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How to Challenge Fluctuating Requirements – Results from Three Companies

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Abstract. This paper presents the results from a research project conducted by the research group Computer Supported Engineering Design (CSED) in Jonkoping University in Sweden. The project has the aim of increasing companies' ability to respond to fluctuating requirements when developing new products and product variants. The companies participating in the project represents automotive, aerospace and production equipment industries. Three different cases of applications have been developed and implemented in the companies. Product models ranging from product to knowledge centered for use in the company's product and technology platforms have been demonstrated and evaluated though interviews with professionals at the companies. To summarize, the results shows that the companies' abilities to respond to fluctuating requirements have increased albeit concerns have been raised on the maintenance of knowledge in the implementations.

Keywords. Product Model, Platform, Requirements

Introduction

This paper summarizes the results from a research project spanning between the years 2014 – 2017 and attempts to generalize the results from cases of applications made at the participating companies within the project so far. The title of the project is Challenge Fluctuating and Conflicting Requirement by Set-Based Engineering (ChaSE). It involves four senior researches and four PhD students and around 12 representatives from four different companies. Three of the companies are first and second tier suppliers in automotive and aerospace and the forth supplier is in production equipment. The fourth company supplies tailored production lines consisting of standard equipment such as CNC machines and robots that are selected and arranged to an efficient and robust production line. The special parts needed to tie together the machines to a complete production line are designed and built.

The companies are business to business (B2B) suppliers except one of the two automotive suppliers which in part is an original equipment manufacturer (OEM). The companies are further described in [1].

The aim of the ChaSE project is finding how companies can increase their ability to quickly respond to fluctuating and contradicting requirements when designing products. This was identified as an important competitive factor when setting up the project.

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The companies experience fluctuating and contradicting requirements due to their business model. The suppliers are expected to quickly answer questions from the customers about what consequences proposed changes in the requirements specification will have for the product being developed. Further, the OEM:s has to orchestrate a multitude of sub-suppliers in their aero engine or automotive development projects.

At the starting point of the project, it was assumed that Set-based Concurrent Engineering (SBCE) will support this ability in that a set of different design suggestion is more likely to meet fluctuating and conflicting requirements than a single one.

In the project it was also assumed that the use of product and technology platforms can contribute to increasing the capability of responding to changing requirements. In the platforms (Figure 1), the knowledge on products and processes are represented as models. From these models, new designs and design variants can be derived or alternatively the know-how on how to design them can be retrieved. It is the companies' common body of knowledge that is represented in the platforms with a varying degree of formalization [1].

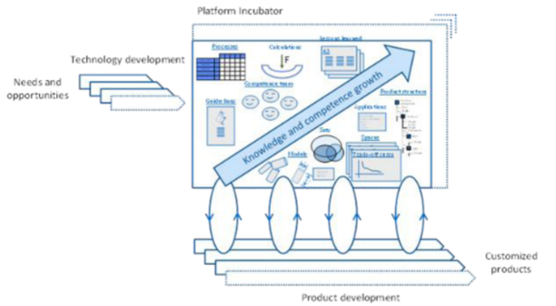

Figure 1. Conceptual platform in ChaSE.

Starting from the left, there is a technology development for introduction into the platform going on, represented as several parallel processes. This is governed by the market needs and opportunities that emerges. When sufficiently ready, these technologies are formalized into models and amended to the platform. This is gradually extending the platform, and a continuous refinement of the models are being made, hence the name incubator.

From the platform, solutions are derived and used in product development projects with the aim of designing a specific product or variant as seen at the bottom of the figure.

The ChaSE project is concerned with the format of these models, aiming to prescribe how they should be constituted to increase the ability to handle the fluctuating and contradictive requirements. The project also aims to prescribe how they should be operated in the set-based environment to increase knowledge reuse and support a streamlined development process with controlled variation.

1. Literature review

As mentioned, the basic assumptions of the ChaSE project involve SBCE and product platforms. In this section the state of art of the terms is accounted for and the interaction between them is elaborated.

The set-based approach is characterized by using a larger set of design suggestions rather than striving to freeze the design specification as quickly as possible. This leads to a more thorough exploration of the design space and a knowledge build up. More resources is spent in SBCE than in traditional PD [2].

SBCE also affect how the requirements are handled. Rather than specifying a point, a range is specified. As the design work progresses, the ranges are gradually narrowed down to arrive at a point at the end of the project. This means that the dependencies in the design can be resolved or be made less strict. Thus, design work on several sub systems and components can begin at the same time. This have had positive effects in industry as observed by [3].

1.1. Platforms used in engineering design

There is no precise definition of a product platform. The existing definitions ranges from a platform consisting of components and modules [4], a group of related products [5], a technology applied to several products [6], to a platform consisting of assets such as knowledge and relationships [7]. This is also reflected among sub suppliers, as shown in [1] where the company platform description is categorized on four levels of abstraction and compared to their customization strategy. A risk emphasized in literature is the trade-off between commonality and distinctiveness [7]. Another trade-off is the one between increased development efforts for the initial platform and the uncertainty whether the right platform is chosen in order to develop a sufficient number of variants to gain back the extra expenses [8]. Platforms are generally described to be of one of either two kinds: Module based (discrete) or scale based (parametric) [9]. Source [10] suggests that one deliverable from TD can be a technology platform, this is further investigated by [11]. In [12] the author questions if companies have a choice regarding implementing a platform or not since platforms can exist on several levels. All companies pursuing product development has a product platform to some extent.

In the cases of the ChaSE project, the level of readiness of the product before the agreement with the customer is made, varies between the cases. The point where the adaptation of the product to a specific customer is made is referred to as the costumer order decoupling point [13]. Source [14] divides specification processes into four levels in the following way: (1) Engineer-to-order, (2) Modify-to-order, (3) Configure-to-order and (4) Select variant. In (4) everything is prepared prior to the customer’s order. The other extreme is (1) (ETO) where very little is prepared. In this case the platform consists of product knowledge such as applicable norms and regulations. (2) is represented by a generic product that is adapted to the specific case and (4) is combining ready modules without altering the design.

2. The research method

Along the project, interviews and workshops with the companies to identify which factors have an influence on their ability to respond to fluctuating and contradictive requirements have been conducted. The work has followed the DRM (Design Research Methodology [15]. In DRM it is emphasized that after an initial research clarification, success criteria (SC) and enablers (EN) should be formulated early in the project.

In the ChaSE project, the companies were gathered at several workshops where they formulated the SC:s and prioritized among them. “Reuse of knowledge” emerged as the most important followed by “Time to respond to quotation”. At the third level of importance was “Short start-up time”, “Time to build and maintain infrastructure”, “Assure fulfillment of requirements”, “Number of iterations” and “Keep project time”. Finally “Support the designer” and ”Re-use components” were rated as the fourth most important.

In each of the companies, the SC:s are supported by EN:s. The EN:s were also identified through interviews. Work started to set-up pilot systems at three of the companies to implement these EN:s.

The business model of the fourth company (production equipment) is different from the three others. In this company, the requirements can be definitively set at the beginning of the project and therefore the company is not expected to be responsive for enquiries on changes of the requirements to the same extent as the other three companies.

After implementing the pilot systems, the impact on the SC:s were estimated by interviews with professionals at the companies.

3. Results

In this section, the three company cases are described together with the results of the interviews.

3.1. The Aerospace company

The aerospace company is a very large organization with 44 000 employees. The studied part of the company has 2000 employees.

In new generations of air-craft engines, the demands on weight, thrust, fuel consumption, service life, noise level are increasing. Further, the number of aircraft manufactured are rising, placing demands on the efficient manufacturing of the products. Consequently, the company needs an active and innovative technology development. The company make extensive analyses in the early conceptual stages using an environment consisting of several commercial and in-house software that has been integrated. This is in this paper called the CAE environment. The CAE environment combines parametric CAD with e.g. FEA, CFD and rule-based evaluation. In early phases of development conceptual designs are proposed. These are evaluated in the CAE environment. The motivation is building knowledge and understanding the trade-offs in the conceptual design. The evaluation is done in an automated process so that hundreds of different geometrical variants of the concept are evaluated for structural strength, aerodynamics, lifetime and more. Through these experiments, knowledge is gained on how the geometrical parameters (lengths, angles, number of vanes etc.) affect the performance of the engine.

This enables the company to get an overview of what sets of requirements that can be met, so that they can assist their customers in formulating the requirement specification. It also makes the company very responsive should the customer request to change anything in the specification. Questions of the type “what if..” can readily be answered.

In the case studied, the capability of the CAE environment has been extended to also include manufacturability evaluation applied to robotic welding. For each variant it is evaluated if:

- It is possible to access to weld and inspect the welds.
- The material thickness is within the permissible range of the weld process.
- The variation in thickness is permissible for the weld process
- The material and the material combinations can be welded
- The curvature of the weld is not too small for the weld process

The Figure 2 (right) shows a fictitious static turbine component. It consists of a cast hub and several sheet metal parts that are welded together to 10 sub-assemblies that in turn are finally welded together to a complete component. This is done in a series of robot welding operations, requiring fixtures to be made in each welding sequence.

Figure 2. Welded turbine part.

The company employ a variety of different robotic weld methods: TIG, Laser, Electron Beam (EB) and Plasma. For each of these weld methods different ranges to the above items apply. In the evaluation it is checked which of the weld methods (if any) that comply with all the constraints. This results in a list of permissible welds methods for each group of welds. To make a final selection of weld method, a prioritization list for the intended manufacturing site is employed. Among the possible weld methods, the most preferred one is selected. After establishing weld methods, process plans are automatically derived so that a cost estimate and a sustainability evaluation can be made.

The estimated cost and sustainability values are reviewed together with the results of the other analysis allowing a decision to be taken on how to set the geometrical parameters of the concept to comply with the requirements. This is described more in detail in source [16].

The company describes different platforms i.e. manufacturing platform, analysis platform and so on. It consists of a number of well described and validated methods on how to perform the activities needed. The platform also encompasses in–house developed software for automating the described activities.

To evaluate the weld part of the CAE environment, one production and one design engineer with long experience in the company where interviewed separately.

Their answers were consistent that the company has a need of predicting the manufacturability in early stages. The proposed manufacturing module seem promising, but the results from in presented as manufacturability index was difficult to interpret. Instead key indicators like the number of welds that are expected to be difficult to inspect or the minimum weld-radii should be presented. Further, more runs on actual components were needed.

3.2. The first automotive company

The company employ 10 000 in total and about 600 in the studied organization. It supplies equipment for enhancing driver safety and comfort such as active head restraints and seat heaters, massage and ventilation in car-seats. The focus of the case at this company is the quotation process. There are frequently requests for quotations (RFQ) sent by car manufactures. In some cases, an off-shelf technical solution can be adapted to the car seat design proposed by the car manufacturer. This is, however, rarely possible which means that some design work has to be done to respond with any precision to the quotation. Further, the cost for preparing the quotation is in most cases not covered by the car manufacturer. In addition, the likelihood of actually getting the contract is low for some quotations. The company is in principle willing to customize or redesign each part of the system if required in order not to lose business. It is however desirable to reuse as much as possible from previous designs and previously created knowledge. Due to the high level of customization that is offered, the speed and accuracy in the quotation process is an issue. Speed is important to quickly return an offer to the customer whereas accuracy is of importance to charge the right price. It is therefore vital to reuse as much of already developed assets as possible which puts high demand on finding the needed information and be able to judge the applicability of it.

In order to respond to the need of efficiently conducting customization, a platform approach was developed, adapted and to some extent realized in the company. Due to the relatively low possibility of component and sub system reuse the introduced platform approach, called Design Platform (DP), aim at reuse on a higher level of abstrac-tion. In the DP approach, the platform is defined by:

- Descriptions of product instances and their interrelation to a generic description, which means that the platform evolves as the instances are successively created.
- Descriptions of the building blocks of the designs and design process and the both generic and specific descriptions of those.

The approach is object oriented and starts by the identification of generic product items which is the main class. The generic product item can many times be in the form of a generic product structure but also in the form of a generic module or component. Design Elements (DE), which are discretized blocks of knowledge descriptions, can then be associated with the items. The DEs are inspired by the ICARE forms in [17] and consist of entity, activity, rule and constraint.

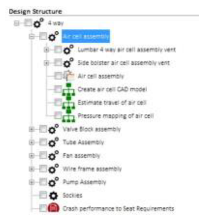

Figure 3. Part of the GUI of Design Platform Manager.

In order to realize some parts of the DP approach, an application was developed called the Design Platform Manager (DPM) (Figure 3).

The application enables the user to model generic product items, couple DE:s to the different levels in the generic product item structure and instantiation. The application is based on spreadsheets, XML and a user interface that allows the user to browse through generic product items, instances and DEs. The DEs are modelled using standard templates that include properties and characteristics that are important to judge validity and applicability of the DE in the specific context. When a quotation arrives the system is used to get a first view on what exists and what doesn't. The Figure 3 shows a 4-way seat comfort being designed. In addition to the available parts and assemblies, the tree structure also contains a number of activities as e.g. " create air cell CAD model" and "estimate travel of air cell" need to be made before the design can be finalized.

At the company a Request for Quotation (RFQ) usually concerns several specific types of systems with different levels of functionality. The corresponding generic product item can then be browsed in order to find DEs that fulfills the customer re-quirements. For some levels in the structure there will be associations with finished designs of components and subsystems (Entities) that fulfills the customer requirements. For other levels there will be no associations to finished designs, this is specifically common for the components and systems that interfaces the customer product and where subjective requirements are common. In these cases there might be associations to other kinds of descriptions describing e.g. a task, parametric CAD model or calculation spread sheet (Activities, Rules or Constraints) that aids in the designing of the desired component or sub system. The DEs that are judged to comply with the customer requirements are picked to be included in the instance.

Also this system has been evaluated through individual interviews with three employees with long experience in the company: One engineering manager, one design manager and one quality engineer. There was consistency in their answers. The system will contribute to decreasing the time spent on answering quotations as well as ensuring that all requirements are fulfilled. It will also contribute to a better re-use of components and product and process knowledge by providing an overview of the components and the knowledge. The system will require an effort in keeping up to date as identified at the interviews.

3.3. The second automotive company

The second automotive company supply solutions for the active, sporty consumer to bring equipment such as bicycles, kayaks and skies, allowing them to be transported on motor cars. The organization studied employ around 300 people. The company works both directly towards the consumers with aftermarket products as well as towards the car manufactures as an original equipment supplier.

The case is concerned with the aftermarket products. As new car models emerge, the solutions are adapted to fit the new model. One bottle neck when in doing these adaptations is to predict the behavior in a crash. Regulations stipulate that the roof rack must stay on the car when subjected to a specified acceleration. The simulations needed to predict if a proposed design will pass the crash regulations are complex, involving not only the product itself, but also the car roof. To set up the simulations require expert work. However, augmentation software has been developed within the project and has been introduced in the company's CAD / FEA systems, showing that it is possible to partially automate the process. This shortens the time to make the evaluation. It is possible for the design engineers to operate the system. The system is designed for a special type of roof-rack where a basic design is adapted to various car models. This is done by customizing a pad and a bracket interfacing the roof. The complexity of the simulations which includes large deformations makes it necessary to make structured meshes rather than just tetrahedron filling, adding to the difficulty. The system identifies the different components by their names in the CAD models. It then finds lower level elements in them so that the structured meshes can be created in the FEA system using extruding, revolving or sweeping. An FEA model can be solved on a powerful computer cluster in a few hours, resulting in a prediction if the proposed design will pass the regulations for road safety of not. This makes it possible to enlarge the set of designs under consideration, adding to the ability to quickly respond to requests for changed requirements in other aspects than crash regulations.

The evaluation interview involved five professionals at the company: Chief engineer, simulations expert, project leader, director of product development and a technical manager.

All participants saw a potential use of the system at the company. Positive comments with respect to the potential time and safety improvements were given. One went so far as to say it was a requirement to be able to meet the deadlines in the future.

However, skepticism was emphasized on the lack of detailed information regarding the implementation and maintenance required. As well as risks related to losing control by putting too much trust in the system.

Most participants saw the responsibilities for the CAD models to fully lie with the designers themselves, FE-models with the simulation engineers and the connecting subsystem with the researchers.

Potential drawbacks given were; the amount of time required to formalize the methods to automation standards, loss of control with respect to quality of results, maintenance and development might require large amount of time.

Further work suggestions involved starting to run the simulations because that is when issues appear, improve user-friendliness when defining the FE-models and provide proper instructions, have periodic follow ups between researchers and company staff and finally a warning not to underestimate the complexity.

4. Discussion

The three systems presented are in roughly the same state of development where the wanted system characteristics have been defined and demonstrated. The systems' place in the organizational work flow have been pointed out. The Table 1 below summarizes the company cases in terms of the type of platform, how it supports the ability to respond to fluctuating requirements, and the considerations for maintaining the platforms over time.

Table 1. Summary.

Company	Platform type	Response to fluctuating requirements	Maintaining the platform
Aerospace	Automated explorative studies.	Explorative studies in conceptual stage provide overview of the relation between design and performance parameters.	Uncertainty on future concepts. Useful for accessing incremental improvements of existing designs.
1st Automotive	Augmented product structure.	Provide overview of the effort required to meet a proposed set of requirements.	Support the stepwise introduction of new technology. Does not require complete automation.
2nd Automotive	Automated verification process.	Shortened time to verify designs compliance with safety regulations.	Need to monitor changes in road traffic regulations. Single base concept.

Since the systems have not so far been operated on actual design problems, the interviews have mainly been concerned with demonstrating and evaluating the proposed working principle and the systems role in the organizations. There is consensus that the companies' ability to respond to fluctuating and conflicting requirements will increase. The reason is that the time to evaluate a design suggestion will be shortened, making it possible to work with an enlarged set of design suggestions. Further the variations in doing the evaluations are expected to decrease in that the process becomes more formalized. This is expected to decrease the risk of overlooking any of the requirements.

What has been identified as an obstacle through the interviews is how the systems will be kept up to date. Should the information be obsolete, it can be assumed that the organizations confidence in the systems will soon be diminished. The intent is that the professionals in the companies will keep the systems up to date. However, this require high transparency and maintainability of the systems. Resources needs to be allocated for system maintenance. The staff must be given time to learn the systems and to operate them to be able to assess the amount of resources needed.

The second automotive case has the most well defined scope. It is one type of product where only few adaptations are made. It will presumably be easiest of the cases to implement in the organization. The system will need to be extensively revised when the basic concept is altered.

The situation at the aerospace company is less well defined since it is more of an ETO company than the automotive companies. It lacks the generic product structures. It is not known what types of engine concepts will emerge in the future. In the intake parts of aero engines carbon has begun to replace titanium. At the exhaust side more ceramics have started to be used instead of nickel alloys. This can make welding as a joining method less important. The system will then have to be extensively revised to accommodate new manufacturing methods which have different critical issues than todays. However, the time between the emergence new generations of products is generally longer than in automotive. The lifespan aerospace products are longer, 40 years or so. Here the aerospace platform can serve for a long time when investigating the impact of suggested incremental improvements on existing engines.

The first automotive case can be expected to be long lived. The business model is based on that there is a generic product structure that can be adapted at request for a new seat. New technologies for seat design will likely emerge as more weight will have to be saved in motorcars. This will require new types of components in the product structure, but the product based nature of the problem will remain.

The case of the second automotive company has the most well defined limitations. It is a specific, repetitive task that is well suited for automation. Since the problem is well defined, the risk of implementing it in the actual product development process can be expected to be low.

5. Conclusion

Three company cases have been implemented with the aim of increasing the companies' ability respond to fluctuating requirements using set-based concurrent engineering. The DRM has been followed identifying the SC:s and EN:s by interviews and workshops. It can be concluded that the companies need to increase their ability and that there is a common understanding that and the systems presented will achieve that. The maintenance of the systems that will be done by professionals at the companies is a critical issue for success of these implementations in the long run.

The ChaSE project is in a state where the EN:s i.e. the systems and their desired characteristics have been defined and demonstrated. Before it is possible to collect any data on to what extent they support the SC:s, the systems needs to be tried out on actual design problems. It is intension is that the researchers will show the professionals how to operate the systems both on former and new design problems. A more thorough evaluation will then take place, planned in the fall of 2016. This evaluation will also be based on interviews, however more detailed and with actual data from development projects available. It is thought that it then will be possible to show qualitative data on to what extent each of the SC:s are supported by the EN:s, possibly in a matrix format like QFD, house of quality.

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