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Developing Engineering Creativity in the Early Design Stages of Product Development Process

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Abstract. The aim of the paper is to outline the background and basis for the TRIZ for Early Design stage research project that is about to be launched. Based on previous research, this paper presents an overall analysis of the tools used for supporting innovativeness in product developmet processes and how innovativeness is taught at the Tampere University of Technology. As the outcome of the analysis, two main research objectives were found: first, there is potential for a new framework for integrating the TRIZ methodology into the early design stage, and second, there is a need for a new approach for teaching and promoting the use of TRIZ. The goal of the research project is to create a novel method for utilising TRIZ at the early design stage that can be easily applied in companies.

Keywords: TRIZ, Early Design Stages of Product Development Process, Front End of Innovation

1 Introduction

This paper presents the background and basis for the research project MOSES – "Modelling and Simulation at the Early Design Stages - Novel Concept Design Applied to Energy Efficient Air Bearings" and especially for the part of the project where innovativeness is needed. The aim of this paper is to discuss the main theories of the early design stage of a product development process and to describe the key results from the previous Radical Innovation by Design Research Project (Project RID). As a new point of view, we will present our experiences of teaching innovativeness in university and consider the challenges of teaching the Theory of Inventive Problem Solving (TRIZ). Ultimately, we will outline the main challenges related to the MOSES project, formulate research questions, and define objectives.

As an introduction to the paper, we will present the general nature of the problems related to the early design stage of a product development process and the challenges of creating higher-level innovations. After this, the aim of the paper is considered in more detail and the organization of the paper is presented.

1.1 Nature of the problem

A modern product development process sets major challenges for development teams and for researchers of the product development community. This is often due to the great level of uncertainty faced during the development process and especially during the early stages. The early design stage can be defined as:

- "Planning and Clarifying the Task Phase" of the Process of Planning and Design (Pahl&Beitz, 2007);
- "Concept Development Phase" of the Generic Process Development Process (Ulrich&Eppinger, 2008);
- or as the "Fuzzy Front End" phase that should be carried out before entering the actual New Product Development (NPD) process (Koen&al., 2002).

From the viewpoint of managing the product development and control of resources, the early design stage is very challenging because it consists of several iterations between the various tasks and involves a great amount of uncertainty. Also, needs are difficult to capture and often ill-defined. In addition, the decisions taken at an early stage, which are widely recognized to have enormous impact on the latest development stages, are based on early definitions of problems that are characterized by a high level of qualitative information and partial definition of the goals and constraints.

According to Altshuller, the developer of the Theory of Inventive Problem Solving (TRIZ), approximately three-quarters of the inventions analysed were apparent solutions (Level 1) or improvements (Level 2) that can be regarded as incremental innovations - upgrades in a product or a service. However, nowadays productive invention creativity belongs to the range between the third and mid-fifth levels in Altshuller's scale. (Altshuller, 1999) To enable higher-level innovations or radical innovations (~Levels 4-5), there is a need to support innovativeness already at the early design stages of a product development process. According to Altshuller (Altshuller, 1999) TRIZ offers efficient tools and methods to support the discovery of new high-level radical innovations.

Finland's National Innovation Strategy draws the alignments for improvement operations for developing innovation processes in Finland. According to the action plan of the National Innovation Strategy, one of the most important tasks is to develop the competence base. (Ministry of Employment and Economy, 2010) However, in order to be able to exploit the competence base, we need methodical knowledge for creating innovations.

1.2 The Aim of the Paper

The aim of the paper is to define the basis for the research project MOSES. Based on the nature of the problem, the paper presents an overall analysis of the tools used in supporting the early design stage. This is carried out by taking an overview of the main results of the previous research project (Eloranta&al., 2004). To present the problem of learning innovativeness and especially TRIZ in more detail, we will describe how innovativeness is taught at the Tampere University of Technology. On the basis of the analysis and the experiences, it can be seen that there is a need for approach that promotes innovativeness at the early design stage.

The MOSES research project is about developing a novel method for utilising TRIZ at the early design stage and an approach to teach it. Research will be carried out using the Constructive Research Approach (Kasanen&al., 1993) via literature surveys, interviews, benchmarking, and case studies (Eisenhardt, 1989). The results of the research project will be validated and verified in cooperation with selected companies and their early design stages. The results will be applied in the development of teaching methods and the contents of the Innovation course.

1.3 Organization of the Paper

Section two will present some theories of processes and tools used by the major business units in the Tampere region to create and manage the creation of new innovations. In addition, the section will contemplate on the reasons why these working methods require further evolution. This section creates the theoretical basis for the research project. Section three presents an analysis of how the Tampere University of Technology (TUT) teaches innovativeness with Simplified TRIZ at the Innovation course, and thus attempts to ensure the innovative capability for industrial needs. Section four will clarify the research questions and objectives for the research project and presents the hypothetical combination of method as the result of the research. The final section concludes the paper and opens the discussion.

2 Results of the Project RID and Need for a New Innovation Framework at Early Design Stages

The Project RID provides a good theoretical background and starting point for the MOSES project. This section presents the main theories examined during the Project RID as well as the results and findings.

The Project RID was executed in cooperation with companies that manufacture technology products of a high variety in the Tampere Economic Area, by assisting in the development of the innovation processes. The companies involved in the project are global market leaders in their respective niche areas. Table 1 presents the companies analysed together with their respective world market shares in 2006

Table 1. Global Market Leaders with major business units in the Tampere Region (Tampere Business Region, 2007).

Company	World market share	Products
Nokia	40%	Telecom solutions
Kalmar, Cargotech	>50%	Container handling machinery
Sandvik*	35%	Mining and construction machinery
John DeereForestry*	45%	Forest machinery
Metso Automation	>15%	Automation for process industry
Metso Minerals	15%	Mobile rock crushers
Glaston	>50%	Safety glass machinery
Bronto Skylift,FSC*	>60%	Fire and rescue platforms
Fastems	70%	Factory automation
Ata Gears	45%	Spiral bevel gears for marine
Gardner Denver*	30%	Ship compressors
Avant Techno	40%	Mini loaders
Sisu Diesel, Agco Corp.*	10%	Diesel engines
UPM Raflatac	35%	Self adhesive laminates

*Foreign investments

The companies listed in Table 1 operate on business-to-business markets. They have made innovations and implemented new technologies: for example, the biodegradable implant, a walking forest harvester robot, and a fully-automated mine.

2.1 Theories for the Supporting Innovation Process at the Early Desing Stage and Their Realisation in Project RID Companies

According to the results of Project RID (Eloranta&al., 2004) many of the companies had systematised and improved their product development processes. Their New Product Development (NPD) design processes (Koen&al., 2002) are documented in quality manuals. The companies have implemented Cooper's Stage-GateR model (Cooper, 1993) (Fig. 1.). (Eloranta&al., 2004) The stage-gate model does not, in actual fact, promote innovations but rather provides an effective means for managing the NPD.

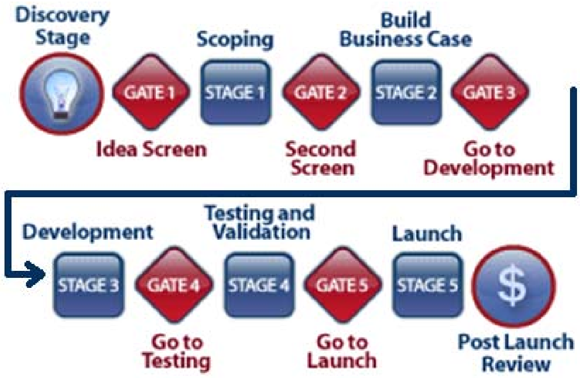

Fig. 1. Cooper's Stage-Gate[R] Model (Cooper, 1993).

Nevertheless, in these companies, the development of processes and tools to support product development is mainly focused on the Embodiment Design phase (Pahl&Beitz, 2007) only. For example, product modelling and simulation are mainly used in the Embodiment phase. The companies have recently developed their use of prototypes and defined the requirements for prototypes of the various phases as well as those for the expected results. (Eloranta&al., 2004)

As a result of the analysis of the companies' product development processes, we discovered that they all apply the Guaranteed Innovation (GI) system presented by Kuzmarski & al. (Eloranta&al., 2004). The components of the GI system are: Priority, Policy, Platoons, Process, Problem Orientation, Platforms, and Payback Metrics, which are also known as the 7P's (Fig. 2.) (Kuczmarski&al., 2001).

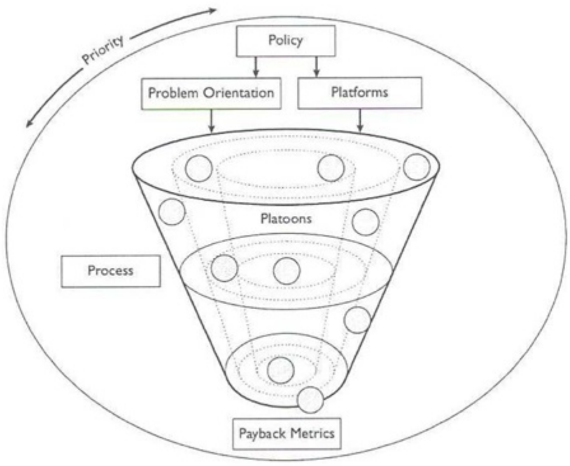

Fig. 2. Components of Guaranteed Innovation (GI) System (Kuczmarski&al., 2001).

Innovativeness in product development process is promoted with the help of the components of the GI system, and this way the value of the company is increased (Kuczmarski&al., 2001).

2.2 The Creativity Techniques Used in Project RID Companies

According to the Project RID research, the creativity technique most commonly used in the companies is simply considering and solving the problem together with a colleague without any guidelines or methodological support (Eloranta&al., 2004). The problem with this particular technique is the fact that the core reasons for the problems and possibilities are not discovered, but instead, the solution leads to the mere elimination of the symptoms.

Many of the companies also use the brainstorming method, or some variations of it, as the main creativity technique. One of the more advanced creativity techniques used in companies is the Double Team Technique, created by Innotiimi, which is based on several creativity techniques e.g. brainstorming and the Gallery Method (Pahl&Beitz, 2007). The Double Team Technique combines independent ideation, ideation in pairs, and ideation in groups of different sizes. The Double Team Technique is also known as the OPERA method: the initials in the acronym stand for the phases of the process: Own thoughts, Paired suggestions, Explanation, Ranking, and Alignment. The method can be used in the analysis of the problem, the innovating, and the making of resolutions. The Double Team Technique resembles the international method known as the Nominal Group Technique, but adds to it the phase of working in pairs. This method of groupwork aims to accelerate and ensure innovativeness by eliminating psychological and social obstacles. (Innotiimi, 2010)

The aforementioned methods seek to systematise product development and make incremental innovations more efficient. The main problem with these methods is psychological inertia that often leads to seeking the solution from the wrong direction. Also, the seeking of solutions is not as systematic and comprehensive as it is thought to be. (Altshuller, 1999) Incremental innovations are vital to businesses, but in the area of incremental innovations, the minimising of costs is often in essential position. If the main focus in the product development in companies lies in the creation of incremental innovations, there is hardly any room for radical innovations. Also, the problem with the variety of creativity methods in companies is clear: the aforementioned methods are relevant only to the lower level (Levels 1-2) problems, not to radical innovation (~Levels 3-5) (Altshuller, 1999). The companies have faced whole new types of competition, for example, in the area of User experience, where the companies had to assume the role of followers instead of being leading innovators.

2.3 Conclusions from the Results of the Project RID

As a conclusion of the industrial analysis, we can state that industry makes an efficient use of the following theories and methods:

- NPD;
- Stage Gate^{R} Process;
- Analysis methods (FEM, Simulation, PDM) but mainly at the Embodiment Design stage;
- GI and 7P;
- Brainstorming and Double Team Technique.

Of these methods, 7P creates prerequisites for innovating and finding new opportunities. Brainstorming and the Double Team Technique promote creativity and enable efficient evaluation of ideas. These two methods support the creation of incremental innovations. The analysis of the companies in Project RID proves that the companies have developed and implemented a high-quality management of innovation processes, but that they have limited tools and methods for generating new, radical innovations. The TRIZ is a effective and more advanced method for creating radical innovations but it is nearly an unrecognized approach for companies. (Eloranta&al., 2004)

3 The Challenge of the Building Up the Basis of Innovativeness in University Education

The Tampere University of Technology (TUT) provides the highest education in technology and architecture leading to Bachelor's, Master's, and Doctoral degrees. TUT offers lessons in the Theory of Inventive Problem Solving (TRIZ) as part of the Innovation course organized by the Department of Production Engineering (TTE). Learning how to use the TRIZ is one of the most important goals of the Innovation course. For the duration of the academic year 2010-2011, the Innovation course is undergoing a development process. The time has come to upgrade the teaching methods used, as several problems have arisen related to the learning and the teaching. This section briefly examines the taught framework of Simplified TRIZ, the teaching methods used at the Innovation course, and the types of problems arisen. The final chapter discusses the Development of Teaching TRIZ for University Students and why it is important to rethink the teaching methods.

3.1 The Innovation Course

The Department of Production Engineering (TTE) at the Tampere University of Technology (TUT) teaches the Theory of Inventive Problem Solving (TRIZ) as part of the Innovation course. The Innovation course, 4 ECTS, is a part of the Integrated Product Development and Production Engineering Minor study module. The Innovation course is based on the Project RID. The course is scheduled to be conducted in the autumn of the 3rd year of Master of Science studies. Every year, approximately 80 students participate in the course. The aim of the course is to identify and increase the engineering creativity of students and to introduce the processes of innovation based on the context of core literature.

3.2 The Simplified TRIZ - the Framework Used at the Innovation Course

TRIZ is an extensive theory: it has several applications and approaches, and it also offers several tools and techniques for innovative problem-solving. However, it is not possible to introduce and apply all the related viewpoints in the syllabus within the temporal limits of the Innovation course. Due to this, it has been necessary to limit the contents of TRIZ taught. At the Innovation course, the chosen TRIZ application is Kalevi Rantanen’s Simplified TRIZ.

Simplified TRIZ is a collection of certain central tools and methods of TRIZ, which are made as easy to use as possible. It resembles a workbook and a short guideline for TRIZ users. Simplified TRIZ includes three central concepts and two supporting tools of TRIZ: Contradiction, Analysis of Resources, Ideal Final Result, Patterns of Evolution, and 40 Innovative Principles (Fig. 3.).

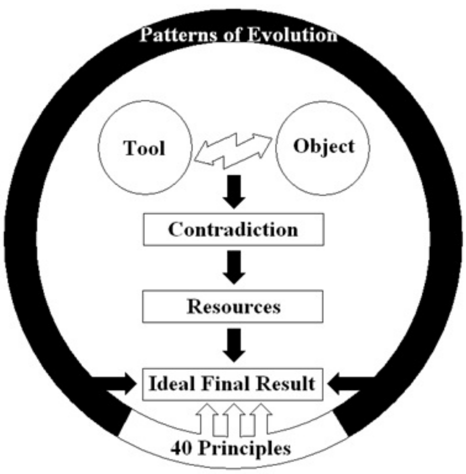

Fig. 3. Key concepts and tools of Simplified TRIZ (Rantanen, 2002).

Simplified TRIZ is based on three concepts: Contradiction, Analysis of Resources, and an Ideal Final Result. The core of the problem is clarified and simplified to become a Contradiction. To remove the essential Contradiction, the available resources are analyzed, with a particular emphasis on the resources that were not noticed earlier. With the help of the resources, the aim is to get as near an Ideal Final Result as possible without compromising the solution. To facilitate the discovery and the evaluation of the Ideal Final Result, Simplified TRIZ introduces the tools of the Six Patterns of Technical Systems Evolution and 40 Innovative Principles. (Rantanen, 2002)

3.3 Methods of Teaching the Simplified TRIZ at the Innovation Course

Rantanen has written a book about Simplified TRIZ in Finnish (Rantanen, 2002). This book is used as compulsory reading material at the Innovation course. There is also one introductory lecture for Simplified TRIZ. After reading the book, the students are grouped into innovation teams of four, and they carry out project work applying Simplified TRIZ tools in practice. Each group chooses one promising problem from their area of knowledge and tries to find an inventive solution with the help of Simplified TRIZ. As a result students write a detailed report of their problem-solving process, which are peer evaluated by other teams. The main ideas and results of the project are presented to other teams in a poster session.

According to the scaling of the course, learning the Simplified TRIZ takes about 35 hours: 2 hours for lecture, 8 hours for reading the book, 20 hours for practical work, and approximately 5 hours for the poster seminar including the preparation. This is about one third of the whole course.

3.4 The Challenges of Teaching and Learning the Simplified TRIZ

Students have faced several challenges while learning how to use Simplified TRIZ in their practical projects. An analysis of the practical work from the academic years 2008-2009 and 2009-2010 showed four typical problems: students often fail already in choosing the problem to be solved, the analysis of the problem is lacking, the use of Simplified TRIZ tools is deficient, and the solutions are foreseeable. Students choose the problem for their practical work independently: very often they have chosen a problem that can be classified as one of the following:

- The problem is an eternal problem;

- The problem is too challenging to be solved with elementary knowledge and within the time limits of the course;
- The problem is formulated based on the solution in mind; or
- The problem is so simple that it becomes frustrating for the students.

After the problem is chosen, the Contradiction tool is used rather negligently in analyzing the problem, because the students are eager to reach the phase where the actual solutions are sought. Often the analysis is carried out so as to point to a specific solution. In addition, other Simplified TRIZ tools are used carelessly and the iterative reuse of the tools is skipped or the tools are used even less than during the first round. Students assume that the use of tools brings the ideal solution outright and often they are trying to reach the solution with minimal effort. However, according to the feedback collected, to become acquainted with Simplified TRIZ is generally regarded as one of the best and most important parts of the Innovation course.

3.5 The Need for a New Approach in Teaching and Learning the TRIZ

The time it takes to learn Simplified TRIZ at the Innovation course is approximately 35 hours, and still the subject matter is not understood well enough for the students to be able to use it properly in project work. It takes plenty of time to fully understand the subject and to be able to apply it, so is it even possible to learn to master certain TRIZ tools over a single course where it is not the only learning objective? It is a well-known fact that students carry their knowledge into the industry and working life. What if the student wants to use TRIZ in his or her company – do the other people in the industry have enough time and desire if it takes more than 35 hours to familiarize oneself with the very basic tools of TRIZ? What other ways there is for the student to transfer his or her knowledge of TRIZ into action in the industry? How should TRIZ be taught to university-level students so that they, in turn, are able to teach it and to apply it? This is the main challenge in developing the Innovation course.

One of the sub-objectives of the project is to achieve some knowledge on how TRIZ should be taught and promoted to people in the industry, and consequently, how it should be taught to university students. The aim is to find out what kinds of TRIZ tools and approaches exist and to make benchmarking about how TRIZ and innovativeness is taught.

4 The Objectives of the Research Project

4.1 Formulating the Research Questions

The industrial analysis proved that companies effectively use theories and practical methods that support the creation of incremental innovations and product development process broadly. However, they lack tools and techniques for supporting the creation of radical innovations, at the early design stage in particular.

TRIZ has been developed to support strong inventions, in other words, radical innovations. TRIZ seems to be a promising and strong theory for creating radical innovations if it is utilized in capable hands. The analysis of teaching innovativeness with Simplified TRIZ proved that the teaching methods need to be developed in order to enable an efficient use of the TRIZ tools. Also, introducing TRIZ to the industry solely via the knowledge of students would be a slow process. Therefore, an efficient teaching method ought to be created which could also be utilized in industry. An entirely new framework for teaching TRIZ is needed so as to make it attractive and worthwhile to implement in companies.

As we described as the nature of the problem in general, the early stages of the product development process are hard to manage and schedule, yet crucial and critical for success. Koen & al. have criticized Cooper's Stage-GateR model for not working with the early phases of innovation and product development processes. The Fuzzy Front End (FFE) is defined by those activities that come before the formal and well-structured New Product Development (NPD) process. Even though there is a continuum between the FFE and NPD, the activities in the FFE are often chaotic, unpredictable, and unstructured. In comparison, the NPD process is typically structured, which assumes formalism with a prescribed set of activities and questions to be answered. Koen & al. have developed the new concept development (NCD) model for FFE (Fig. 4.).

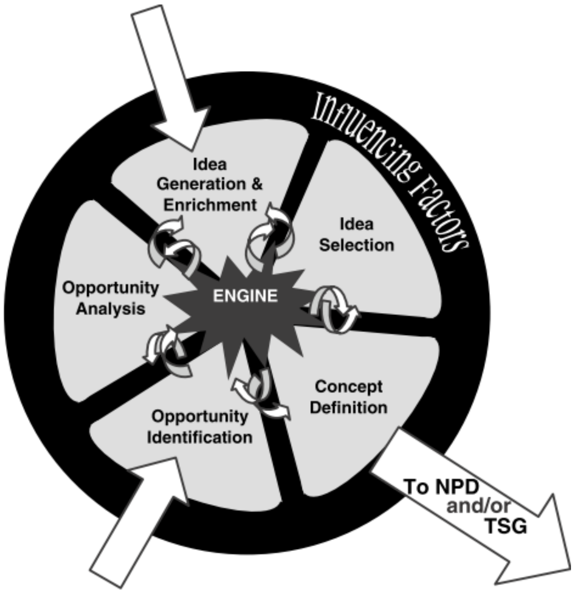

Fig. 4. The new concept development (NCD) construct is a relationship model, not a linear process (Koen&al., 2002).

The NCD provides a common language and definition of the key components of the fuzzy front end (FFE). The engine, which represents senior- and executive-level management support, culture, and business strategy of the organization, powers the five key elements. The inner spoke area defines these five activity elements (opportunity identification, opportunity analysis, idea generation and enrichment, idea selection, and concept definition) of the FFE that are controllable by the corporation. The engine and the five elements of the NCD model are placed on top of the influencing factors which consist of organizational capabilities, the outside world, and the enabling sciences that may be involved. The arrows pointing into the model represent the starting points and indicate that projects begin at either opportunity identification or idea generation and enrichment. The exiting arrow represents how concepts leave the model and enter the new product development (NPD) or technology stage gate (TSG) process. (Koen&al., 2002)

The aim of the MOSES research project is to develop and integrate TRIZ as part of the early design stages of the industry. A natural element in the NCD framework to apply TRIZ is Idea Generation & Enrichment. The hypothesis in the MOSES research project is that the TRIZ method can also make other elements more efficient in producing radical innovations. According to Koen & al., the circular shape of the NCD model is meant to suggest that ideas and concepts are expected to iterate between and among all the five elements. The flow may encompass the elements in any order or combination and may use one or more elements more than once. (Koen&al., 2002) These principles also suit TRIZ well.

The competitiveness of the cooperating companies in the MOSES project is based on technological innovations, but a number of them also have strengths in the service industry as well. With technological innovations, it is important that the selection of ideas is based on reliable facts. Especially in complex system products, modelling and simulation are becoming ever more important. Modelling and simulation at the early stages require that the simulation models must be able to abstract and summarize the essential core of innovation. Recently, modelling and simulation techniques as well as simulation models have been developed to become even more precise. In the MOSES project, the aim is to utilize simulation models that differ from the general development trends. An example of similar model development is Order of Magnitude Scaling presented by Professor T.W. Eagar & al. at the MIT (Mendez&al., 2004).

Based on this analysis, the following research questions were formulated:

- What combination of TRIZ tools and methods is the most suitable for solving problems in the early design stage?;
- How to teach effectively and promote the use of TRIZ to people who are unacquainted with it so that they would be able to transfer their learning into new contexts?;
- Is the use of the developed approach really promoting the origination of radical innovations?

4.2 Outlining the Objectives of the Research Project

The project extends towards six fundamental objectives:

1. Problem formulation;
2. General search strategy selection;
3. Application of idea-provoking techniques;
4. Requirements for conceptual design tools;
5. Evaluation of different TRIZ schools utilising the requirements list;
6. Creating a description of a Conceptual TRIZ approach.

This approach is characterized by:

- The possibility to use the approach at the very beginning of the product development process;
- The possibility to assess potential solution concepts very early by the modeling and simulation;

- The possibility to surmount limitations of early design stage in conjunction with TRIZ.

TRIZ provides a set of viewpoints among which the aim is to find the ones crucial for developing variable products in particular.

As a result of the research project, there will be available a combination of methods which consists of the FFE model by Koen & al., TRIZ, and advanced modelling and simulation methods, and the approach to learning to use them. The operations of these methods together and the teaching approach will be verified by industrial examples.

5 Conclusions and Discussion

The MOSES research project will be carried out in close cooperation with international industry. The project focuses on the early design stage and puts a special emphasis on creativity support during this stage. The research project has good chances to be successful in developing a novel design approach dedicated to the early design stage and the creation of radical innovations.

This paper has presented the analysis of product development and innovation processes in some leading businesses in the Tampere economic area. It can be seen that the companies are doing well in the area of incremental innovations but they have no sufficient methods for creating radical innovations. As a hypothetical solution, the NCD framework suggested by Koen & al. will be combined with some branches of TRIZ and advanced modelling and simulation tools.

The study about the experiences of teaching Simplified TRIZ at the university pointed out the need for a different kind of teaching approach. Before finding the solution to this challenge, the state-of-the-art in this field must be mapped and the tools to consider must be defined. The guideline in this should be that the combination of methods and tools should work logically and visualize the results during the process in a tangible way; otherwise the method cannot be successfully applied in the industry. Results of the MOSES research project will be applicable in companies with highly variant products, e.g. the mobile machinery industry. In the upcoming paper, we will present in detail how the method works and what are its industrial results.

This paper presents the analysis of needs and the theoretical framework but no detailed results of the method combination itself. However, based on industrial and educational experience and previous research projects, we trust that the results will be within the correct range.

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