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TOWARDS A CHANGE PROCESS PLANNING TOOL

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Abstract

The relationship between a product and its design process is generally complex and not fully understood. When modifying a product, industry still rarely considers the implementation process and its consequences for other design activities in the company, which is hard to assess with conventional planning methods. Although change processes are highly constrained, product and process constraints are not usually considered together or traded off against each other when planning the change. Inadequate assessment and planning of the change implementation process can lead to costly knock-on effects across the product and the design process. This paper argues for a combination of change and process research and discusses requirements for a change process planning tool. It proposes a system for the analysis of the impact of change on the product as well as other company activities. Then, a more informed selection between change alternatives is possible.

Keywords: change processes, product planning, design management

1 Introduction

Today, most product design is incremental development by redesign of existing products. Making use of existing products, processes and technologies reduces risk and cost for companies and reassures the end customer, who often shies away from radically different products. Change can then be defined as "*a modification to a component or a product, after that product has entered production* " [1] or "*changes to parts, drawings, or software that have already been released* " [2]. Change processes transform existing product descriptions into new or revised product descriptions. Change implementation follow two main aims:

- *Product enhancement* where the aim is to meet new needs or raise the standard of the current product, for example by complying with new customer requirements, new legislation, technological progress, etc. and
- *Problem correction* which includes all changes where the primary driver is a not a change to the specification of the product. This is mainly for error correction but could also be for purposes of cost reduction, new production techniques, replacement of a supplier, etc.

However, independent of the cause of change, fundamental properties of the resulting process are the same [3]. Change implementation activities need to be planned for, resources drawn in, and the implications on the product and the different processes within the company estimated.

1.1 Observations in industry

This paper is primarily based on observations during case studies in industry. Over the last few years, the authors have studied the management and execution of change at four major UK industrial companies: GKN Westland Helicopters [3, 4], Rolls-Royce, Perkins Engine Company [4] and Airbus UK. Change practise was observed and designers interviewed with the aim of assisting the companies in understanding and improving their change processes.

The role of change varies between the companies. At GKN Westland change is often seen as the core business. Because helicopters are custom made, they are constantly redesigned into new versions tailored to new customer requirements. Designers are constantly involved in change work across projects. In highly complex and interconnected products such as a helicopter change is very difficult to predict.

Rolls-Royce commits dedicated experts to the assessment of change implications. They analyse the scope and the impact of the change on the company, and plan the change implementation. Due to the great effort required, it is often only possible to examine one solution alternative for implementation.

Airbus UK uses a tightly defined change procedure and has dedicated change teams for every project to cope with very large numbers of different changes competing for resources. The procedure requires constant revision of the state of change but contains little technical detail. Process impact and resource allocation is assessed by the leaders of the engineering teams.

Finally, Perkins Engines also has a tightly defined change procedure, but uses the same designers for change and for new product development. With a highly customised product they have hundred of small changes to the periphery of the engine being implemented at the same time. While they are extremely successful in the incremental development of their core product, they are challenged by the logistics of executing so many small changes.

1.2 The problem of change

One significant cause of the problem in managing change originates from a lack of understanding of the connectivity between products and processes in industry. The links between the product, the change process, other processes of this or other projects, and wider business implications for the company are not equally understood by all members of a change team. Figure 1 diagrammatically shows the impact of change.

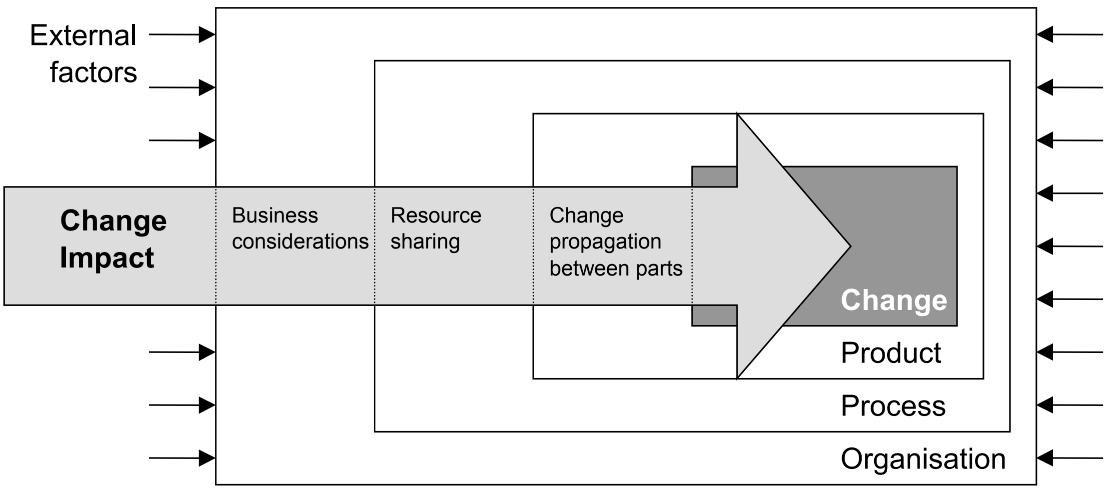

Figure 1. The impact of change

Additionally, it is important to distinguish between the individual impact of *one* change on the product, process or organisation, and the interactions of *many* changes planned for, or executed, at the same time. However, all problems that apply to a singular change also apply to multiple changes. The impact of the changes can be observed at the levels shown above:

1. *Product level*: The direct or indirect influence of the change on the product or components itself. Change can propagate between components within the product. One change can therefore affect one or more parts. Extra work is necessary to either contain the change or redesign the affected components [3]. Many modifications on the same product at the same time may influence each other. Two changes may affect the same tolerance margin and lead, if carried out in isolation, to conflicting design decisions. The lack of understanding of the connectivity between modifications and components is probably the main reason why people often fail to consider change propagation.

2. *Process level*: The associated change implementation process and other design processes happening at the same time. Since it is difficult to estimate the number of components affected by a change, it is also difficult to plan for change implementation and allocate the right resources to the change process. For one modification, trade-offs between product and process constraints may be possible. For example, by letting change propagate to other components, the change implementation process may be simplified.

   Similarly, change processes may interfere with each other if they affect the same components. They do so through the sharing of (human or material) resources from the same resource pool. Other design processes may also be affected. In the worst case, seemingly independent projects may be affected or hindered by indirect resource sharing.

3. *Organisation level*: The influence of the company's internal attributes (organisation, manufacturing process, company culture etc.). Tight budgets, limited resources and organisational issues may also constrain the change analysis. It may then not be possible to investigate different solution alternatives. Consequently, designers may go to great efforts to contain change within their field of work without considering alternatives. Simpler solutions may be overlooked.

   If a company is mainly doing change work, this may affect its company culture. It may be the stated aim of some companies to specialise in modification of existing products (car tuning companies, for example), whereas others may see modifications more as a burden than an opportunity to improve the product [5].

4. *External factors*: Attributes of the change external to the business, for example legislation, technology, market situation etc. The company may intend to influence some of these factors, but does not have a direct handle on them. However, external factors act on change through the organisational level. Thus, their influence is included above.

1.3 Overview of the paper

The first section of the paper intends to show common practise in industry and the challenges change poses. Next, the paper examines existing change tools to analyse the benefits and drawbacks of these methods when planning for change. Existing planning tools are also discussed for their relevance to change process planning.

This establishes a clear need for a combined tool, which will be outlined in the final section. The requirements for a new solution are given and a first attempt of providing a Change Process Planning tool is made. Future work is discussed and conclusions drawn.

2 Understanding and supporting change

Industrial as well as academic change tools can broadly be separated into two categories: those that mainly address organisational issues of change and those that include more technical product information. Through the different focus, the methods emphasise different change levels.

2.1 Organisational tools for change implementation

Paper flow tools and configuration management techniques focus on organisational issues. Much research has gone into streamlining change procedures by creating tools that help organising the paper flow in companies [2]. Configuration management tools [6] provide a rigid framework for managing requirements and changes, ensuring conformance and providing correct documentation for change implementation. The aim of these tools is to standardise a high-level change procedure to retain business control. They do not adjust to low-level requirements of specific changes, thus emphasising the change process in its company context.

More advanced Product Data Management (PDM) or Product Lifecycle Management (PLM) systems allow a deeper organisational change analysis, linking some product information to design activities. The software databases connect such formerly independent units as the Bill of Materials (BOM), task maps and schedules. They also serve as repositories for documents or technical drawings. However, so far PDM software does not offer much technical support for change planning apart from allowing users to link parts, processes and resources.

2.2 Product-specific change tools

Solid modellers like CATIA or ProEngineer assist from a more technical viewpoint. They can investigate the impact of spatial changes to the rest of the product. By allowing for virtual testing, a better feeling can be obtained of what a change may entail. However, the analysis can only be carried out once the change has been modelled and a large fraction of the design investment has already been made. This discourages designers from investigating alternative solutions. In addition, solid models only identify geometric mismatches and do not indicate change propagation. They do not provide process information.

Change propagation methods like [7] or [8] investigate the connectivity between product parts not just in geometric terms but based on heuristic rules. They also include information about change propagation paths. While the former method connects customer requirements, components and design parameters in an attempt to modularise the product architecture, the latter method links parameters to allow for quick estimation of change impact. Both methods identify affected components but do not describe ways for implementing the change.

The Change Prediction Method of the Engineering Design Centre (EDC) in Cambridge is also product focussed. This method predicts the likelihood, impact and resulting risk of change propagation based on a product breakdown into components [4] (Figure 2). The columns in the matrix indicate the change initiating components. The likelihood of change propagation to other components can be read off the rows. Then, algorithms calculate the risk of change propagation based on a combination of direct and indirect impact and likelihood of change propagation between components [9].

The Change Prediction Method uses estimates based on experience from previous changes. Process knowledge, in terms of cost and time, is implicitly embedded in the impact data. Other relevant factors for change planning like task failure (and the resulting redesign) or product unrelated tasks (design approval, documentation update etc.) are not explicitly included in the model. Although the change model does not give direct planning information, it gives the user an indication which tasks may result from a change and therefore includes process information. For example, a “change component A task” leads to a “change component B task” by assessing the risk of change propagation to B.

Toaster		Initiating component																						
receiving component		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Top casing	1	1	0.8	0.8											0.2							0.8	0.8	
Lower casing	2	0.8	2		0.2	0.8													0.2	0.2	0.2	0.8	0.8	
Bun rack assembly	3	0.5		3												0.2								
Crumb tray	4		0.5		4	0.8							0.2											
Metal base plate	5		0.5		0.8	5				0.2			0.2											
Nichrome wire	6						6	0.8	0.2		0.2	0.8	0.2											
Mica sheet	7						0.5	7	0.2	0.8	0.2	0.5	0.2											
Bread guiding grates	8						0.2	0.2	8	0.5														
Metal railings	9					0.2		0.5	0.8	9			0.5			0.5								
Toast holder	10						0.2	0.2			10		0.2		0.5									
Non-resistive wires	11						0.5	0.5				11	0.2						0.5					
End plates	12				0.2	0.5	0.2	0.2		0.8	0.2	0.5	12	0.8	0.5	0.5	0.8	0.8	0.2		0.2			
Slider guide rod + springs	13												0.5	13	0.8									
Slider assembly	14	0.2									0.5		0.2	0.8	14				0.2					0.5
Metal top cover	15			0.2						0.5			0.5			15	0.5	0.2						
Metal back insulator	16												0.5			0.5	16	0.5						
Metal side insulators	17												0.5			0.5	0.5	17						
Main circuit board	18		0.2									0.5	0.5		0.2				18	0.5	0.2	0.5		
Circuit cancelling board	19		0.5																0.5	19			0.8	
Cable + Plug	20		0.2										0.2						0.5		20			
Browning control dial	21	0.2	0.2																0.2			21		
Cancel button	22	0.2	0.2																	0.8			22	
Plastic handle	23														0.2									23

Figure 2. A likelihood of change propagation matrix for a toaster

3 Understanding processes and planning methods

High-level process models indicate the stages of design processes across products and disciplines. Other planning tools model specific design processes in more detail and compute sequences for design activities. Signposting is such a planning tool. It forms the basis for the planning part of the Change Process Planning method discussed in the next section.

3.1 Prescriptive design process models

High-level process models prescribing task sequences for design have been proposed by Pahl and Beitz [10] and others. These models provide generic high level tasks that can be found in most design activities, including change work. These models are not useful for low-level change process planning, as no specific design activities or components are addressed.

Other process models use generic building blocks to describe the design and manufacturing process [11]. The building blocks represent typical company activities and are linked by hand-over documents. Due to the limited number of blocks usually presented, such models also provide a high level view, but they allow for the linkage of activities between design, manufacturing and assembly, and hence allow greater connectivity within the process.

3.2 IDEF and Design Structure Matrices

State-action models such as the IDEF methods include product information in some detail. IDEF captures precedence and causality relations between activities and events by providing a structured method for expressing knowledge about systems, processes or organisations [12]. An attempt is made to link activities through the design state. By explicitly modelling the state, alternative activities can be captured and their execution impact observed. IDEF models can include resource and constraint information but the information tends to be high-level.

Design Structure Matrices (DSM) indicate precedence between building blocks such as components or activities. Activity DSMs [13] intend to provide a lower level view of task activities. Tasks can be created at any level, as long as preceding and succeeding tasks can also be given. Algorithms calculate an optimum task order. DSMs are a strong visual tool for displaying task precedence and recognising task iterations in the process. However, DSMs also require completeness of the model before sequencing algorithms can be applied. They assume that a task is completed before another one can begin.

Product, activity and organisational DSMs can be used to model the products, processes and organizations within a company to investigate the connectivity, interactions and complexity of product development processes [14]. However, few attempts have been made to combine different views in one DSM. One such attempt is the ADePT method [15] that combines product building blocks with DSMs to assist the planning of civil engineering projects.

3.3 Signposting

The Signposting model is a planning technique developed in the Engineering Design Centre in Cambridge, UK [16]. It models processes through tasks and their linking parameters. Unlike other models it includes an indication of the minimum required maturity of the input parameters required for the successful execution of a task. This measure of maturity is termed confidence. The design is completed when relevant parameters have been successfully brought to sufficient levels of confidence. Signposting algorithms have been developed that find the best process strategy and predict the likelihood of task iteration [16]. This is possible because task failure can be modelled probabilistically, resulting in the confidence in task parameters decreasing instead of increasing. When including task resources and costs in the model, processes can be simulated and compared [17].

Like in most low-level process models, product information is implicitly given in Signposting through product-specific design tasks. Like IDEF models and DSMs above, Signposting also requires task elicitation prior to planning. The Signposting model is knowledge intensive, since it requires tasks and parameter values, as well as cost and resource information, to be estimated by the engineer before the model calculates the best task route. The elicitation process to date does not support the design analysis based on a combination of product and process information that is called for here.

4 A vision for an integrated Change Process Planning method

Change tools and planning methods were discussed in sections 2 and 3. None of the change tools and planning methods discussed is ideally suited for change process planning needs, because they do not provide connectivity between product and process information. To explicitly achieve the combination of process and product models and consider implementation alternatives for change, a new method is needed. Requirements for such a method are given in this section. The main steps of the method, which is under development, will be outlined, identifying open research questions.

4.1 The requirements for a new method

The aim of the Change Process Planning method is to provide process information for the selection of solution alternatives for given change needs. It should consist of a product analysis that is specific enough to consider the product in detail and indicate connectivity between product parts to allow for identification of the consequences of implementing change alternatives. The product analysis should indicate tasks that result directly from change propagation within the product.

General design tasks that are not strongly product orientated should also be included in the change process. Tasks like “raise modification proposal” or “procure resources” may not result from a product analysis but they nevertheless require resources and therefore have an impact on the change process. They need to be considered specifically for each change because tasks may require different efforts depending on the change alternative.

The method should assist in finding the best change implementation process among the change alternatives and indicate its impact on other parts or the product. It may also be possible to predict the change impact on other activities and projects within the company.

The method should enable the designer to consider the change propagation and process planning implications of several change alternatives that they propose, before investing considerable time into any of them. An estimate of the likely workload, cost and duration of the change implementation should be given to support the selection of a particular solution.

4.2 The change process planning method

An approach to address the requirements above can be seen in Figure 3. Four high level activities form the basic building blocks of the method. These activities will be explained in more detail in the following paragraphs.

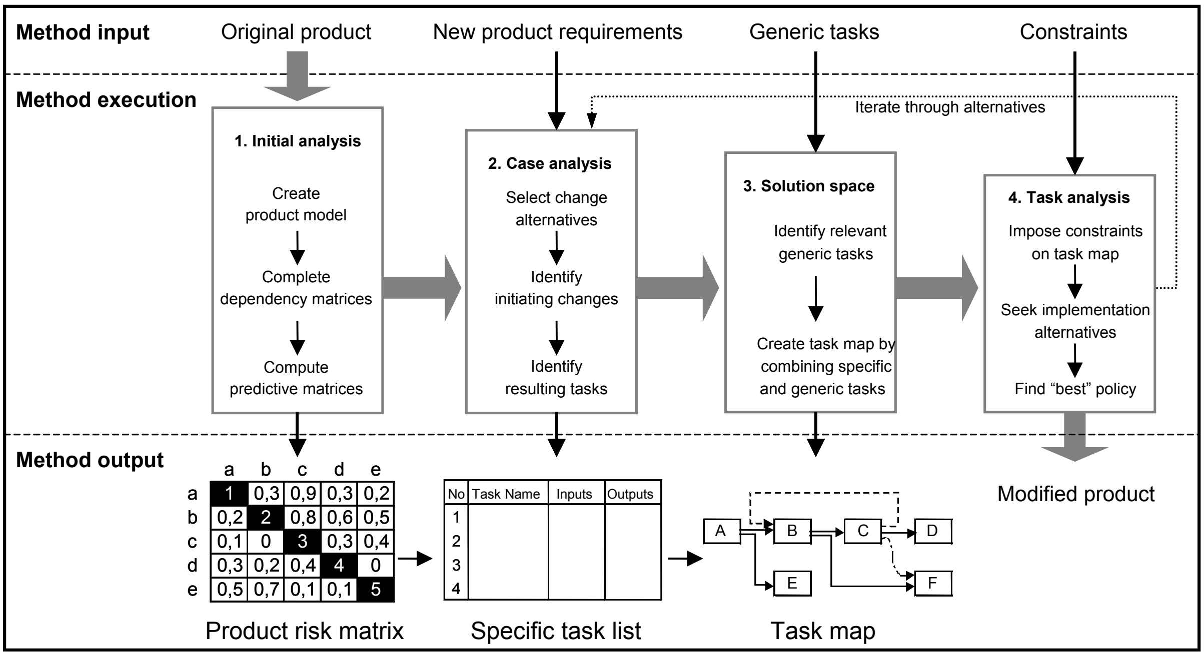

Figure 3. The Change Process Planning method

1. Initial Analysis

   A product model of the existing product is created and the connectivity between parts elicited. The risk of change propagation between components is estimated using Change Prediction Method algorithms developed in the EDC (see section 2). When following these techniques, the product analysis should be relatively straightforward.

2. Case Analysis

   The Initial Analysis is based on the product, without considering a particular change intention. Now, the designer analyses the new product requirements and provides a list of possible implementation alternatives. For each alternative the components that initiate the change are found and the risk of change propagation is assessed.

   The change prediction method provides a list of components that may need to be redesigned or tested if they are affected. From the many change paths, an experienced designer can discard many propagation paths that are not relevant. They can also judge whether the redesign of components has to be broken down into several tasks. These judgements are based on past experience, but the methods prompts designers to consider paths that they may forget otherwise.

   So far, the Case Analysis has not been researched in detail. However, we are working on using linkage models to predict likely paths for a certain type of change. We are considering developing a method based on linking parameters, which would be common to product and process models.

3. Solution space

   Design process models do not specifically consider product-related tasks alone. General tasks that are not product-related also have strong influences on the design process. Checklists of tasks can be derived from high-level process models [10]. Generic tasks are combined with the product specific tasks to create a task map for the implementation of the change solution. These tasks can be to calculate, check, design, produce or test etc. according to an estimation of what is required by the designer.

   How to build generic task models is another area of active research in the EDC [17]. Generic tasks can be set by designers or be primed by the system. The longer the Change Process Planning method is used, the more experience is gained about general design task and the more tasks are already available in a task repository prior to change planning. However, a great challenge is to make sure that the resulting process models are complete and on a suitably even level of hierarchy.

4. Task analysis

   Once a solution space has been created, process and organisation constraints can be imposed on the tasks. Planning algorithms can then generate and evaluate implementation routes for the change alternative, using existing Signposting algorithms. At the end of this process designers can compare different change alternatives and their processes.

4.3 Future work

As has been indicated, further work is needed to investigate the connectivity between change process, the product and other activities in the company. Change propagation from product to process and visa versa is not entirely clear and requires further research.

In terms of the new model, the transformation of data from the EDC Change Prediction Method into tasks that can be analysed by a planning tool based on the EDC Signposting algorithm needs to be investigated further. Parameters may form the common building blocks that provide the basis for such a transformation.

The feasibility of the whole concept also has to be verified. The model requires input in the form of a product model, new requirements, generic tasks, and constraints. It will have to be investigated if the effort of creating such a complex model can be justified by the output. Also, the robustness to incomplete or incorrect data input has to be analysed.

Different modelling alternatives for change process planning are also conceivable. For example, the qualifier concept in the Signposting model can be used to select design tasks. Design parameters of the existing product are then assigned a high confidence and only parameters initially affected by change are given low confidence. Then, the aim of the model is to increase the confidence of all parameters to acceptable levels again.

5 Conclusions

The drawbacks of current change tools have been investigated. Product models alone do not give sufficient insight into the implications of change. A change process is always more constrained than a new product development process, because changes have to fit into existing resource and cost allocations. They typically need to meet an existing schedule. This paper presents an outline of a method that attempts to integrate change prediction and design process planning through all levels of product, process and organisation interaction. It relies on the generation of tasks from a product model and suggests a combination of specific and generic tasks for the creation of task maps considering process constraints.

This research builds on existing change predication and process planning tools, but has only began to develop the concepts for an integrated tool. Further research is required into the nature of the relationship between product and process, and especially the generation of process models from product models, before the approach can be verified and validated in practise.

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