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Procedia CIRP 34 (2015) 93 – 97

www.elsevier.com/locate/procedia

9th International Conference on Axiomatic Design – ICAD 2015

Design of changeable production units within the automotive sector with Axiomatic Design

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Abstract

Corporations within the automotive sector are faced with major challenges caused among others by high volatile demand fluctuations. An answer to this problem is given by flexible and changeable production systems which allow reacting efficiently to these fluctuations in demand. To achieve this aim, so called enablers for changeability have to be considered already during the design process of single production units within a whole production system. Furthermore the complexity of production units has to be reduced in order to obtain changeable and reliable manufacturing systems.

In the presented paper an approach is proposed with the aim to consider enablers of changeability in Axiomatic Design (AD). Moreover it is outlined which different interest groups within a single corporation have a direct or indirect influence on production unit design. Frequently complexity originates from many different attributes demanded by the single groups. On this basis, it is demonstrated how AD can help to enter into dialogue with the mentioned groups with the aim to lower the requirements of the production unit and to reduce complexity of the resulting design. This is done by using the design matrix which illustrates the dependencies between functional requirements (FRs) and design parameters (DPs) as a basis for discussion.

Peer-review under responsibility of the organizing committee of 9th International Conference on Axiomatic Design

Keywords: Axiomatic Design; industrial application; changeability of production units;

1. Introduction

In recent years the automotive sector was challenged by a highly volatile market for passenger cars. Reasons for these demand fluctuations can be found inter alia in economic crises, shortened product life cycles, an increasing number of product variants but also in increased competition. Because of not very flexible but complex production facilities automobile manufacturers were struggling with reacting on these market movements. In consequence the guidelines for designing production facilities within the automotive sector were subject to major changes. There was a change of thinking from reducing personnel costs by automating as many process steps as possible towards highly flexible and changeable production lines.

The design of a production unit of an automobile manufacturer is influenced by many different groups within the same corporation. Every single group demands requirements which may actually be partly competing to requirements stated by another group. This fact may lead to complex, hereby inflexible and little changeable production units. Examples for these groups may include the operators of the production line, the developers of the passenger cars and occupational safety engineers.

One possibility to sum up all demanded requirements and to find a proper design for production units is given by Axiomatic Design (AD) which is a design methodology with a strict top-down approach for decomposing a design task. Besides this strict procedure another advantage of AD is the representation of dependencies of demanded requirements. Within this paper an AD based approach is suggested with the aim to ease the design of changeable and flexible production units. Furthermore it is proposed to use the representations of dependencies of the requirements to enter into a close

Peer-review under responsibility of the organizing committee of 9th International Conference on Axiomatic Design
doi:10.1016/j.procir.2015.07.006

dialogue with the different interest groups in order to influence the demanded requirements regarding a reduced complexity of the production unit. The research questions of the presented paper are:

- How can AD be applied for design tasks concerning changeable and flexible production systems?
- How can AD be used as a discussion basis to enter into dialogue with other groups within the same corporation?

2. Literature review

Current activities in the field of production unit planning focus on the aspects of changeability. In literature there are many works addressing enablers for changeability. In the following a common understanding of changeability in combination with production units is given. Furthermore a short overview of AD based works relating to changeability is outlined.

2.1. Changeability of production units

The term "changeability" describes the ability of a production system to react and adapt to unforeseen conditions. These conditions are caused by a so called turbulent environment influenced by e.g. technological developments, politics, and world economy [1, 2]. Another term, that should not be mixed up with changeability is flexibility. This describes the possibility to react and adapt to varying conditions within a predicted scale. The difference between these two terms can be seen in Figure 1 where flexibility characterizes the possibility to react to minor fluctuations and changeability means the possibility to react to major variations.

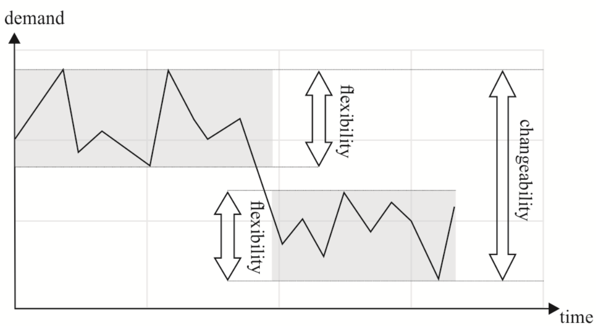

Fig. 1. Differentiation of flexibility and changeability [3].

In order to be changeable, a production unit has to feature characteristics which allow changeability. These are called changeability enablers and can be divided into primary and secondary ones. Most important changeability enablers are universality, mobility, scalability, modularity and compatibility [4].

In this context universality describes the design of production units relating to the production of different product variants. Mobility names the possibility to move production units by for example mounting them on wheels in order to ease their relocation. Scalability means the capability to expand or reduce a production unit in terms of technology, required space and degree of automation. The term modularity describes the usage of standardized and exchangeable units. Compatibility is the ability to connect production units in terms of materials, information, mediums and energy [4].

2.2. Axiomatic Design

Axiomatic Design is a non-empirical design theory based on mainly two axioms. The design process takes place in four domains (Figure 2): customer, functional, physical and process domain. Within the customer domain customer attributes (CAs) are summarized. These are transferred to the functional domain by stating proper functional requirements (FRs) which have to be fulfilled by the final product. These requirements are mapped to the physical domain by finding proper solutions which are called design parameters (DPs). In turn these DPs are mapped to the process domain by defining suitable process variables (PVs).

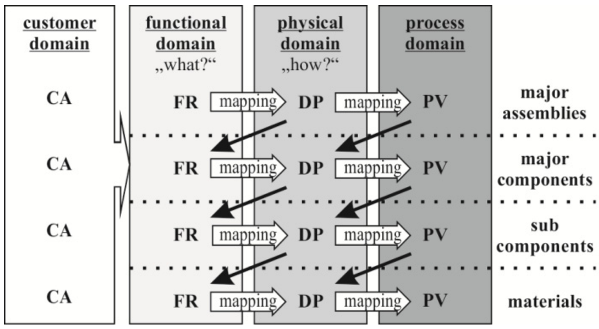

Fig. 2. Mapping between domains in AD.

The decomposition of the design task by alternating between functional and physical domain follows the two axioms of AD called Independence Axiom and Information Axiom. The first one claims that the FRs have to remain independent by finding appropriate DPs. The second one demands the minimization of the information content of the design. This founds on the fact that the information content is related to the complexity of the proposed solution [5, 6].

2.3. Research gap and need for action

In [7] an interesting solution is presented for designing and implementing franchise-networks with distributed manufacturing units considering changeability. This approach addresses a high, strategic level dealing with several different manufacturing locations.

On a lower level focusing on single machines changeability in association with AD has not been object of investigation. To this effect one question that has to be answered particularly is how the already mentioned enablers for changeability can be integrated in AD theory. Moreover a better understanding of the origins of complexity of the demanded requirements of a production unit has to be created. On top of this a basis for argumentation with the aim to simplify the asked requirements has to be found. The following paragraphs try to give an answer to these questions.

3. Theoretical considerations

As already mentioned changeability of production units gets more and more into focus of automobile manufacturers. In the following a proposal for considering changeability in AD is submitted. Furthermore a way for starting a corporate internal discussion about demanded requirements of production units, which may complicate the design, is suggested.

3.1. Considering changeability of production units in Axiomatic Design

In order to achieve the design of a changeable production unit it is important to consider the already explained enablers for changeability during the design process. This can be done by formulating the already mentioned enablers for changeability as FR. For this purpose a separate branch in the hierarchical tree is created besides the common trees containing the common and technical requirements of the product. The top level FR of this branch demands the development of a changeable production unit. The corresponding DP comprises the consideration of the enablers of changeability. On the next lower hierarchical level the FRs ask for each single enabler for changeability. The FRs are listed in Table 1.

Table 1. Functional requirements for a changeable production unit.

FR 1	Creating a changeable production unit		
	FR 1.1	Ensuring modularity	
	FR 1.2	Ensuring scalability	
	FR 1.3	Ensuring universality	
	FR 1.4	Ensuring compatibility	
	FR 1.5	Ensuring mobility	

3.2. Interest groups influencing production unit design

Within large corporations the design of production units is influenced by a variety of interest groups. These groups are for example production planning, production unit operators, occupational safety engineers, maintenance engineers, product developers and management. They all influence in a direct or indirect manner the design of production units (Figure 3).

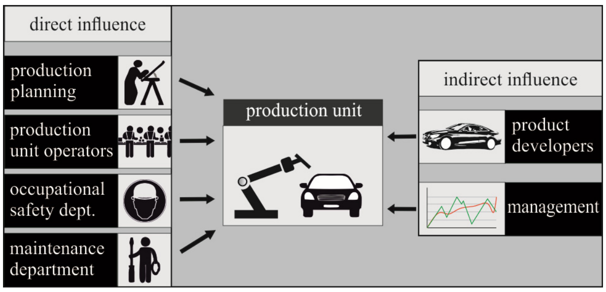

Fig. 3. Interest groups influencing production unit design.

For example product developers influence the design of production units by the shape of their product design. In this particular case this would be the shape of the designed car. Another example for indirect caused impacts on the production unit design may be economic targets formulated by the management. Claims for a high rate of return for example can have effects on the degree of automation of a production unit.

In contrast to this a direct impact on production unit design is caused by e.g. production planners, operators and occupational safety engineers. These groups formulate specific attributes agreeing with CAs in AD theory that can be directly translated into FRs.

Obviously the demanded attributes do not originate from a single source. Under some circumstances this heterogeneity may hinder a holistic thinking regarding the design process of the production unit because some of the goals can be competing.

3.3. Revealing the origin of complexity of a design task

In order to achieve the goal of changeable production units it is necessary to think out of the box and to rethink established demands of requirements. Excessive demands of requirements regarding e.g. maintainability or machinery safety lead to complex and little changeable systems. To break the cycle it is essential to find a kind of visual representation to be able to start a discussion about the extent of demanded requirements. The aim of the discussion has to be the reduction of the requirements, which is consistent with corollary two in AD that states the minimization of FRs.

By illustrating the decomposition of the design task in a hierarchical tree and by the transformation of this tree to a design matrix (DM) AD already offers a proper tool for the visualization of dependencies of FRs. To uncover the origin of the FR another step is necessary. For this reason the FRs in the hierarchical tree are marked according to their origin. The color is assigned analogously to the DM. With this step it gets obvious which FRs caused by which interest group have the most dependencies. This information can be used to break fresh ground regarding the design of production units.

4. Use case: design of a mobile platform for final assembly

A mobile platform (Figure 4) is a common technology for the final assembly of automobiles in flow production with the objective to reduce work loading. The functional principle is the following: the assembly operator stands on the platform and is moved synchronously and parallel to the product (in this particular case to the car). The relative velocity between product and worker is approximately zero. This allows the worker to do assembly operations as if the car is standing still. Immediately when the assembly operations are done the platform moves contrary to the conveying direction in order to catch up with the following car. The benefits of this technology can mainly be seen in improved ergonomics and in an increased profitability. Ergonomics are improved because of reduced distances to be walked and because tools and materials are laid down on rest tables on the platform and do not have to be carried along. Profitability is increased because preassembly operations can be carried out during the return of the platform to the subsequent car.

Fig. 4. Example of a mobile platform for final assembly.

In a first step the CAs of the mentioned interest groups have to be collected. These have to be transformed into FRs which have in turn to be mapped to the physical domain. A challenge can be seen in the task to take the indirectly stated attributes into consideration. For this purpose the design task is decomposed in mainly two hierarchical tree branches. On the one hand the first branch especially deals with the requirements addressed by groups directly involved in the production unit design. Examples for FRs like these may be "hard facts" like demanded load capacity of the platform. Other examples may be the velocity performed by the drive module of the platform. The highest level FRs and corresponding DPs are listed in Table 2.

Table 2. Top level FRs and DPs considering direct CAs.

FR 1	Easing work load for assembly line workers		
DP 1	Mobile platform		
		FR 1.1	Being movable
		DP 1.1	Drivetrain
		FR 1.2	Ensuring synchronicity to conveyor
		DP 1.2	Positioning system
		FR 1.3	Providing space for worker
		DP 1.3	Even surface
		FR 1.4	Providing space for materials and tools
		DP 1.4	Rack for materials and tools
		FR 1.5	Guaranteeing accident-free work process
		DP 1.5	Safety technology

On the other hand the second branch handles structural requirements postulated indirectly by the management owed to the current corporate policy. In this particular case this corresponds to the in 3.1 listed FRs (Table 3).

Table 3. Top level FRs and DPs considering changeability.

FR 2	Creating a changeable production unit		
DP 2	Changeability enablers		
		FR 2.1	Ensuring modularity
		DP 2.1	Modular design
		FR 2.2	Ensuring scalability
		DP 2.2	Resizable design
		FR 2.3	Ensuring universality
		DP 2.3	Conveyor independent linkage between car and platform
		FR 2.4	Ensuring compatibility
		DP 2.4	Compatible electrical and control technology
		FR 2.5	Ensuring mobility
		DP 2.5	Mobile design

The decomposition is also carried out on lower, more detailed levels. Subsequently the hierarchical tree is getting color coded. A specific color is assigned to each FR in order to mark the origin of the requirement. This can be seen in Figure 5. It is obvious that the indirectly stated attributes only have influence on the right branch of the tree. In the case at issue most of these FRs originate from management satisfying the claim of changeable production systems. This practice of considering changeability within the hierarchical tree helps tremendously to achieve the goal of changeable production units. This results from considering the enablers for changeability already at a very high level which helps to direct the design of production units into the right channels.

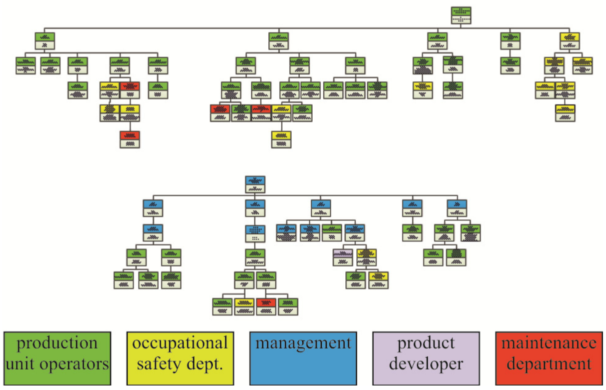

Fig. 5. Decomposition of the design task with color-coding.

Nevertheless this does not help to identify the origin of complexity of the given design task. For this purpose it is necessary to translate the hierarchical tree into the design matrix (DM). Corresponding to AD theory the dependencies of various FRs is visualized. By retaining the color-coding of the hierarchical tree it is getting apparent which interest group influences the design of the production unit most (Fig. 6). This information can be used to start a discussion about the demanded attributes and to adjust the claimed goals.

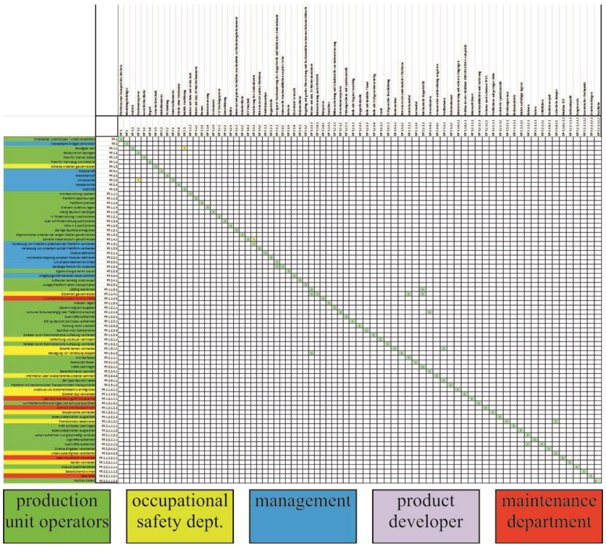

Fig. 6. Design matrix with color coding.

5. Discussion

The strategy of considering changeability of production units by formulating the enablers of changeability as FR seems to be a rather good way. Restrictively it has to be said that the mobile platform from the chosen example is not the most complex production unit. It might be more challenging to design a more sophisticated production unit where in some circumstances individual enablers of changeability compete with other requirements. In any case the demonstrated example shows a proposal to consider changeability in Axiomatic Design. Designers of production units facing a similar design task regarding changeability may fall back to the shown decomposition. This will help to accomplish the goal of a changeable production unit.

Using color-coding for the hierarchical tree and the design matrix an argumentative basis was created to discuss demanded attributes within a large-scale company. On the one hand it is certainly possible to enter into a dialogue with groups like operators or occupational safety engineers who influence the design in a direct manner. On the other hand the question is, if it is possible to start a discussion with groups which influence the production unit design only in an indirect way. For example it will be a demanding task to influence management in order to simplify the design of production units. Finally it is a basis to show where complexity of designs originates from and thereby where high investment costs result from.

6. Conclusion and perspective

Changeability of production units is one of the major challenges for corporations within the automotive sector. This originates from high volatile demand fluctuations to which production facilities have to react.

Within the frame of this paper an industrial application of Axiomatic Design with focus on the design of changeable production units was shown. In this context a proposal for considering changeability within AD was submitted. Common enablers for changeability were formulated as FRs in a separate branch during the decomposition phase. This strategy helped the designer to raise awareness of changeability during the whole design process.

Furthermore the strong advantage of AD by visualizing dependencies unlike to other design methodologies was used to reveal the origin of complexity of production units. Underlying assumptions were that complexity originates from the multitude of FRs stated by various interest groups. These different groups within a large-scale corporation like the production unit operators, planners, safety engineers, etc. influence the design of production unit in a direct or indirect way and may complicate the design.

To reveal the origin of the complexity of the design task the hierarchical tree describing the decomposition of the design task was colorized. In addition the design matrix which shows the dependencies of FRs was colorized. Hereby it was possible to start a discussion within the company about the sense of established requirements demanded for production unit design.

In summary, the consideration of changeability enablers within the hierarchical tree just like the color-coding of the design matrix helped to design a changeable production unit. For future reference it is necessary to transfer the proposed procedure to a more sophisticated design task to verify its benefits.

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