimportant as sources of innovation. But the preference for using codified sources of knowledge is also sector-specific and seems to be higher in high technology sectors and firms with existing absorptive capacity [17]. But not all innovations are patented by firms since different technologies are differently patentable and the tendencies and reasons to patent innovations differ between firms [18]. With this said little has been done to investigate how internal sources of codified knowledge affect innovation capability.

3. RESEARCH METHOD

In this descriptive study existing models were identified by the research coordinator of the company with help from managers and the authors of this study. Thereafter originators of all the identified models were contacted and asked to participate in a study concerning engineering knowledge models, a majority of the contacted originators accepted. Qualitative data for this study was then generated from five semi-structured interviews, length ranging from 50 minutes up to 1 hour and 30 minutes. All interviewees are employed at the same company, but in different departments within R&D with experience within the firm ranging from 4 years up to 20 years (average approximately 14 years). The company in question is a leading brand of tools and tool holding systems for metal cutting, established in 1942. All interviews were conducted face-to-face in Swedish by the same interviewer, tape recorded and thereafter fully transcribed and analyzed. A semi-structured approach to interviewing means that a standard list of open-ended questions exists but that the interviewee is allowed even encouraged, to talk expansively on the main subject and raising topics as he or she wishes. The interviewer can also follow up on leads provided by participants with questions like *How? Why?* and *When?*. Each interview started with a brief overview of the purpose of this study, the intended use for the data and questions concerning the background of the interviewee. Succeeding questions dealt with fundamental definitions for this study such as: *What is knowledge for you?* and *What is innovation for you?* followed by probing questions. Thereafter questions concerning the purpose and use of the model in question were posed with the first question being: *Tell me about the model?* The interview also included questions like: *How did your latest innovation occur?* and *What would you need of a model* *for it to be useful in the innovation process?*. The semi-structured approach to data generation was used in order to understand and gain insight into the originators perspective on situations and events concerning the identified models.

3.1 Method of analysis

All models in this study can be categorized as computer based symbolic models according to Ackoff. It is also possible to categorize the models further, in regard to what they are based on; into either analytic models that package existing knowledge to make it more accessible and provide visualization or empiric models where new knowledge was developed experimentally and then presented in the form of a model. This categorization provides insight into the context of each model.

4. EMPIRICAL FINDINGS

This section begins with a description and categorization of identified models into analytic or empiric based groups. Thereafter extracts from the interviews are presented in order to lay out why and how the models were developed or used and their connection to innovation activities. It should be stated that "model" is an umbrella term used in this article to describe simplifications of reality that provides an overview of affecting parameters. The interviewees sometimes use other words to describe these simplifications, for example program or "twirl". See Figure 1 for examples of engineering knowledge models.

4.1 Categorization of identified models

Analytic models: Derived from theories and relationships between quantities

A1: A spreadsheet based model describing for example how pitch and diameter of a screw affects the generated force on the screw head and how much torque that is transferred to the thread when the screw is tightened, see Figure 1.

A2: A model constructed in Visual Basic, consisting of a drawing module and mathematics, describing cutting forces in segments of an indexable insert drill. The forces in each segment are combined to describe the forces acting on the entire drill.

A3: A model predicting how the cutting forces will be depending on different geometries of a milling insert. This is done using orthogonal to oblique transformation. Compared to A2 the biggest difference is, besides the application area, that the model is integrated into existing CAD software.

Empiric models: Based on measurement data

E1: The method of least squares is used to approximate measured/empirical data in a spreadsheet application. Scroll bars and graphs are used to display the data and make the model interactive.

E2: The purpose of this model is to systematize existing information on material properties of cemented carbide. The model contains information ranging from simple line fit graphs describing specific material properties to commercial software used to perform thermodynamic and phase diagram calculations.

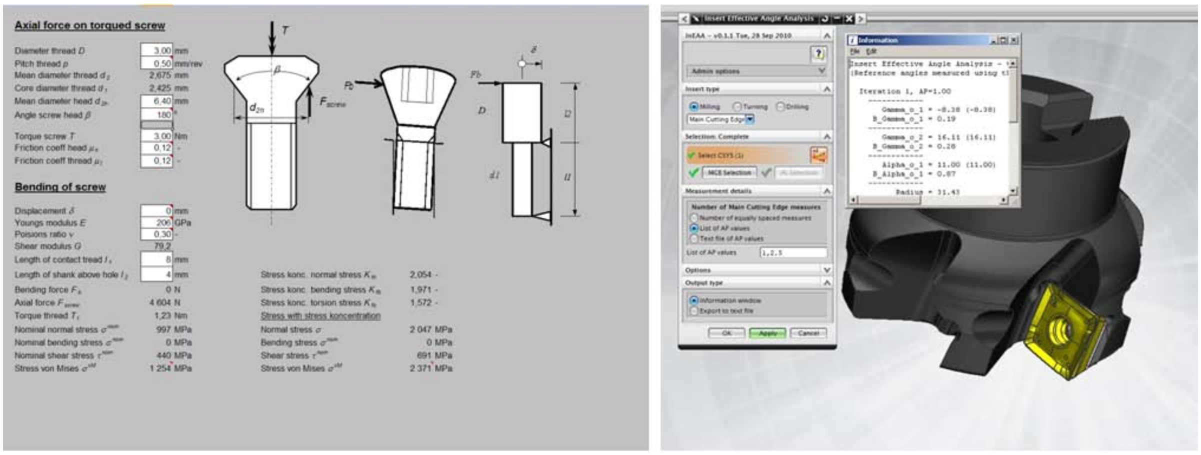

Figure 1: Examples of engineering knowledge models

4.2 Intention of identified models

The initiative came from diverse directions, most commonly the model was initiated by the person that later became the originator. The purpose for the different models differed, but they were all intended to be used for development work. One of the interviewees, a product developer, provided this answer to the question; why was the model developed:

"Because I wanted to learn more! To be honest I was bored one afternoon, so I sat down and pondered on what I wanted to do. Then I marked it down and sent it to my boss."

Other reasons for making models were that development engineers struggled with analyses (A1) or with handling existing information such as experimental measurements (E2).

"Analyses was not carried out…the development engineers did not have the knowledge to work with theory in the way that was necessary…When prototypes were tested screws sometimes broke and the inserts came off, this was due to bad guesses."

To make the analyses easier a model (A1) was constructed and according to the interviewee this model constituted an intermediate link between theory and prototypes. Often development engineers gave feedback and commented that they now understood, after using the model, why earlier prototypes had not worked. The last category of models visualized phenomenon i.e. how forces affect a conceptual product. In both cases (A2 & A3) similar models existed. The originator for the model A2 recounts:

"And then we said, well that [existing model] *is good but it really does not work. So we concluded, then we make a program like that."*

He continues to explain why the existing model was not sufficient:

"I think that it was too difficult to draw conclusions. Besides, it is not possible to play with that program, you had to know the result beforehand, complete it totally and then you would get the feed-back."

The model (A2) that the interviewee later developed was intended to help in the generation of a new concept.

4.3 Usage of the models

When it comes to usage of models a commonality between all models is that they have been used for other purposes than the one for which they were originally intended. For example some of them are handed over to new employees to improve their understanding, which is one example of how models are used for communication purpose. Other examples of models used for communication is using models as advertisement within the company or to explain and promote an idea i.e. using model E2 to rationalize among cemented carbide substrates during a merger:

"To remove existing substrates, identify unnecessary substrates in our production and propose replacements… In contexts like that it [the model] *is an important tool both in the identification process but also pedagogically to build confidence to dare to implement* [changes in production]*"*

The originator of model A2 recollects a similar situation:

"And everybody understood, the result is easy to understand… To spread innovative ideas and explain concepts to others, because then you can get input from others that you would not have otherwise, well it supports cross-functional teams.

Other areas where models have been used are to provide input to FEM-software (Finite Element Method) or in programs for design automation. Parts of a model (A3) also provided another opening, namely the possibility to measure CAD-models, something the interviewee finds very useful.

"For example forces and measuring [two parts of the same model, visualizing forces and measuring of for examples angles in 3D CAD-models], *measuring* [in the CAD-model] *is most likely much more important because it saves so much time in their* [product developers] *daily work. But that possibility arose by coincidence."*

This quote clearly indicates that time savings can be very important and a reason to develop models, something several other interviewees agree with. One of the originators explains that time was a factor because it was very time consuming to complete a CAD model before the model was constructed. With the new model the time it took to complete a simple 3D-geometry was significantly reduces:

"And it takes maybe just two, three minutes to draw an insert in this interface [part of the model], *the one I created, and therefore it is possible to run up to 50-60 ideas each day."*

He continues:

"Many of the ideas would never have been tested if we would have done prototypes. Because then it would have been too much hard work, the idea was so wild and farfetched that no one would have tested it."

One of the ideas the interviewee refers to is integrated in a product, now on the market, that have received awards for being innovative.

"[this product] *would not look as it does today if we did not have this program, of that I am totally convinced. It would be, completely impossible otherwise."*

Common in some of the excerpts above is that saving time is of importance. When it comes to innovation it seems even more important what gets done with this obtained time. In use of these models the problem statement also seems to be very important. It is when someone stands before a problem that needs to be solved the person in question is receptive enough to really benefit from a model. Expressed in the words of the originator of model E1:

"We humans are naturally lazy so we don't dig in places where we don't need to. We dig for a reason, to find something, and more often than not we dig because we hope that it will make it easier in the future."

This reasoning might seem obvious but is important to consider when thinking about constructing a model, especially if it is someone else that will use the final result. It also indicates that it can be hard to reuse models because the focus i.e. the problem statement changes over time.

4.4 Connection to innovation

The interviewee's reason quite differently when it comes to the use of models in the innovation process.

"Often models are built on existing knowledge. And it is not the great innovations when you take something and combine it with something else, well I don´t know, but you don´t get the things that are outside the box… The models we have here, the ones I have seen anyway, are more towards optimization than innovation"

Another interviewee reasons around the fact that it is not always the same persons that develop models and finally creates the innovative solution:

"Innovations do not just occur because you have the knowledge, it has to be clear that knowledge is created and innovations can be made by totally different people [different from the people that created the model]. *So maybe that should be clarified, that an important part of knowledge creation is to build the knowledge so that the innovative forces can access it."*

Another interviewee sees benefits with creating knowledge that someone else will use. On the question if it should be the same persons that create the knowledge and take it the last bit into a model the interviewee answers:

"Well, it definitely does not have to be, it could even be an advantage if it is different persons. Because then someone has to understand [the model]*… it is a natural threshold you have to pass."*

The quote illustrates the importance of involving users in the development of a model. This contrasts to another point of view, namely that it is the creator of the model that benefits the most. On the question what the most important thing the model has resulted in, one of the interviewees answers:

"That I understand better, the one who has created it [the model] *understands better. Secondly that some of the others have gained some insight, but they have not remained with the company long enough to fully absorb it all."*

Increased understanding of a specific relationship is often the main reason for creating or using a model. According to the originator of model E2 existing models can also be used to identify lacks in existing knowledge, especially when the model is compared to measurement data.

"I use it myself sometimes when I receive experimental results that I react upon, is it really like this? Then you use the model and see that this is right, it was not that strange .Or, sometimes the result does not make sense, and you start to wonder what the reason is?"

The same interviewee also stated that:

"If you don´t have a model to base old knowledge on, then you don´t know what is new!"

Clarity and simplicity is important when a model should be used for innovation purposes, both when it comes to what is known and what is unknown but also to make it possible to see opportunities. Another important aspect of a model is that it is visual and fast, as one of the interviewees' answers on the question, what is needed from a model to make it useful in the innovation process?

"That it is visual and fast… I think that it can contain a good deal of inaccuracies and still be useful. To get the direction is often sufficient"

He continues to explain.

"It is from the visual you should get the connections, consequently if I do this, that will happen. You start to see patterns, start to understand patterns."

5. DISCUSSION OF EMPIRICAL FINDINGS

The engineering knowledge models identified in this study are all symbolic, limited in size and specialized towards specific knowledge areas. The main reason for the symbolic nature of the models is probably that they become easily transferable and manipulated e.g. handled. But at the same time the models can become quite abstract which in turn becomes a barrier for a user to surpass. The possibility to also use other types of models e.g. iconic or analogy models can be of benefit for a user other than the originator. Furthermore, the models described in this paper are just one special case of how an individual or group within a company can acquire already existing corporate knowledge; see Figure 2 a). Other ways to find this knowledge are, as already mentioned, to find out who knows or to search externally. The models identified in this study should not just be seen as codified knowledge since they comprise both an explicit and a tacit dimension. Usage of the models, for communication and learning purposes, indicate that the models support communication of tacit, experience based, knowledge e.g. the expanded use field in Figure 2 b). Although the preference for personal contact with an expert still stands strong when it comes to acquiring knowledge, there might be a good chance that mentioned expert will use a model to explain certain phenomena. There is also a possibility to use engineering knowledge models in an external context (i.e. accessible by customers). This is not suitable or even possible for all models.

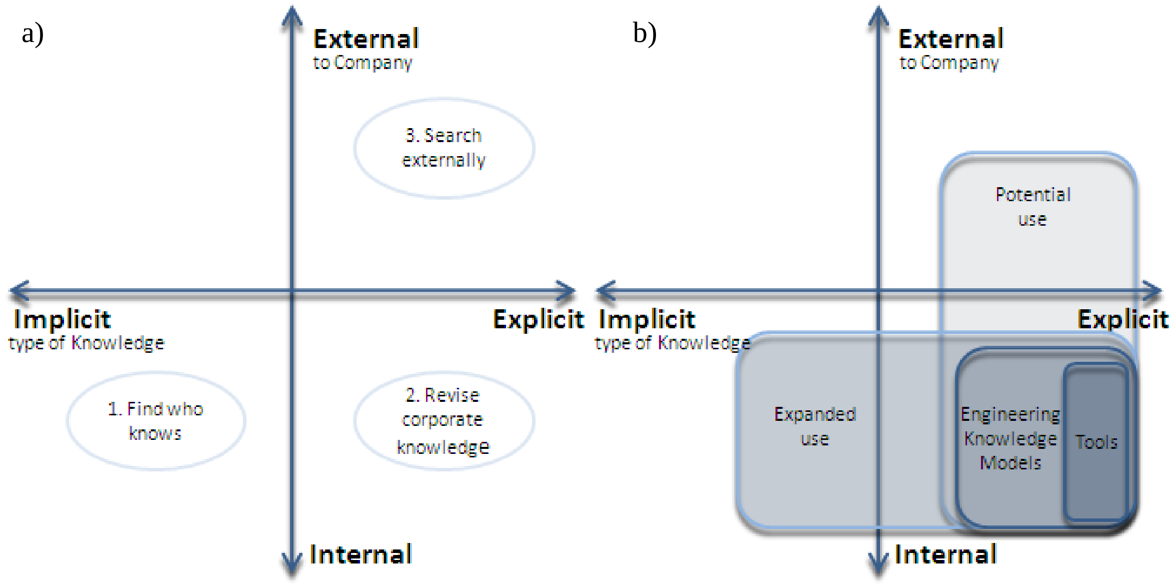

Figure 2: Placement and use of engineering knowledge models related to type of knowledge and company context

The models appear to be more focused on learning i.e. providing insight and communication rather than managing and storing of knowledge (as in PDM and PLM). Since the majority of the models were initiated by the originators themselves curiosity is also an important factor to consider. An organization needs to allow employees to take initiatives that will satisfy this curiosity. The models can be seen as delimited KBE tools to be used in early stages of product development. Some of the more mature models were also developed into a tool. The difference between the model and the tool (in this paper) is that the tool contained a more refined user interface, defines the boundaries in which the model is valid. The tool could also be used without the intervention of the creator. One advantage of the models in this study over a static document is the interactivity they provide. When models are created in connection with specific product development projects, they also provide understanding of why a product is designed the way it is; meaning that a model can be a good way to capture the design rationale of a product. This capturing of design rationale can also explain why the identified models are handed over to new employees. The research is limited to the originators of knowledge models in just one company. In order to generalize or give recommendations based on the result it is therefore necessary to expand the research to also include for example users of models, models of manufacturing, service and marketing activities as well as models from other companies. The narrow scope for this study has the advantage that the phenomenon of interest can be examined in a rather uncomplicated way, thereby providing better insight into the phenomenon [19]. With this in mind, the research shows that engineering knowledge models are developed mainly for three reasons; to aid idea generation activities, support learning within the company and to facilitate development work. If a model is or should be reused as well as how much error that is acceptable appears to be dependent on the original intention of the model:

- In idea generation it can be enough for a model to indicate the direction for designs, therefore a higher margin of error seems to be allowed. In models purposed for learning (based on internal data) and for facilitation of work, the allowed margin of error is narrower, which can depend on the usage later in the development process i.e. when they are used for optimisation purposes.
- If models are reused or don't seem to correspond with the original intention for the model. When it comes to models purposed for idea generation the reuse for that specific purpose is lower compared to models purposed for supporting learning and for facilitating work. Yet, models intended for idea generation are reused but for other purposes than originally intended, for example to provide insight to new employees.

- Reuse of a model poses demands on a clear scope for every model; therefore limitations have to be clearly specified in order for the models to be used in adjacent areas. Otherwise there is a risk that knowledge contained in the model will be interpreted differently.

Degree of codification is said to increase when knowledge matures [15]. The use of engineering knowledge models to present data from internal projects, with the purpose to support learning, and also in idea generation indicate that this might not always be the case. The high degree of reuse among models intended for facilitating development work indicates that models containing mature knowledge are more accepted and therefore used more in the organization. Generally, this study shows that engineering knowledge models need to provide visualization as well as simplicity and clarity of the knowledge it contains in order to be useful in the innovation process. The type of knowledge, problem statement, and parameters that the model is based on will affect the ways simplicity and visualization can be realized.

6. CONCLUDING REMARKS

This study shows different viewpoints exist when it comes to the use of knowledge models to achieve innovations. Some perceive the development and use of knowledge models to be a basis for innovations since innovations are seen as combined bodies of knowledge. In order to create new innovations it is therefore necessary to raise the bodies of knowledge. Others see innovations as greater leaps, not possible to achieve by combining known knowledge. Obviously there are other ways to capture and handle knowledge; therefore knowledge models should not be seen as a universal cure to all problems within an organization. However, these knowledge models can be used to identify gaps in current knowledge and clarify what actions needs to be taken to fill in lacking knowledge and thereby enhance innovation. Based on the interviews with originators of engineering knowledge models, the following aspects can be emphasized:

- *The ambivalent aspect of reuse*, or in other words the engineer does not always see the reuse of a model as the best way to handle knowledge and learning. Sometimes, depending on the purpose, it appears to be better to develop a new model than to reuse an existing. This is because problem statements change over time and a lot of new knowledge is developed when developing a model, new knowledge that can contribute to innovations. With this said reuse of existing models should not be neglected.
- *Multi-use of already developed models* for other purposes than the originally intended is a common factor for all models, often for communication purposes like spreading of knowledge. To use models in this way opens up the possibility to extend the use of models to capture design rationale. This can be done throughout a project to communicate between different “thought worlds” [9] i.e. departments in a company (R&D, manufacturing, sales etc.) as well as in the documentation after the completion of a project.
- *The increased interactivity* provided by the possibility to manipulate a model (through, geometries, parameters and coefficients) compared to a static document is seen to contribute to a deeper insight in the corresponding cause and effect relations. This deeper insight enhances both idea generation as well as optimization.

To simplify the reality into a model is a natural engineering activity where affecting parameters are abundant. Whether the resulting model is codified or not i.e. exists only in the minds of people or as an artifact, physical or not is not problematized in this study. Instead the development and use of explicit knowledge models are studied with the assumption that they complement the tacit knowledge existing in the minds of individuals. It is interesting to get further understanding related to when an explicit model is preferred over a tacit and how this affects the innovation process.

ACKNOWLEDGEMENTS

The participation and openness shown by respondents in this study is acknowledged by the authors as well as the reading and advice from Nicklas Bylund. This research is provided for by SSF (Swedish Strategic Foundation) through the ProViking THINK project at Luleå University of Technology.

REFERENCES

[1] Lynn G.S., Skov R.B. and Abel K.D. Practices that Support Team Learning and Their Impact on Speed to Market and New Product Success, *The Journal of Product Innovation Management*, 1999, 16, pp. 439-454

[2] Ericson Å., Karlsson A., Wenngren J. and Törlind P. Where do innovations come from? *Proceedings of the 11th International Design Conference DESIGN 2010*, Dubrovnik, May 2010, pp. 545 – 554

[3] Ackerman M., Pipek P. and Wulf V. *Sharing Expertise: Beyond Knowledge Management*, 2003, (Mass: MIT Press, Cambridge)

[4] Arora A. and Gambardella A. The changing technology of technological change: general and abstract knowledge and the division of innovative labour, *Research Policy*, 23, 1994, pp. 523-532

[5] Nonaka I. The Knowledge-Creating Company, *Harvard Business Review*, 2007, 85(7-8), pp. 162-171

[6] Jensen M.B., Johnson B., Lorenz E. and Lundvall B-Å. Forms of knowledge and modes of innovation. *Research policy*, 2007, 36, pp. 680-693

[7] Johnson B., Lorenz E. and Lundvall B-Å. Why all this fuss about codified and tacit knowledge? *Industrial and Corporate Change*, 2002, 11(2), pp. 245-262

[8] Dougherty D. Interpretive Barriers to Successful Product Innovation in Large Firms, *Organization Science*, 1992, 3(2), pp.179-202

[9] Popadiuk S. and Choo C.W. Innovation and knowledge creation: How are these concepts related? *International Journal of Information Management*, 2006, 26, pp. 302-312

[10] Garcia R. and Calantone R. A critical look at technological innovation typology and innovativeness terminology: a literature review. *The Journal of Product Innovation Management*, 2002, 19, pp. 110-132

[11] Oslo Manual, *Guidelines for Collecting and Interpreting Innovation Data, 3rd Edition, available at* http://www.oecd.org/document/23/0,3746,en_2649_34409_35595607_1_1_1_1,00.html (2011)

[12] Ullman D.G. *The Mechanical Design Process*. 3. ed, 2003 (McGraw-Hill Companies, New York)

[13] Andreasen M.M. Modeling –the language of the designer, *Journal of Engineering Design*, 1994, 5(2), pp.103-116

[14] Ackoff R.L. *Vetenskaplig Metodik*. 1972 (Beckman, Stockholm)

[15] Senker J. The Contribution of Tacit Knowledge to Innovation, *AI & Society*, 1993, 7, pp. 208-224

[16] Díaz-Díaz N.L., Aguiar-Díaz I. and de Saá-Pérez P. Technological knowledge assets and innovation, *International Journal of Technology Management*, 2006, 35(1-4), pp. 29-51

[17] Brusoni S., Marsili O. and Salter A. The role of codified sources of innovation: Empirical Evidence from Dutch manufacturing. *Journal of Evolutionary Economics*, 15, 2005, pp. 211-231

[18] Breschi S., Malerba F. and Orsenigo L. Technological Regimes and Schumpeterian patterns of Innovation, *The Economic Journal*, 110 (April), 2000, pp. 388-410

[19] Valkenburg R. and Kleinsmann M, Performing High Quality Research into Design Practice, In *International Conference on Engineering Design, ICED'09*, Vol. 2, Stanford, August 2009, pp. 135-144

Contact: Anna Karlsson
Sandvik Coromant
811 81 Sandviken
Sweden
Tel: Int +46 26 2 66227
Email: anna.karlsson@sandvik.com

Anna is an industrial PhD student affiliated with Sandvik Coromant, a leading manufacturer of tools for metal cutting. Her interests are innovation practices, in particular the impact of visualization, communication and collaboration.