INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

SIMULATION READY CAD-MODELS AS A MEANS FOR KNOWLEDGE TRANSFER BETWEEN TECHNOLOGY DEVELOPMENT AND PRODUCT DEVELOPMENT

Johansson, Joel; André, Samuel; Elgh, Fredrik
Jönköping University, Sweden

Abstract

Manufacturing companies tend to separate technology development (TD) from product development (PD) as has been devised by research within the field of innovation management. When a technology is ready it somehow has to be made available to the PD teams so that the engineers working in PD projects can adapt the new technology into new products. The question is how that work can be supported. The ultimate goal of the research presented in this paper is to develop methods and tools to assist the knowledge transfer between TD and PD with a focus on supporting the actual use of the new technology in PD. This paper presents an industrial case along with a proposed method to achieve this. The TD and PD processes in the case company were reviewed with focus on how simulation models evolve over time and how they are used for different purposes. It was discovered that simulation ready CAD-models can be used to transfer the output from TD to PD.

Keywords: Technology, Early design phases, Simulation, Knowledge management

Contact:
Dr. Joel Johansson
Jönköping University
School of Engineering
Sweden
joel.johansson@jth.hj.se

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Manufacturing companies tend to separate technology development (TD) from product development (PD) as has been devised by research within the field of innovation management (Nobelius 2002). The reasons for separating these two processes include reducing the risk of the PD processes and reducing the time to market for the products. The objective of TD is to develop new technologies or to investigate what is feasible for new technologies in the scope of the company's interests. When a technology is ready, according to the company's standard, it can be made available to the PD teams. The handover can be done through a technology transfer process, see Figure 1. According to Eldred and McGrath (1997) the transferring step should be performed by a technology transfer team consisting of members from both the TD and PD. The output from TD contains knowledge, skills, and artefacts to be used by the design engineers in the PD processes. The knowledge developed in TD is valuable and should of course be transferred and reused in the product development process as far as possible. It is in other words vital for a manufacturing company to have an effective technology transfer process to keep the competitive edge in the long-term (Cooper 2006).

The interface between TD and PD has mainly been researched from a management point of view with a focus on issues related to organisation and processes. However, the engineers that are working in product development projects still need to adapt and evaluate the new technology when it is to be used in new products. The question is how that work can be supported. What is it that TD hands over and what actions are required to make the results from TD more applicable in PD? The ultimate goal of the research presented here is to develop methods and tools to assist the knowledge transfer between TD and PD with a focus on supporting the actual use of the new technology in PD. In this paper an industrial case is presented where the objective was explore and develop support that would enable the company to achieve this. The company has well defined TD and PD processes and, even if not explicitly described, there is a technology transfer step in the company's documentation. Since the company want to enhance the transfer of knowledge and models between TD and PD, the two processes were reviewed with focus on how simulation models evolve over time and how they are used for different purposes. It was discovered that simulation models are created in both TD and PD and that they are similar but not equal. The aim was then set on how to make it possible to transfer the skills and knowledge about how to simulate new technology. The research work is based on the hypothesis that the technology transfer should be made in such a way that the design engineers in PD can run the simulations without even consulting the FEA engineers, which calls for formalised and automated simulations.

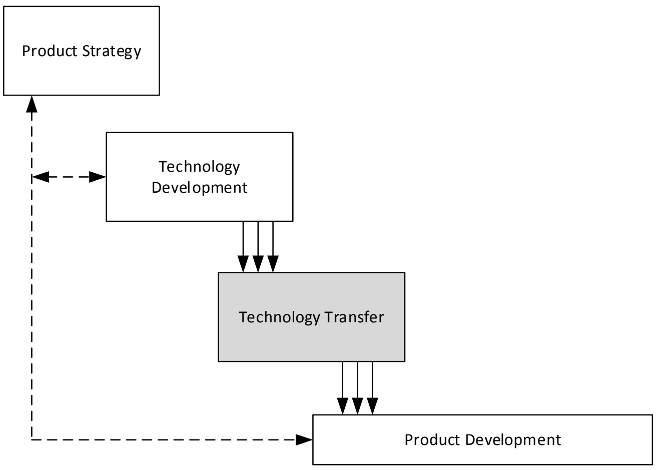

Figure 1. The technology transfer process. Adopted from (Eldred and McGrath 1997).

1.1 Research method

The research method is explorative and based on observations made by one of the author being on spot at the company once every two weeks over a period of five years. The research is also based on an interview study (André et al. 2014) and the reviewing of the studied company's documentation of development processes.

2 FRAME OF REFERENCE

2.1 TD and PD

The definition of technology, used in this paper, is knowledge applied to products or production processes (Säfsten et al. 2014). TD can be described as a stream where a company develops technologies that is in line with the company strategy (Clausing 1996). TD aims at developing knowledge, skills and artefacts in order to enable product development (Högman 2011). Deliverables from TD can also be in the form of demonstrated feasibility (Nobelius 2002) or a technological platform (Cooper 2006). It is further described by Cooper (2006) that TD is important for a company's long-term growth but is however often down prioritised and represents a small portion of the total effort of a company. Cooper proposes to use a stage gate process for TD.

PD is defined as transforming a market opportunity to meet the need of a customer and strategic goals of the company. This is done through a set of coherent activities that interacts with each other (León and Farris 2011). Due to the complexity of PD several development process models have been practiced and developed over the years with the sequential model being the norm (Engwall 2004).

It is suggested by several authors that decoupling technology development from product development is a winning strategy (Nobelius 2002, Säfsten et al. 2014). But why separate these two development processes? Since it is hard to estimate the outcome of TD due to its uncertain nature it needs a different management strategy. TD also differs from PD in its prerequisites, technical maturity, time horizon, need for competence, process repeatability and completion point and deliverables (Nobelius 2002). It follows that by separating TD from PD one can reduce risk in PD projects (Lakemond et al. 2007).

Lean product development (LPD) has become the cloak under which a number of "lean" product development strategies has been gathered. The true origin of lean product development is debated, however most authors agree that the concept originates from the Toyota Production System. Knowledge value stream has been called the core of LPD according to Kennedy (2008). The author states that the knowledge value stream consists of capturing and reuse of knowledge about markets, customers, technologies, product and manufacturing capabilities. Knowledge is considered to be an important asset to an organisation, therefore the loss of knowledge is a waste. In order to make use of the created knowledge it should be generalised and visualised as far as possible to flow across projects and organisations. Knowledge can be of two kinds according to Kennedy (2008): (1) Knowledge that is conserved in people and (2) knowledge that can be stored outside people.

Another important methodology that falls within LPD is Set-Based Concurrent Engineering (SBCE) that opposed to a traditional point based approach develops sets of solutions in parallel (Sobek II 1999). In a point based approach a concept is chosen early in development and then iterated towards reaching a feasible solution. With SBCE on the other hand a wider spectrum in the design space is covered, making it more likely for the solution to be found. The focus is to eliminate bad or unfeasible solutions when enough knowledge about the solution exist as opposed to early picking a solution when not enough knowledge exists. Positive effects when applying SBCE has been observed in industry (Raudberget 2012). Ward (2007) summarises the benefits as (1) Enables reliable and efficient communication, (2) allows for greater parallelism in the process, with more effective, early use of sub-teams, (3) bases the most critical, early decisions on data, (4) promotes industrial learning and (5) allows for a search of globally optimal designs.

2.2 Automation of Finite Element Analysis (FEA)

Automating FEA processes has been target for research for years. Sellgren (1995) developed a framework for simulation driven design, in which simulation models were extracted based on the CAD-model relationships. Chapman and Pinfold (2001) described how to use KBE and FEA for the design automation of a car body, and a system was presented by Hernández et al. that automatically designs distribution transformers using FEM automatically (Hernández and Arjona 2007). The design process of different jet engine components has also been the subject for design automation using KBE (or KEE) integrated with FEA (Boart 2007, Sandberg 2007). Stolt (2008) developed methods to automatically generate FEM-models for die-cast components and Sandberg et al. (2005) presented a CAD/FEA integration to simulate distortion effects of different manufacturing methods.

3 CASE DESCRIPTION

The studied company develops and manufactures products that support an active life style. Some of the products are transport centred, e.g. roof boxes, and bike carriers. It makes roof racks for cars an important product for the company which also has been the target for this case. The current platform for car roof racks has been on the market for decades and was decided to be replace and a new platform is currently in the early technology development stages. In the study of the company's practise, tools and models for FEA used in TD and PD for development and definition of both the current and the new platform, were reviewed. The current practice at the company is described in the following sections.

3.1 Conceptual FEA in TD

Simulation of conceptual models are performed in the investigation and completion steps in the TD process at the company. In the investigation step the simulation models are two dimensional and focuses on what characteristic features and what motion certain components should have in order to achieve the desired function, in this case maintaining the racks on the roof in case of collision but not buckling the car roof when mounting the rack. Figure 2 displays one example of a number of schematic models that were used in the case project.

When progressing to the completion of the TD the simulation models are refined and made three-dimensional (this step has not been modelled in the documentation of the company). The refined simulation models includes conceptual components providing basic functions of the product. In this process step the simulations are run to explore other parameters than in stage 2, the focus is on material properties, wall thicknesses and other more low-level parameters compared to in stage 2.

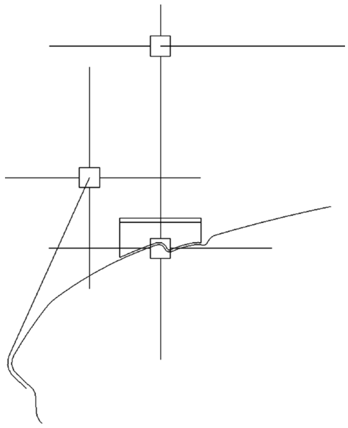

Figure 2. Early conceptual simulation model.

3.2 Automated FEA in PD

The old roof rack platform has been alive for decades and models and tools for it have continually been developed and refined. For instance there exist tools for automated geometry based search for solutions to new roof specifications. There is also a system for automated FEA-simulations (André et al. 2014).

The automation of FEA already done at the company specifically targets roof racks that are mounted directly on the car roof, i.e. there are no rails on the car. Consequently, the roof rack product has to be adapted to every car-model it is supporting. The adaption is done by changing two components, the footpad and the bracket. The footpad is a rubber pad on which the rack is standing on the roof, and the bracket is used to fix the rack by keeping around the roof end where the doors are. There are both safety and geometrical requirements on these two components, especially the bracket, since it has to keep the rack on the roof in case of a crash but still not buckle the car body when fixing the rack.

The main idea behind the automated system for crash simulations is to connect a CAD-system to the pre-processor. The connection is based on named CAD-features, a neutral CAD-file, a custom object-model, and generic script files.

The setup of the automated simulations includes preparing CAD-models with geometrical features that represent the idealisations in the final FEA-model. These features (or bodies) can be points, curves,

surfaces, or volumes and are named using a name convention. In the example system, all such names begins with "FEM_" followed by a type declaration and additional information (see left bottom in Figure 3). The named features serve as the base for the mesh-model. From Figure 3 (bottom) it can also be seen that the idealisations do not have to perfectly match the CAD-geometry (that often includes small features unnecessary/undesirable in FEM-model). The features are still connected to to the geometry making the idealisations update correctly on changes in the CAD-model.
In addition to the feature name convention an object model was also developed to carry information of all the different idealisation features and a connection to the real CAD-feature object. The object model in the system includes classes for beam elements, shell elements, and structured mesh by offsetting, revolving or filling meshed surfaces.

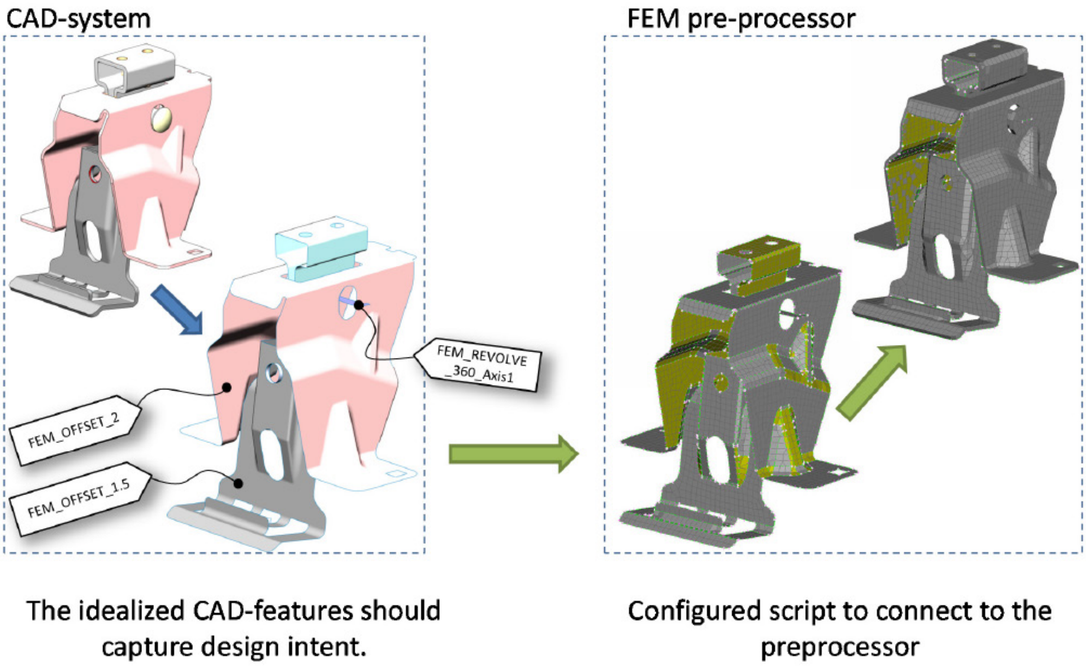

Figure 3. Examples of named idealisation features and resulting structured mesh.

FEA-models not only contain nodes and elements but also information about constraints, loads, and other definitions that are to be incorporated into the simulation ready CAD-models by the FEA-experts. That is done using a custom made add-in to the SolidWorks-system and results in a collection of *Definition* objects which correspond to what is often referred to as *control cards* in the pre-processor. The benefit of making the specifications of the simulation within the CAD-system is that connections, such as contacts and joints, can be added interactively with the CAD-model and that changes of the CAD-model then can be propagated to the FEA-model.
In addition to the prepared CAD-models and the object models, also template scripts has to be developed. These templates are used to generate script files to render the final simulation models. The final script has to include commands to generate all the different meshes of which some are rendered in several steps, e.g. a sheet metal part are generated by first meshing its surface and then offsetting that mesh incrementally. To achieve this, a special scrip-language was developed at the company that is an extension of the script language used by the pre-processor.
When the simulation ready CAD-models are prepared with the idealisation features, the specifications of the simulation are done, and the template scripts are developed, the system is ready to run repeatedly with new combinations of components. The first step when executing the system is to scan the CAD model-tree in order to collect all idealisation features by interpreting feature names. While scanning the CAD-model tree, features not being idealisation features are hidden away in order to subsequently export an IGES-file containing only the geometry to mesh (this approach is specific for SolidWorks and might differ in other CAD-systems). A collection of objects representing the final mesh model is created and used to configure the script template. Code to generate the specifications of

the simulation is finally automatically added to the script file. When the script finally is ready, it is submitted together with meshing parameters to the pre-processor in batch-mode to generate the complete FEA-model.

The system was developed in the following seven steps:

1. Identify what type of FEM features are to be automated, including mesh geometry types and FEM-properties.
2. Develop object model for mesh geometries
3. Develop object model for definitions of FEM-properties. Each object should have a function to export its values to either the targeted scripting language or the targeted FEM-solver.
4. Introduce Idealisation features in CAD-models
5. Make a specification of the FEM-properties (including constraints, boundary conditions, contacts, loads, and other) using the object model
6. Develop a template macro for generating a mesh-model. It might be necessary to have the macro producing an output file for logging errors or to track resulting identification numbers (e.g. PID or NID)
7. Develop the system to make use of the above steps according to the running procedure

When running the system the following six tasks are completed:

1. Scan the CAD-model to generate a macro using the macro template based on the idealisation features
2. Execute the macro in the pre-processor to render the mesh model
3. Loop through the list of “Definition”-objects to update them to the resulting mesh (this includes setting correct identification numbers of parts, elements, and nodes)
4. Compile the definition objects to the format of the targeted FEM-solver by using the objects built-in procedure of exporting to text. The mesh model should be appended to the file
5. Optional: Open final model in pre-processor for acceptance by FEA-engineer
6. Submit to solver

The conclusion from the case is that FEA plays important but different roles in TD and PD. It is also concluded that the way the simulations are developed and executed differs too. In TD simulation models are developed in manually whereas in PD simulation ready models are used to automate the FEA process. The next section deals with the question on how to bridge TD and PD.

4 TOWARDS BRIDGING TD AND PD

The purpose with TD is to develop new technology, explore feasibility of existing technology, and develop parts or systems involving high uncertainty and thus decreasing the uncertainty in the customer focused projects. The process is expected to deliver concept prototypes, bill of materials, prototype tests, consequence analysis, and concept presentations. The TD projects are initiated by the product manager based on trends on the market. When the development passes from the technology phase to the product phase all requirements have been transformed to quantifiable requirements. The processes dedicated for TD and PD at the company (see Figure 4 and Figure 5) are partly integrated and depended on each other. When starting a TD project there is already a release date for new products that are to be based on the intended output. This means that there is a given time frame for TD and that the process is initiated when a PD project is already planned.

FEA simulations are used both in TD and PD at the company. The simulations are used for different objectives, but they capture the same phenomena. At the current stage there exist conceptual simulations in TD for a new roof rack platform and there exist fully automated simulations for the current platform in PD. Since there has been a large effort to develop the tools and models for the current platform it is desirable to reuse as much as possible as it would cut both cost and lead time in development. The question is how to combine the conceptual models for the new platform and the simulation ready models for the current platform to get the needed system for automated simulations for the new platform (see Figure 6). Hence, the main objective for the company is: How can the skills and knowledge about how to simulate the new technology be transferred from TD to PD. This transfer is needed due to the calculation engineers primarily working in TD with setting up the early models.

When the models have been prepared for automation in the technology transfer step, the design engineers can execute the models without the help of a calculation engineer duo to the knowledge being built in to the CAD model.

4.1 Introducing design spaces and SBCE

Simulations are performed in the investigation and completion phases of the TD and during concept and design phases of PD (1-4 in Figure 7).

Figure 4. Technology development process at the investigated company.

Figure 5. Product development process at the investigated company.

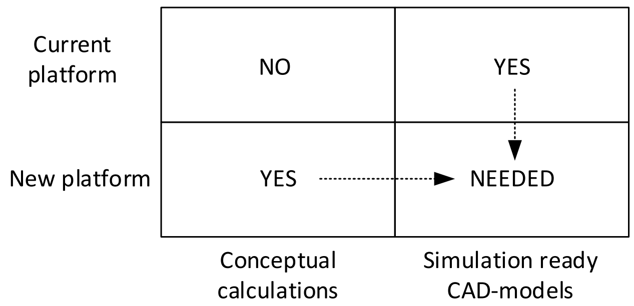

Figure 6. Simulation Ready CAD-models are necessary in the new platform. Can the conceptual models be used to transfer the current simulation ready CAD-models to the new platform?

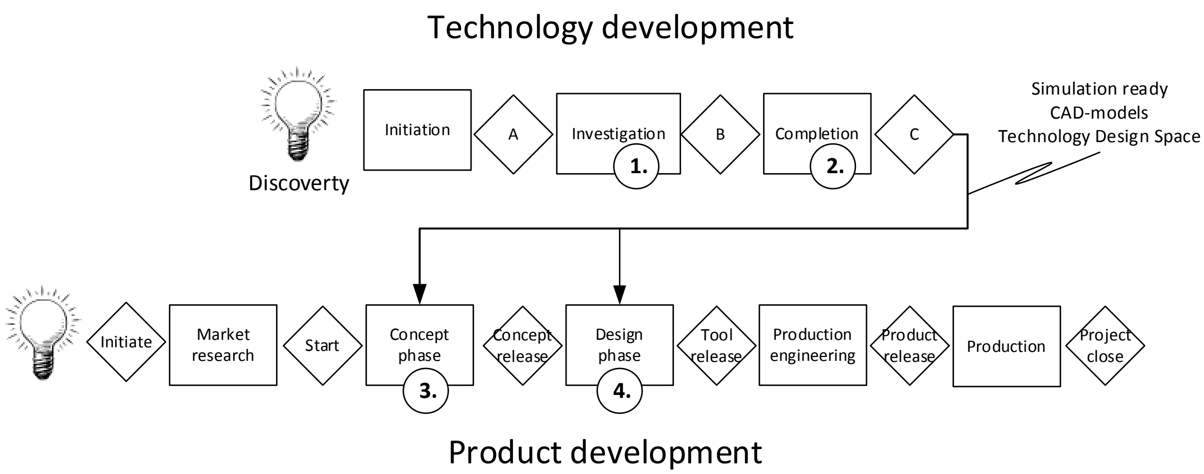

Figure 7. Stage-Gate model adapted from (Cooper 2006) and applied to the case company indicating the simulation ready CAD-models as a means for transferring skills and knowledge. Simulations are performed at 1-4.

The output from a TD process is a technology design space. The technology design space can be defined as a description of when the technology solution is valid as well as how and when the technology is or can be applied. Figure 8 illustrates what two outcomes of TD, i.e. two technology design spaces, could look like. The intersection between these then becomes the feasible technology design space which denotes the space where the two technology solutions are valid at the same time. The technology design spaces are modelled and captured within simulation ready CAD-models by containing the knowledge describing the boundaries. The intersection is implicitly transferred to PD by the combination of these CAD-models. One of the first tasks of PD is then to clarify the task and to gather information about relevant requirements and company capabilities. The feasible technology design space will then be shrunken but not completely fixed. Since a SBCE approach can be used, requirements is expected and allowed to fluctuate as the solutions converge. The design space that is left is referred to as the product design space. Within these boundaries, a product design is feasible. By the use of these knowledge rich CAD models a set-based approach is enabled, giving the possibilities to draw the benefits from such an approach. It should however be noted that the set-based approach is not the solution but rather an enabling factor in the complete picture in the company.

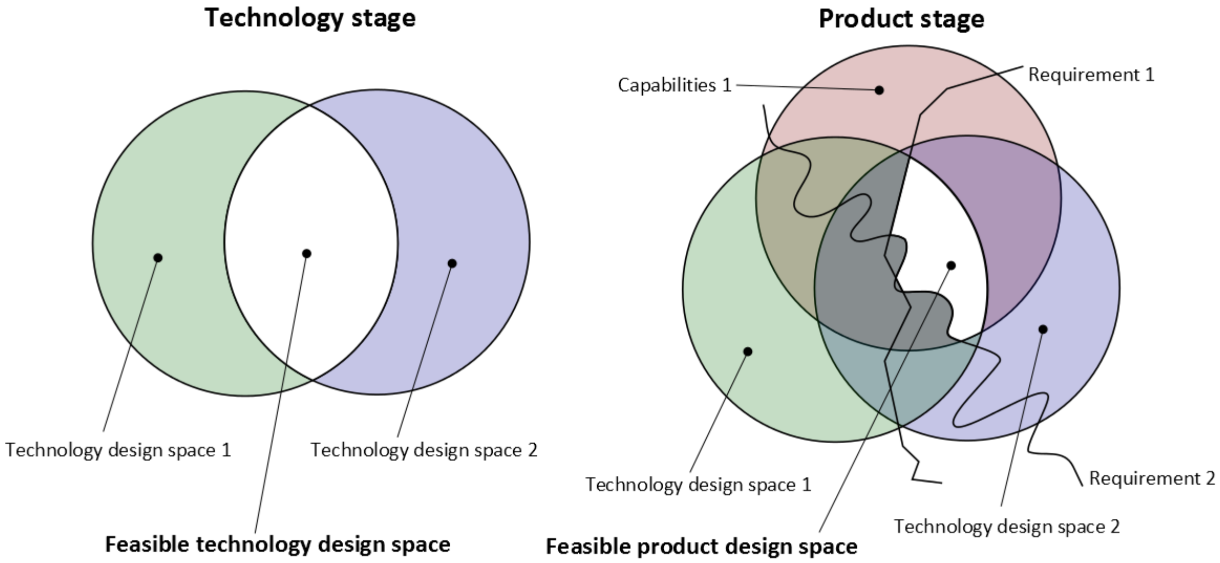

Figure 8. Technology and product design spaces. The technology design spaces is one way of realising the sets in SBCE.

4.2 Revise the Project Process Model

The work with simulations early in the TD process has to be formalised and should be performed in two steps, first in the investigation step as conceptual models for finding driving parameters and then in the investigation step to explore the technology design space and to generate trade-off curves. The completion phase in TD should also include the task of reviewing the technology process (see next section) in order to make the newly gained knowledge ready to be used by the design engineers in the PD. When doing so, the engineers can work set based and concurrent. Also, when completing the technology review task the newly gained knowledge is added to the corporate knowledge through the preparation of simulation ready CAD-models, supporting the knowledge values stream.

4.3 Formalise and Share FEA Skills and Knowledge

According to Eldred and McGrath (1997) the technology transfer is preceded by a technology review step. Here it is proposed that the technical review step should be done in the final stage of TD and that it includes the task of refining the late simulation models in TD into simulation ready CAD-models. That means refining the FEA-models further and formalising the knowledge behind these models (e.g. answering questions on why certain constraints are used, what material models has to be applied in different areas of the design space, what geometrical problems might occur). A suggested format of the simulation knowledge is the A3 format as has proven to be a good format for storing corporate knowledge (Sobek II and Smalley 2011), Shook (2008), Saad et al. (2013), Raudberget and Bjursell

(2014). The formalised knowledge about how to perform the simulations is then transferred into extended CAD-models, which here are referred to as simulation ready CAD-models. The simulation ready CAD-models utilise the name convention and extended features described in section 3. The transfer is done by the design engineers in guidance of the simulation engineers using the A3-formatted knowledge. The simulation ready CAD-models are then used by the design engineers in the PD to explore and verify design instances of the product. This speeds up the development process and makes design engineers aware of problems they might have overlooked before, ultimately it will confirm and replace the engineers gut feeling by expectations based on simulation, i.e. simulation based design.

It is in the technology review process were the technology design space is formally modelled and captured in the simulation ready CAD-models. In this way one idea of the knowledge value stream is realised to a higher level, namely the storing of more knowledge outside people and the sharing between projects. The calculation engineer's knowledge is here stored in the CAD model in an early stage.

4.4 Revise the Roles of Design Engineers and Computational Engineers

The separation of the TD and PD as well as the added technology review task, as proposed here, changes the role of the simulation-team. Instead of running simulations for product instances the focus is changed to exploring the behaviour of technical components or manufacturing methods. The shift is from verifying (or many times falsifying) design suggestions to developing new knowledge about the products and processes. This is a big change affecting the manufacturing company's organisation, its workflow, its software, and its models. Who will do the validation of design suggestions of product instances when the FEA-team are busy exploring the technology design spaces during TD? These validations will be performed by the design engineers in the PD making use of the simulation ready CAD-model. So, not only the role of the FEA-team is changed, but also the role of the engineering design-team. The design engineers can explore the design space defined by the simulation models, evaluate different solutions and trade-offs which would allow for a set-based concurrent engineering approach in the search for a solution. The simulation models can be further improved based on the experience gained from their use in PD-projects. They would evolve as more knowledge is gained and could be viewed as knowledge carriers in the company's knowledge value stream.

5 CONCLUSIONS AND FUTURE WORK

Separating TD and PD has proven to reduce risk and time to-market for product development. Here it is proposed technology transfer into the PD can be realised through the preparation of CAD models in order to make them ready to generate automated simulations. The preparation of the CAD-models should be done in the technology review step finalising the TD. This enables the design engineers to work set-based and concurrent making use of the corporate knowledge contained in the simulation ready CAD-models. It makes the FEA-team moving from PD to TD (moving from processes steps 3 and 4 to processes 1 and 2 in Figure 7) instead focusing on adding to the knowledge value stream rather than verifying product instances. The simulation ready models becomes knowledge carriers containing information of how to simulate a certain technology and what its boundaries are.

This research project is in early phases and future work includes finalizing the system for the automated simulations for the new generation of roof racks as well as developing facilities for visualising and overviewing the design spaces represented by the simulation ready models.

REFERENCES

André, S., Stolt, R., Elgh, F., Johansson, J. and Poorkiany, M. (2014) 'Managing Fluctuating Requirements by Platforms Defined in the Interface Between Technology and Product Development', in The 21st ISPE International Conference on Concurrent Engineering, 8-11 September, Beijing, China, Amsterdam, IOS Press, 424-433.

Boart, P. (2007) The Enabling of Product Information in the Conceptual Phase, unpublished thesis Luleå University of Technology.

Chapman, C. and Pinfold, M. (2001) 'The application of a knowledge based engineering approach to the rapid design and analysis of an automotive structure', Adv. Eng. Softw., 32(12), 903-912.

Clausing, D. (1996) 'Total Quality Development. A step-by-step guide to world-class concurrent engineering, 1994', American Society of Mechanical Engineers, Cambridge Massachusetts.

Cooper, R. G. (2006) 'Managing technology development projects', Research Technology Management; Nov/Dec, 23-31.
Eldred, E. W. and McGrath, M. E. (1997) 'Commercializing new technology-II', Research Technology Management, 40(2), 29-33.
Engwall, M. (2004) 'Produktutveckling bortom kunskapens gränser: mot en osäkerhetens grammatik'.
Hernández, C. and Arjona, M. A. (2007) 'Design of distribution transformers based on a knowledge-based system and 2D finite elements', Finite Elem. Anal. Des., 43(8), 659-665.
Högman, U. (2011) Processes and Platforms Aligned with Technology Development - The perspective of a supplier in the Aerospace Industry, Göteborg: Chalmers tekniska högskola.
Kennedy, M., K. Harmon and E. Minnock (2008) Ready, Set, Dominate: Implement Toyota's Set-Based Learning for Developing Products and Nobody Can Catch You!, Richmond: Va: Oaklea Press.
Lakemond, N., Johansson, G., Magnusson, T. and Säfsten, K. (2007) 'Interface between technology development, product development and production - Critical factors and a conceptual model', International Journal of Technology Intelligence and Planning, 317-330.
León, H. C. M. and Farris, J. A. (2011) 'Lean Product Development Research: Current State and Future Directions', Engineering Management Journal, 23(1).
Nobelius, D. (2002) Managing R&D Processes - Focusing on Technology Development, Product Development and their Interplay, Göteborg: Chalmers University of Technology.
Raudberget, D. (2012) Industrial Experiences of Set-Based Engineering - Effects, results and applications, Göteborg: Chalmers reproservice.
Raudberget, D. and Bjursell, C. (2014) 'A3 reports for knowledge codification, transfer and creation in research and development organisations', International Journal of Product Development, 19(5), 413-431.
Saad, N. M., Al-Ashaab, A., Maksimovic, M., Zhu, L., Shehab, E., Ewers, P. and Kassam, A. (2013) 'A3 thinking approach to support knowledge-driven design', The International Journal of Advanced Manufacturing Technology, 68(5-8), 1371-1386.
Sandberg, M. (2007) Design for Manufacturing - Methods and Pallications using Knowledge Engineering, unpublished thesis (Thesis), Luleå University of Technology.
Sandberg, M., Larsson, T., Åström, P. and Näsström, M. (2005) 'A design tool integrating CAD and virtual manufacturing for distortion assessment', in Samuel, A. and Lewis, W., eds., 15th International Conference on Engineering Design (ICED05), Melbourne, Australia, 15-08-05, Institution of Engineers, Australia, 628-630.
Sellgren, U. (1995) Simulation drive design : a functional view of the design process, unpublished thesis (Thesis), KTH Royal Institute of Technology.
Shook, J. (2008) Managing to learn: using the A3 management process to solve problems, gain agreement, mentor and lead, Lean Enterprise Institute.
Sobek II, D. K., A. Ward, J. K. Liker (1999) 'Toyota´s Principles of Set-Based Concurrent Engineering', Sloan Management Review, 67-83.
Sobek II, D. K. and Smalley, A. (2011) Understanding A3 thinking: a critical component of Toyota's PDCA management system, CRC Press.
Stolt, R. (2008) CAD-Model Parsing for Automated Design and Design Evaluation, unpublished thesis (Thesis), Chalmers university of technology.
Säfsten, K., Johansson, G., Lakemond, N. and Magnusson, T. (2014) 'Interface challenges and managerial issues in the industrial innovation process', Journal of Manufacturing Technology Management, 25(2), 5-5.
Ward, A. C. (2007) Lean Product and Process Development, Cambridge: Lean Enterprise Institute.

ACKNOWLEDGEMENTS

The work has been carried out within the project ChaSE (Challenge Fluctuating and Conflicting Requirements by Set-Based Engineering), Vinnova.