Modelling and Management of Manufacturing Requirements in Design Automation Systems

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Abstract. Initially, when implementing a design automation system the focus is to successfully develop a system that generates design variants based on different customer specifications, i.e. the execution of knowledge and system output. However, in the long run two important aspects are the modelling and management of the knowledge that govern the designs. The increasing emphasis to deploy a holistic view on the products properties and functions implies an increasing number of life-cycle requirements. These requirements should all be used to enhance the knowledge-base allowing for correct decisions to be made. In a system for automated variant design these life-cycle requirements have to be expressed as algorithms and/or computational statements to be intertwined with the design calculations. The number of requirements can be significantly large and they are scattered over different systems. The aim of the presented work is to provide an approach for modelling of manufacturing requirements, supporting both knowledge execution and information management, in systems for automated variant design.

Keywords. Design automation, requirement management, requirement modelling, manufacturing requirements, producibility

1 Introduction

Today, many companies have adopted the strategy of product customization. To be able to reduce the workload and handle the large amount of information that this strategy entails, companies have to make use of appropriate methods and tools. Further, companies have to capture the knowledge behind a design for internal reuse and/or to be able to provide design history documentation as requested by customers and authorities. This implies that they have to consider the modelling and management of the knowledge that govern the designs. This includes the core elements of the knowledge, the range of the knowledge, its origin, its structure, and its relations to other systems and life-cycle aspects.

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The purpose with this work is to integrate the properties and the functions for knowledge execution and information management into one system. The work is based on two previously developed systems: one system for automated variant design [1] and one system for management of manufacturing requirements [2]. Both systems can be used as analysis or synthesis tools concerning producibility aspects [3]. The systems have different functionalities and properties, e.g. regarding knowledge execution and information management, and it would be fruitful to combine these in one system. The aim of the work is to provide an approach for modelling of manufacturing requirements in systems for automated variant design, supporting both knowledge execution and information management.

One strong reason for using IT-support to manage requirements is the need for traceability. This implies that changes should propagate to the product definition guided by traceability links. According to [4], a requirement is traceable if one can detect:

- the source that suggested the requirement,
- the reason why the requirement exists,
- what other requirements are related to it,
- how the requirement is related to other information such as function structures, parts, analyses, test results and user documents,
- the decision-making process that led to derivation of the requirement, and
- the status of the requirement.

To support traceability between customer requirements and systems/parts [5] propose the employments of tree additional structures: *functions*, *solutions*, and *concepts*. A similar approach is adopted in [6] to enhance traceability using additional structures for *functions* and *function-carriers*. Both approaches are based on the chromosome model [7], which is a further development of the theory of technical systems [8,9].

To map manufacturing requirements for the physical product, [10] proposes the introduction of a *process function domain*, with process requirements, in the four domains of the design world [11]. However, the focus with this approach is to manage process requirements set by the product. This is intended for a company strategy where the design of the manufacturing system is subordinated the design of the product and a new manufacturing system is developed for every new product. Another approach is proposed by [12], arguing that manufacturing requirements can be structured according to the product and manufacturing domain. They suggest that the manufacturing structures (*processes*, *functions*, *functional solutions*, and *resources*) could be used for the structuring of manufacturing requirements. However, they do not describe how to support the conceptual phases where different manufacturing alternatives are to be evaluated or how to model requirements arising from the combination of resources. The approach is applicable for product documentation and configuration systems. Although, the approach's applicability for systems supporting evaluation of different courses of action or for generative process based systems is considered to be limited.

2 Modelling of Manufacturing Requirements in Design Automation

From an engineering design view, the origin of manufacturing requirements is the coupled relationship between the product design, the material and the manufacturing process. The main objectives of manufacturing requirements are to ensure the product's conformability with the manufacturing system, i.e. prevent problems in manufacturing from occurring, and to enhance producibility. From a modelling perspective, some of the manufacturing requirements can be considered to arise in the interfaces as depicted in Figure 1 [2].

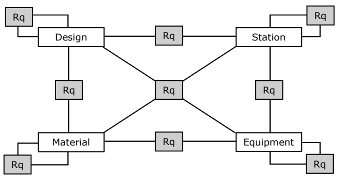

Figure 1. From a modelling perspective, the manufacturing requirements are considered to arise in the interfaces [2].

The requirements have to be collected and structured in a systematic way. A number of properties need to be defined in order to ensure that they fulfil the needs of the different interested parties. This can be achieved by looking at how the requirements relate to the other concepts. The requirements can have different ranges, be applicable at different company levels, be of different types, be expressed and illustrated in different formats, and have a number of links to other concepts and instances. Different concepts and their links are depicted in Figure 2.

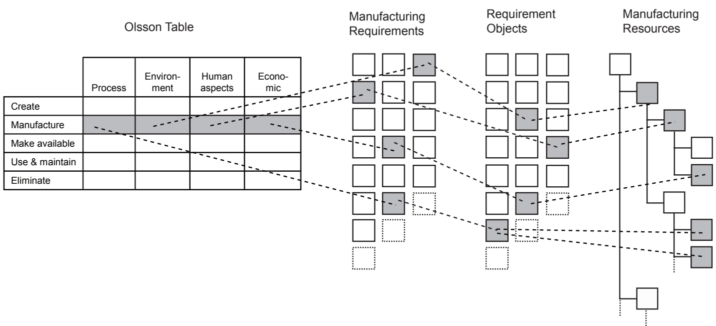

Figure 2. Different concepts for modelling of manufacturing requirements. The Olsson table [13] supports the definition of requirements.

The manufacturing requirements are defined by applying different views from the Olsson table [13] on the manufacturing resources to ensure that all important aspects are considered. Individual manufacturing resources as well as their combinations can constitute a base for a manufacturing requirement. This is supported with the concept of requirements objects by which different resources, together or individually, can be related to a specific manufacturing requirement. The manufacturing requirements contain the statements of the requirements. Additional information can be provided as attributes or relations to other objects.

2.1 Manufacturing Knowledge and Producibility Rules

The initial steps in the system development procedure are to define [3]: the variables and requirements origin from the customers within a Customer space, the resources within a Company design space, the product variables within a Product design space, and finally to formulate the design algorithms, rules, and relations that transform customer and company variables to product variables (Figure 3).

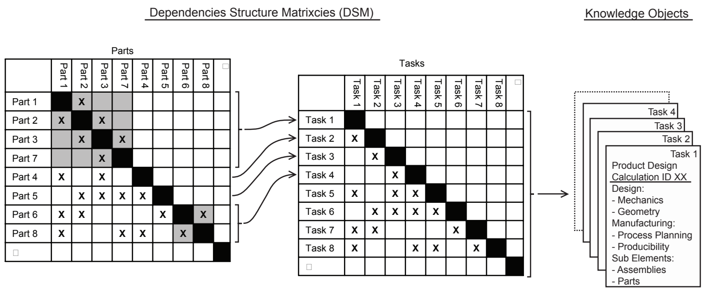

Figure 3. An analysis and a modelling of design algorithms, rules, and relations that transforms customer and company variables to product model variables results in a generic product structure. The items in this structure have to be clustered in executable knowledge objects by deploying a process view to resolve the bidirectional dependencies and/or the recursive dependencies.

The gathered knowledge of manufacturing requirements that are expressed in text has to be transformed into to executable producibility rules, i.e. numerical values, computational statements or production rules (If–Then-Else) to be incorporated in the system. The requirement can be expressed as, for example:

- a constraint that must not be violated,
- a boundary for a search space where the most optimal solution is desired,
- a parameter, working as an input to the design calculations.

The resulting statements have to be incorporated as a number of checks in analysis system (executed to control the products conformance with the manufacturing requirements) or they are intertwined with the product design calculations in a synthesis system.

2.2 Mapping of Concepts to Support Traceability

The mapping of manufacturing requirements, manufacturing resources and knowledge objects is done with the concept of requirement objects. This is completed when setting up the system for a specific product, Figure 4.

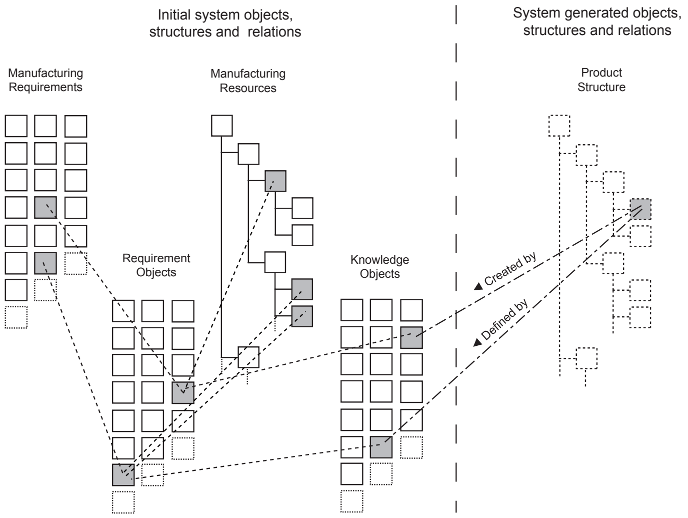

Figure 4. Initial and generated system objects, structures and relations. For the mapping of the knowledge objects to the product structure there are two solutions: explicit mappings of individual knowledge objects to related item(s), or implicit relations that are realised when the knowledge objects are executed. At system execution two relations are created; one for the creation and one for the definition of the product items

3 System Example – Car Seat Heater

The case example is taken from an ongoing research project. The project aims at setting up the principles of a system for automated layout of heating elements, Figure 5. The proposed approach, Section 2 *Modelling of Manufacturing Requirements in Design Automation*, for modelling of manufacturing requirements has been adopted when planning and setting up a first initial solution for a design automation system.

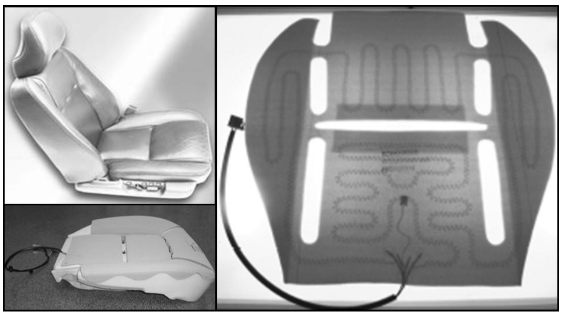

Figure 5. Upper left: a car seat with heating elements in the cushion and backrest. Lower left: a cushion element glued to the seat foam. On the right: a cushion element on a lighting table showing the heating wire with sinus formed loops, the thermostat and the connection cable beween two layers of carrier material.

3.1 Manufacturing Requirements in Case Example

The design of a heating element must conform to the manufacturing system. Examples of manufacturing requirements classified according to the types in Section 2.1 *Manufacturing knowledge and producibility rules*, are:

- No centre line radii of less than 10 mm are allowed due to the winding machine. This is a constraint that must not be violated.
- The number of turns should be minimized. The winding machine has to slow down in the turns and the processing time will increase with the number of turns. This is a boundary for a search space where the most optimal solution is desired.
- There must be a clearance of 5 mm between the element's outer boundary and the outer boundary of the heating area. The reason for this is the gluing of the lower carrier with the upper carrier. The calculation of the heated area must be based on this offset. This is a parameter working as an input to the design calculation of the heated area.

3.2 System Principles

In Figure 6, a principle system architecture for an automated system generating varant designs of the car seat heater is depicted. The purpose is to combine properties of, and functions for, knowledge execution and information management into one system.

The system is based on commercial software applications (Access and Visual Basic, by Microsoft; Mathcad, by Mathsoft; and Catia, by Dassault Systems). The scope of the system is to generate variant designs of heating elements based on different customer specifications and seat geometries. The deployment of the proposed approach will ensure access to company know-how and know-why. The objectives with the system implementation are to: cut quotation lead time, allow for evaluation of different design alternatives, quality assure the design process, capture design knowledge, and provide design documentation. The system ensures the products' producibility in existing facilities by the incorporation of producibility rules and supports traceability between production and product systems. The system will be a vital part of the company business process regarding heat elements and to ensure system longevity, maintainability, and expandability it is important to incorporate meta-knowledge about the origin of the knowledge.

4 Conclusion

The presented work provides an approach for modelling manufacturing requirements in design automation. The approach promotes the integration of properties and functions for knowledge execution and information management into one system, i.e. integration of design know-how with life-cycle related know-why. The focus in this work has been on requirements origin from manufacturing, although the presented principles are perceived as applicable to other life-cycle requirements. An expended support for requirements modelling and mapping will support different stakeholders' needs of requirement traceability and system maintenance.

The proposed approach has been adopted when planning and setting up a first solution for a design automation system. The system provides the company with opportunity to work with producibility issues in a systematic way. It can serve as a tool that enables the evaluation of different courses of action in the early stages in the development of product variants. Future work will include further system development, user tests and evaluations. Issues to be studied can be: the relation between Knowledge Objects and Product Elements, the scope and re-execution of the Knowledge Objects, how general the Knowledge Objects shall be, how to include process planning and cost estimation, how to handle implications on the knowledge base resulting from system generated product structure and process plans, and suitable execution principle (depth-first or breath-first) to be deployed.

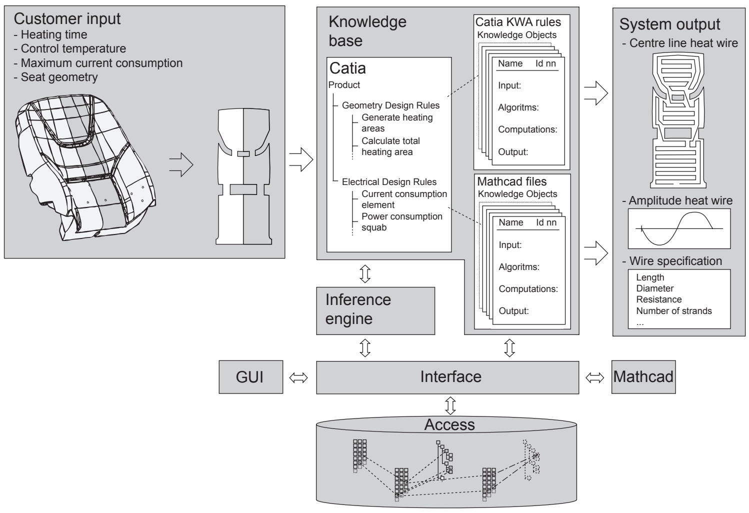

Figure 6. System architecture. The graphical user interface (GUI) and the interfaces to different software applications and databases are programmed with Visual Basic. The knowledge base comprises rules in Catia Knowledge Ware Advisor (KWA). The rules are linked (through an Access database) to different Knowledge Objects. A Knowledge Object is a database object that has a number of input parameters and output parameters. The Knowledge Objects can be of different types (e.g. Catia KWA rules, Mathcad worksheets) in which the methods of the different Knowledge Object are implemented. The rule firing, invoking the Knowledge Objects, is controlled by an inference engine, Catia KWA. The company resources with associated manufacturing requirements are stored in an Access database together with the Knowledge Objects. The product items and structure together with the two relations, Created by and Definied by, are created at runtime. The system is fed with customer specific input (parameter with associated values together with a 2D outline of the heated seat areas). The main output is the pattern for the heating wire's centre line, an amplitude factor for the sinus formed loops and the wire specification.

5 Acknowledgements

This work was conducted within the Vinnova program for “Collaborative platform and rule based product development” and financial support is gratefully acknowledged. The authors would also like to express his gratitude to Kongsberg Automotive for information and knowledge about the case of application as well as for helpful discussions.

6 References

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