

LICENTIATE THESIS

Models, methods and tools for car body development

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Licentiate thesis

Institutionen för Tillämpad fysik, maskin- och materialteknik
Avdelningen för Datorstödd maskinkonstruktion

Models, methods and tools for car body development

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May 2002

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Preface

The research presented in this licentiate thesis has been carried out at the advanced body engineering group at Volvo Car Corporation (VCC). The research has been done while enrolled at the Division of Computer Aided Design (CAD) at Luleå University of Technology. The research was initiated by VCC as part of the VCC industrial PhD program and in close co-operation with the CAD division at Luleå University of Technology. I wish to express my gratitude to my industrial supervisor Jonas Forssell, MSc and my academic supervisor Professor Lennart Karlsson for giving me support, inspiration and stimulating discussions throughout my research work. I would also like to thank the advanced body engineering group at VCC, my colleagues at the CAD-division and my co-authors.

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Gothenburg, May 2002

Nicklas Bylund

Abstract

This licentiate thesis deals with the development of complex mechanical structures, from concept to detail design, as applied to car bodies. The role of concepts has been examined and a standardised language based on three organ types (beams, joints and panels) has been made to break down and quantify concept performance. Concept selection has been addressed with care, not to impose an off-the-shelf method, but to identify the needs of the particular situation.

Efforts have been made to clarify how computer tools and analysis methods are used in product development in industry today. It has been found that the design and the analysis activities are separated. In order to speed up the development, a concurrent engineering approach is needed. This calls for integration of computer support and analysis in the development process. Based on the above findings, a new development process for car bodies has been developed, reaching from concept to detail design. An analysis tool has been developed, tailor-made according to the broken down concept performance, and necessary in the presented process. The main feature of the tool is the possibility to transfer part of the analysis from simulation experts to design engineers, thereby increasing the simulation usage in product development. The first tests of ADRIAN in an industrial environment showed that technical issues such as analysis stability and speed are satisfied, and that the target group, the design engineers without experience of analysis, found it easy and valuable to use, which is equally important. The overall purpose is to arrive at a *simulation-driven* design based on requirements broken down to local level rather than a *simulation-verified* design.

Keywords:

concept development, concept selection, detail design, supportive software, car body, engineering design

Thesis

This thesis comprises an introductory part and the following papers:

Paper A

BYLUND, N., FREDRICSON, H. AND THOMPSON, G.

A design process for complex mechanical structures using Property Based Models, with application to car bodies. In the proceedings to Design 2002 Conference, 14-17 of May 2002, Dubrovnik, Croatia.

Paper B

BYLUND, N. AND ERIKSSON, M.

Simulation Driven Car Body Development Using Property Based Models SAE paper 2001-01-3046, in proceedings to IBEC 2001. (Conference postponed to 8-12 July 2002.)

Paper C

GRANTE, C. AND BYLUND, N.

A Study of the Effects of Different System Architectures on the Development Process.
In the proceedings to Design 2002 Conference, 14-17 of May 2002, Dubrovnik, Croatia.

Paper D

BYLUND, N., SANDSTRÖM, H. AND SHAMLO, M.

ADRIAN a program for evaluating the stiffness of joints and its application in the development process.

To be submitted.

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1 Introduction

1.1 Background

To stay competitive and lead the market, a company needs to be responsive to changing customer demands and moves from their competitors, [Wheelwright and Clark 92]. This implies that product development has to be fast in order to incorporate the latest trends in the product. Therefore, in an augmenting competition, shorter development cycles leading to shorter time-to-market can be the key to gain market shares, product profit and customer satisfaction, [Wheelwright and Clark 92]. In the meantime, industry also has to work with limited budgets although product complexity and customer demands are growing. In order to obtain a successful development of products, industry must understand both the strong and the weak points in their own development processes and tools during product development [Pugh 90]. When a company has achieved these insights about their product development it is possible to formulate and propose an alternative development process leading to more successful product development.

1.2 Motivation

Designing a complex mechanical structure involves a chain of activities that have to be mastered, such as requirement breakdown, concept development, concept selection and detail design. Development lead-time and product performance are strongly affected by success in each of these phases. A multitude of tools for designing geometry in both 2D and 3D has existed for several years and a wide range of analysis tools for simulating mechanical performance also exists. Even with these tools, the design and verification of a structure such as a car body takes a long time, while demands for shorter lead-time and higher performance keeps rising. A more concurrent design process is therefore called for, with better coupling between design and simulation.

1.3 Vision

The vision is to create a robust development process for complex mechanical structures and apply it to car body development. Development is done faster and at the same time enhancing the possibility to introduce new technology. The process contains guidelines, experimental methods and supportive software. The development process is dealt with from requirements to detail design. Concept selection is addressed with the aim to get acceptance throughout the organisation. The focus lies on supporting the drafter/design engineer with low level requirements and easy-to-use tools to check if the requirements are fulfilled. Changes in the requirements are handled rapidly and economically. Knowledge from competitor analysis and earlier in-house projects is automatically available as a reference during the concept phase and further on during the detail design phase.

2 Corporate context

The work resulting in this thesis has been done in close collaboration with industry. The main part of the research has been done at Volvo Car Corporation in Gothenburg, Sweden. Contact has also been made with other companies in the Ford Motor Company, especially with Ford in Detroit, USA and Ford in Cologne, Germany.

Some common tendencies are seen through the automotive industry. Car bodies consist of sheet metal stampings of fairly complex geometry that for the most part are spot-welded together, see

figure 1. The design of these structures is done by teams of design engineers, each focussing on different areas of the car body. The design engineers are specialised in modelling the geometry with CAD tools, trying to fulfil the numerous structural, manufacturing and aesthetic requirements. While the teams working with aspects of manufacturing are co-located with the design engineers the analysis teams are not. In the development of mechanical structures a lot of effort has been put into making the software for representing geometry more efficient, both in 2D and in 3D, in CATIA, IDEAS and Pro Engineer to mention three examples. In parallel analysis, software for calculating the mechanical behaviour has been developed, eg, Nastran, Radioss and Mark. The design engineer in the automotive industry normally has a background as a drafter: See [Ullman 90] for a definition of drafter. He is an expert in designing the complex geometry of a car body, using CAD software. The geometry thus created is handed over to analysts who then use analysis software. The design engineer therefore works with little input and is not able to evaluate his design. Using analysis in late design phases merely serves as a check not as support for design. No established guidelines for concept selection exist and methods are used sporadically.

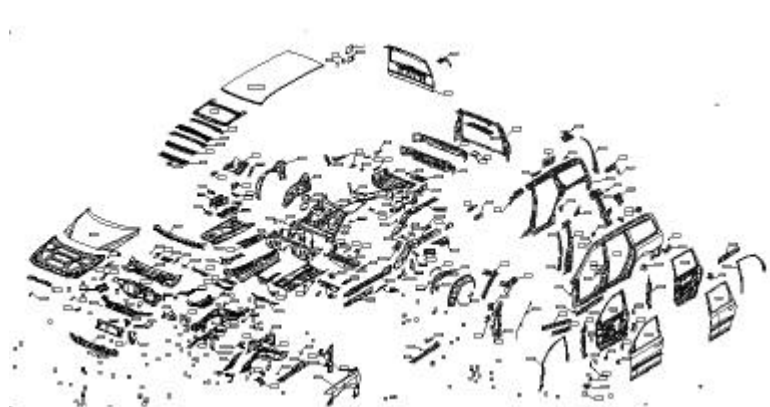


Figure 1. Sheet metal stampings of a car body.

3 Knowledge domains

The knowledge domains presented in this chapter constitute the foundation for the research done so far.

3.1 Product development

Product development is defined [Ulrich and Eppinger] as:

The set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product.

Thus product development could be seen as a whole business case. The actual design of a product is called strict development by [Roozenburg and Eekels 95]. The work leading to this thesis has been concentrated on strict development.

3.2 Design research

The aim of design research has been formulated as follows by Blessing et al [Blessing, Chakrabarti and Wallace, 98] :

The aim of engineering design research is to support industry by developing knowledge, methods and tools which can improve the chances of producing a successful product.

Focusing the research only to products is not enough to fulfil the aim above, because design is not only a technical process but also a social process with relations between individuals and organisations, [Minneman 91]. Design research is therefore multi-disciplinary. Design involves numerous factors including people, products, tools and organisations. Each of these factors has its research tradition and methodology: in social, engineering, computer and management sciences. The second and third factors mentioned are issues normally treated in engineering while the first and last are not, making design research reaching beyond the traditional engineering scope. This thesis dissertation concentrates on traditional engineering domains, but during the development of software tools issues such as man-machine interactions have been addressed.

3.3 Concurrent engineering

For product development to be successful, the production process has to be anticipated already during the design phase. Ullman [Ulman 97] describes this as concurrent design, where the function of a product relates to the following three elements: shape, material and production. Each of these elements has its stakeholders. Shape is represented by the engineering designer struggling to get the latest look and the structural engineer struggling to get the most mechanically efficient design. The structural engineer also strives to get strong high-end materials while the production engineer focus on the possibility to manufacture the product in the least expensive way. In this thesis the word concurrent is also used to describe a simultaneous design and analysis activity.

3.4 Concept development

When a new product is to be designed several different solutions are often possible, which can be embodied in concepts. A concept is an early representation of a product, incorporating only a minimum of details; just enough to show the main characteristics of the product, or, according to Thompson, [Thompson 99]:

A concept defines and describes the principles and engineering features of a system, machine or component which is feasible and which has the potential to fulfil all the essential design requirements.

A concept is thus faster and cheaper to develop and change than the final product design.

3.5 Concept selection

When a multitude of concepts are developed, the concept that best achieves the requirements has to be chosen. This process is called concept selection. Many different selection methods exist and many of them are matrix based, such as the paired comparison matrix, [Isaksen, Dorval and Treffinger 94] and [Pugh 90]. Some weigh the requirements according to their relative importance, as in the concept scoring method by [Ulrich and Eppinger 95]. Roozenburg and Eekels have compiled and explained a great range of selection methods in [Roozenburg and Eekels 95]. The importance of concept selection resides in the fact that for a large project returning to the concept stage after the detail design stage has been launched is often unfeasible and the characteristics and performances of a product are already determined by the concept, [Thompson 99].

3.6 Product models

On a high/global level a product can be represented as a prototype defined as an approximation of the product along one or more dimensions of interest [Ulrich and Eppinger 95]. Each dimension puts forwards one characteristic of the product. Prototypes can be both physical and virtual. A virtual prototype can be a 3D drawing where surfaces and light sources are natural-like and furthermore it could be moveable in space. Prototypes can also be of analytical character and in the case of a mechanical product, permitting simulation of their mechanical behaviour. A concept is an early form of product model where the main characteristics are represented.

Early in the development process, concepts have to be modelled in an efficient way independent of detail solution, so as not to bias the detail solution. [Thompson 99] To handle this, Hubka et al, [Hubka, Andreasen and Eder 88] use organs. These represent functional implementation in products, although they are not detail designed. Organs are often called function carriers, expressing how the system realises its functions. In other words, if a product needs a defined stiffness in some direction, a spring organ can be used in the concept. The organ representation leaves the decision to detail design whether a leaf spring or a cylindrical spring or some other spring type is to be used. In this thesis organs are used to build up product models for concepts.

3.7 Product architecture

The type of interaction between organs [Hubka, Andreasen and Eder 88] or chunks [Ulrich and Eppinger 95] results in different product architectures. The main two product architectures are the integrated and the distributed. [Ulrich and Eppinger 95] The product architecture affects the development process and the possibility to upgrade a product. An integrated architecture needs more iterations during its development than a distributed architecture and is more difficult to upgrade. The structures focused in this thesis is of integrated nature.

3.8 Detail design

A good concept is a necessary but not sufficient condition to ensure a successful product. While the concept limits the maximum achievable performance of a product, the detail design decides the actual performance. For example, if an aeroplane is to be designed and the concept is a traditional propeller driven aeroplane it will not be able to travel in the vicinity of or faster than the speed of sound due to the aerodynamic properties of a propeller. The actual aeroplane designed from the concept will thus travel at some velocity lower than sound, no matter how the propeller is designed in detail. As described earlier, current software for this phase are mostly focused on geometric descriptions, e.g. CATIA and I-DEAS.

4 Problem formulation

4.1 Research question

How to develop, compare and evaluate new mechanical structure technologies for car bodies?

4.2 Research approach

To handle the multidisciplinary nature of design research, Blessing et al propose a research methodology for design research, [Blessing, Chakrabrit and Wallace 98]. The methodology contains the four steps: Criteria, Description I, Prescription and Description II. See Figure 2.

The Criteria are a measure of success; the problem is analysed in Description I; a solution is proposed in Prescription; and the proposed solution is evaluated with respect to the initial criteria in

Description II. The methodology stresses, especially, the importance of both descriptive and prescriptive steps, as well as measurable criteria. The studies presented in this thesis have been performed in industry as exploratory research. As Blessing et al state, due to the time available, it is hard to go through the whole loop all the way to description II in one project, this licentiate thesis reaches the Prescription stage

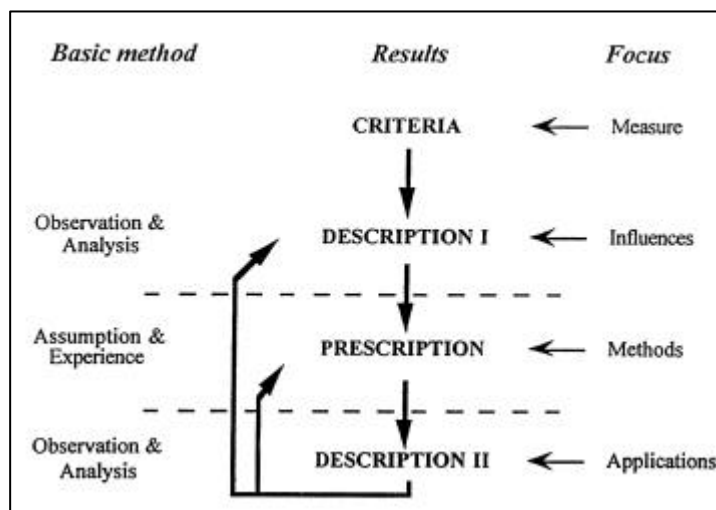


Figure 2. A design research approach, according to Blessing et al.

4.3 Industrial importance

The possibilities and advantages of computer aided simulation of mechanical structures together with structured concept development and concept selection are not fully exploited in industry today. Achieving a more efficient concept treatment and simulation process will enhance a more fair evaluation of innovative concepts leading to better exploration of the solution space. More alternative solutions augment the chances of designing a competitive product. Providing design engineers with appropriate tools and methods reduces lead-time by permitting a more *simulation-driven* development process.

4.4 Academic importance

The descriptive and the prescriptive parts of this thesis develop knowledge about how concepts and concept selection can be made to give optimal support to the detail design. In addition, an identification is made of when the impact is greatest in using an analysis tool in the development process of structures. Finally, experience is gained of the possibilities and difficulties when introducing a new development process and corresponding tools in a company's product development.

5 Design of complex mechanical structures

The design process for complex mechanical structures is considered from the conceptual phase to detail design. The requirements for the design are multi-objective and take the form of weight, stiffness, manufacturing, etc., but the requirements are also not fixed and may change. Therefore, the design process must be flexible to allow for such changes. A car body, see figure 3, encompasses all the above considerations. There is a well-established history of car design and manufacture, and traditional methods have a strong influence on current practices. The design

process described aims to reduce lead times and not exclude innovative solutions. Shortened lead times may well be achieved by reducing the analysis time required for iterative changes during detail design. See [Paper A, Bylund, Fredricson and Thompson 02].

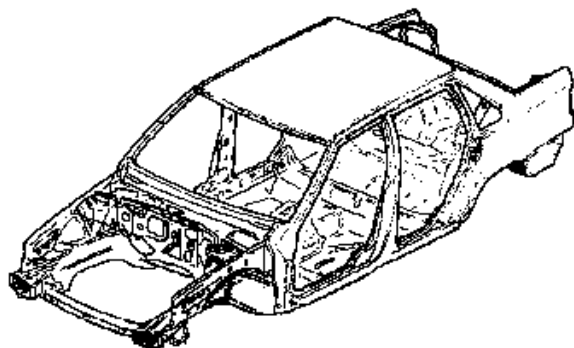


Figure3. Car body

In the automotive industry, a limited number of experienced senior engineers and Finite Element Method (FEM) analysts perform the concept development of car bodies. The concept development can be supported by special design and analysis tools such as SFE-concept and DART, [Zimmer et al 00] and [Chapman and Pinfold 01]. The detail design of a car body is done by design engineers striving to meet a series of requirements including cost, stiffness, durability, strength, manufacturing and aesthetics. The detail design engineer must thus achieve a design that fulfils these requirements, but until now few analysis tools have been made with the aim to help the design engineer check their design against mechanical requirements. The design engineer does not have the time to use general-purpose software such as Nastran or Radioss. Tools exist for the concept development stage, e.g. SFE and DART and for the analysis of the mechanical behaviour of a complete car body, e.g. Nastran, Radioss and Marc. A need has been found for new tools supporting the design engineer in making an approximate analysis of their detail design together with methods to use them.

5.1 Description

The following shortcomings can be identified in the design process currently used.

- Innovative concepts, e.g. ones that use radically different materials or configurations, are often ruled out early. No formalised concept selection process is used.
- Knowledge gained by benchmarking is not used quantitatively.
- Mechanical requirements from the concept are *not* broken down to a level that corresponds to the local design areas. This makes design a trial and error activity, in which the check against global requirements is not done until a complete car body model is finished. This leads to many costly late redesigns during the detail design.
- Late changes in requirements lead to expensive time-consuming redesign activities during the detail design phase.
- Lessons learned from earlier designs are not stored in a person independent way.

5.2 Prescription

To fulfil the criteria, shorten development lead-time whilst not ruling out new types of design solutions, the following have been found:

- Each concept should be represented in the same language by a property based model (PBM) and be of the same level of maturity to permit fair concept selection.
- Using the same metrics when analysing competitors makes benchmarking more efficient, e.g. competitors' performance can be quantified.
- Concept selection must gain acceptance throughout the organisation. Therefore, methods that blindly total up positive and negative features to get an overall score are dangerous.
- The concept model should permit breakdown of requirements into a local level to give design engineers local requirements for their design area.
- Design engineers should be given easy-to-use analysis tools to check if their design fulfils the local requirements. This reduces the need of costly analysis loops at complete car body level, and enhances small parallel/concurrent iterations.
- When design engineers use analysis tools themselves, more design alternatives can be tested in a shorter time and the features from the concept model are *not* lost on the way to detail design.
- To use the capabilities of a concept thoroughly, it should live in parallel with detail design because the feasibility and cost of late unpredicted changes in global requirements can be evaluated more easily on the concept model than the detailed model. To make a parametric concept model is therefore valuable. It can be scaled to confront a broad range of changes in requirements, and is thus an adaptive concept model.
- A library of earlier designs should be made, thus enhancing a learning organisation.

5.3 The use of a Property Based Model, (PBM).

Figure 4 shows the design process that is the subject of the present research. It can be seen that the starting point for all projects is a set of requirements (mass, structural integrity, etc.) [Fenton 96]. A Property Based Model (PBM), [Paper B, Bylund and Eriksson 01], is built up for each concept, and represents the mechanical and spatial properties of the body concept. The PBM is constructed from organs, [Hubka, Andreasen and Eder 88], which represent requirements at a local level. The chosen organs for the car body are beams, joints and panels, [Paper B, Bylund and Eriksson]. In the build up and break down activity, the PBM models for new designs and existing competitors' designs are generated by in-house design teams. A library of organs is used to generate PBM models efficiently. Typical elements are beam cross-sections and joint properties. Each project generates new organs creating an extensive knowledge bank. Such a bank is a resource of expertise, and knowledge is thus readily transferred and the design process is not dependent on particular individuals and their subjective value judgements [Paper A, Bylund, Fredricson and Thompson 02].

An optimisation procedure is used to normalise the alternative concept PBM models with respect to key global requirements, e.g. global stiffness, weight, crash worthiness, etc. The normalisation assures that all concepts are on the same level of maturity. For example, a new innovative concept should not just show a fraction of its performance while an old well-known technology results in a concept close to its maximum performance. The results of the procedure are used as the basis for evaluation of the concepts. The PBM that best fits the quantitative and qualitative criteria is selected. This is a decisive aspect of the design process and is not left to the numerical outcome of any particular design evaluation method. The selection involves the decision-making processes within the company as a whole, and it is important that all relevant parties contribute to, and accept, the outcome of evaluation.

The selected PBM contains all the properties of the model at the organ level. These properties are the guidelines for the detail design engineers. During the detail design phase, the designer is thus provided with requirements at organ level. The detail design engineer is supported by easy-to-use computational tools, [Paper D, Bylund, Sandström and Shamlo 02] to check if his design fulfils the local criteria. In addition, he/she can use particular solutions from earlier designs stored in a library. Local changes required at the later stages of design can be considered objectively by the detail designer. The changes can be tested against the solution requirements (stiffness of the organs, etc.) and if the requirements remain satisfied, then the change can be met.

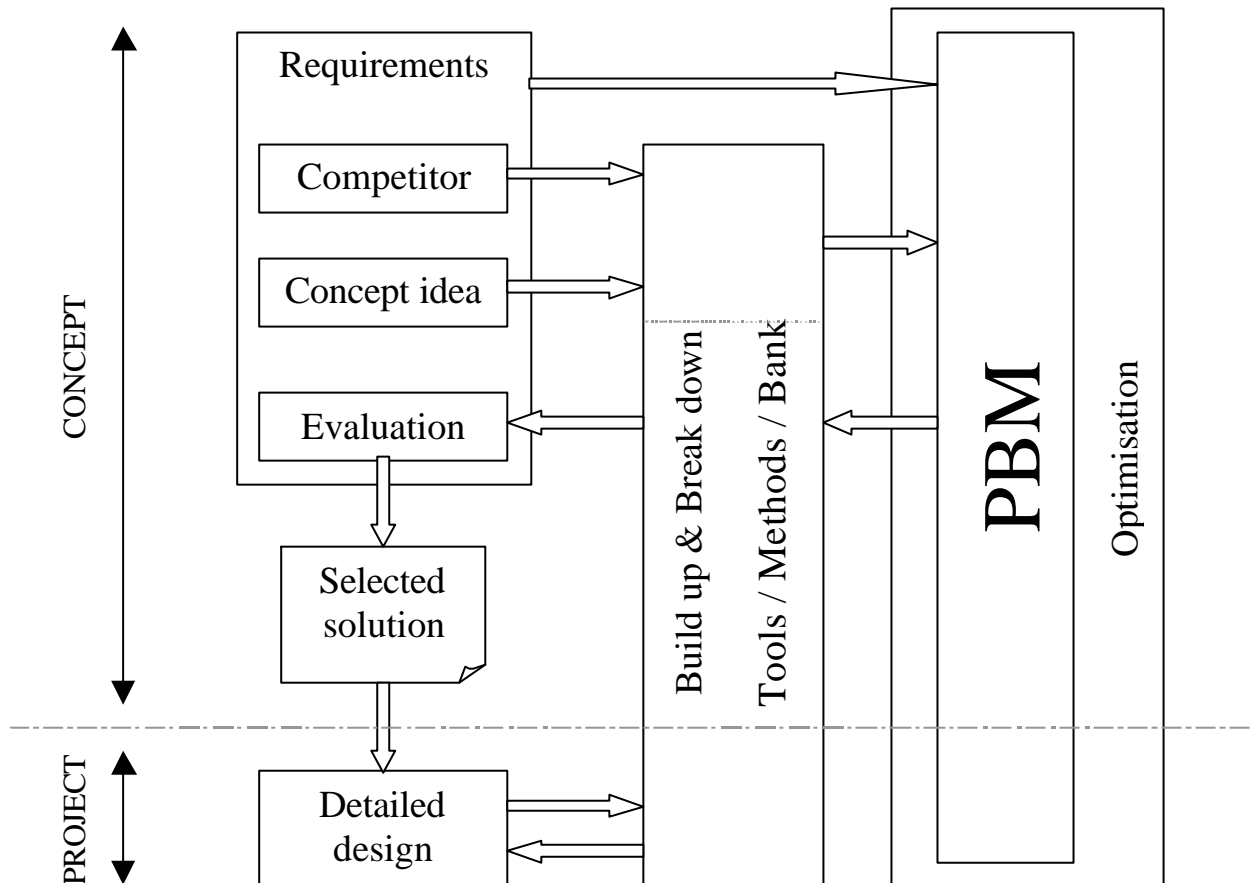


Figure 4. PBM based process for design of complex mechanical structures.

5.4 Status of analysis software supporting the proposed development process during concept development

In order to build a PBM concept model and break down the global requirements on the structure, to a local level, any general-purpose FEM tool could be used. But to fully exploit the possibilities of PBM formulation at the concept stage, the preference is for tools permitting fast-parameterised geometry development with the possibility of automatic re-meshing, such as in SFE-Concept [Zimmer et al 00] or DART [Chapman and Pinfold 01], and the possibility of optimising the performance of the organs with respect to global criteria, as in STRUCTOPT, [Harald et al 02]. Optimising all concept PBMs puts them on the same level of maturity, enhancing a fair concept selection, see section 5.3. STRUCTOPT works with gradient based methods and makes topological

optimisation, e.g. deletes organs that do not contribute to the overall performance. The software is still in the development stage and so far handles beams and joints in the linear domain. Target cascading is an optimisation method in which requirements or targets at different levels of detail are related. Furthermore, mixing of different types of requirements is permitted [Michelena et al 01]. The optimisation routines in target cascading can be both gradient based and non-gradient based permitting both continuous and discrete variables.

5.5 Status of analysis software supporting the design engineer during detail design

As stated in the presented process, the design engineers should be able to analyse the performance of their detail design and compare it with the local requirements from the PBM. Furthermore, relative analysis is valuable, where the results of a change in design can be quantified, e.g. a change of gauge or access holes. Tools for enhancing these analyses have to be integrated with the CAD-tool used in the detail design and developed with the needs of the design engineer in focus, [Paper D, Bylund Sandström and Shamlo 02] and [Lundgren and Johansson 01], see figure 5. As a part of this thesis a tool for analysing the stiffness of automotive joints, called ADRIAN, has been developed [Paper D, Bylund Sandström and Shamlo 02] and is being introduced at Volvo Car Corporation.

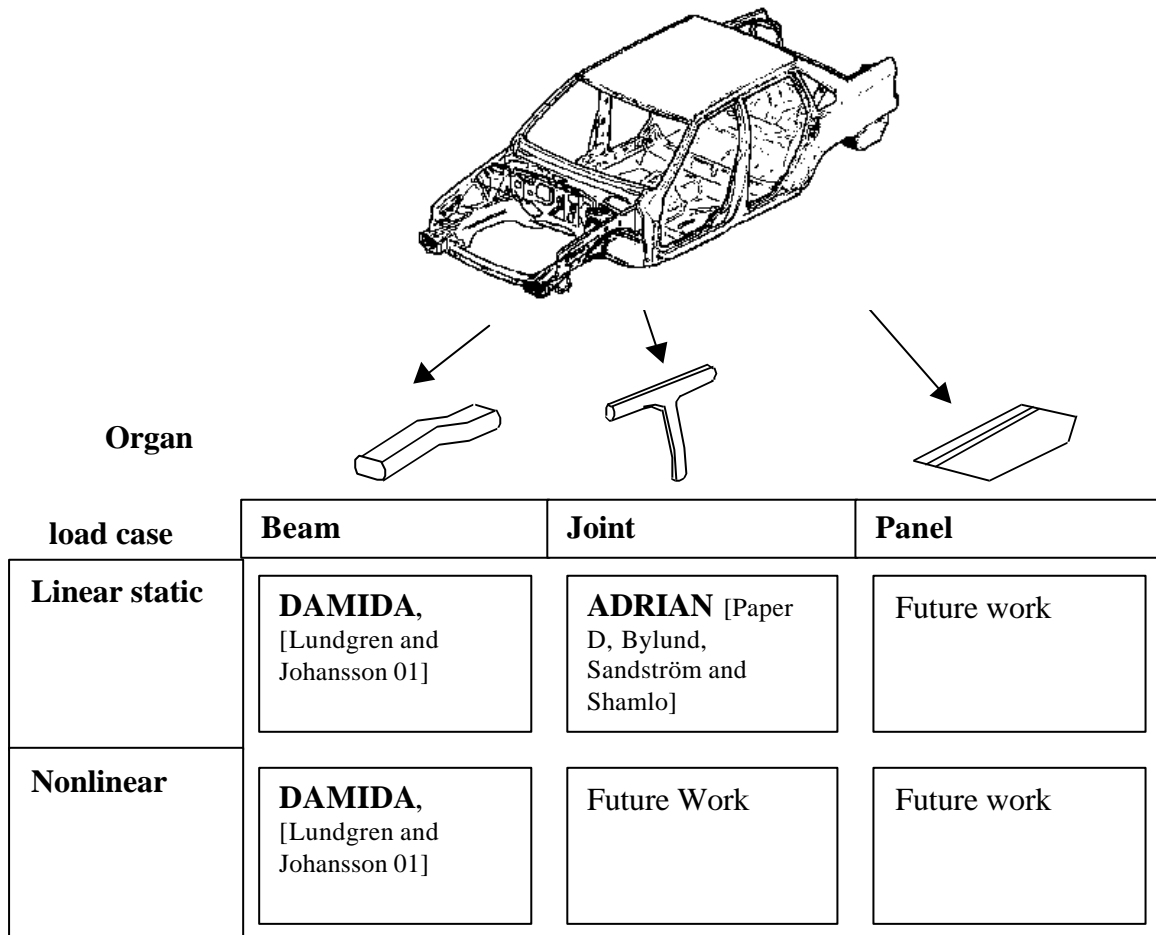


Figure 5. Status of analysis software supporting the design engineer.

5.6 Introduction in industry

When introducing new methods and tools into the industry, ownership, usage and maintenance are the corner stones. The ownership of a software has to be clear; if the software is also used by other parties than the owners a clear strategy for cost sharing has to be developed. Maintenance of a tool is needed to cater for changes in versions of software. Allocating time and money for maintenance right at the start assures a problem-free usage in the future. The introduction of new methods may invoke other ways of work division than have traditionally been used.

6 Discussion of appended papers

Four papers, A-D, have been included in this licentiate thesis. The first paper, *A design process for complex mechanical structures using Property Based Models, with application to car bodies*, is the backbone of this thesis and describes the design process made for reaching the vision, presented in section 5, see also 1.3. The second paper, *Simulation Driven Car Body Development Using Property Based Models*, describes the concept of Property Based Models (PBM) more in depth, with some examples. The third paper, *A Study of the effects of different system architectures on the development process*, is of a theoretical nature and address the role of different product architectures in design. Finally the fourth paper, *ADRIAN a program for evaluating the stiffness of joints and its application in the development process*, describes ADRIAN, one of the programs , for enhancing the design process proposed in the first two papers.

Paper	Method	Application	Theory
A	x	x	
B	x	x	
C			x
D		x	

Figure 6. The focus of the papers.

6.1 Paper A

BYLUND, N., FREDRICSON, H. AND THOMPSON, G.

A design process for complex mechanical structures using Property Based Models, with application to car bodies. In the proceedings to Design 2002 Conference, 14-17 May 2002, Dubrovnik, Croatia.

The paper proposes a method on how to handle development of complex mechanical structures, intended to fulfil the vision presented in section 1.3.

The design of complex mechanical structures is multi-objective and includes the treatments of a wide range of requirements such as quantitative, qualitative, subjective and objective. An example of this type of structure is a car body, where design has a long tradition from which valuable experience can be drawn. However, fixation to old practices has to be avoided. The design process described in the paper aims to reduce lead-time while not excluding innovative solutions. By representing all concepts on a common base as a property based model and use optimisation, an

objective analysis can be done early, thereby only viable concepts will emerge for further selection. The data gained in early phases is used as input to detail design, reducing iterations.

The idea of breaking down both concepts and competitors to organ level makes comparison easy while quantities are of the same type. Using the same tools for breakdown as in build-up (embodiment design) and detail design creates an efficient and self-learning organisation. Concepts not meeting quantitative mechanical requirements after optimisation are rejected; thus only viable concepts need to be considered during concept selection. Qualitative criteria can thus be considered deeper in the selection.

Concept selection processes using paired comparison analysis are not without problems. In order to end up with a concept that is accepted throughout the organisation, it is important not to let some bad aspects be compensated by some other very good aspects. Another way to take decisions is called for.

8.2 Paper B

BYLUND, N. AND ERIKSSON, M.

Simulation Driven Car Body Development Using Property Based Models SAE paper 2001-01-3046, in proceedings to IBEC 2001. (Conference postponed to 8-12 July 2002.)

In order to efficiently develop and evaluate a concept, and finally incorporate the concept features into final products, concepts have to be represented in a common language. The conceptual design is broken down to a numerical PBM representing the mechanical behaviour of the concept. In PBM, the local properties are balanced to fulfil the global stiffness requirements. The main topology is defined and the structural components, i.e. joints, beams and sheets are connected in predefined nodes and represented in a finite element (FE) model as super elements, beam elements and thin shell elements. In the realisation of the car structure, the performance of the PBM components are used as requirements in the detailed design. Different technologies, materials and manufacturing processes can be considered as long as the properties of the component agree with the ones stated by the PBM. Design engineers make the detailed design of each component, supported by easy-to-use single purpose tools. They iterate the design until only a specified difference between target and component performance exists.

Earlier tools for evaluation of mechanical properties have been developed mostly for the concept phase and the final verification phase; thus only for specialists in solid mechanics and FEM, working before or after the design engineer in the development chain. The design engineer, usually with a background as a draftsman, has until now been left without tools to check their results. The advantage of the proposed method is that the design engineer can self-check their design against the mechanical requirements stated by the PBM, supported by simple and quick tools and standard procedure. Therefore, this method has the potential to reduce the number of costly and time-consuming simulations of the detailed vehicle model. By continuously updating the PBM, it can be used as a quick test bench in the design process. And thus show the impact of late changes.

6.2 Paper C

GRANTE, C. AND BYLUND, N.

A Study of the Effects of Different System Architectures on the Development Process.

In the proceedings to Design 2002 Conference, 14-17 May 2002, Dubrovnik, Croatia.

In paper B, a Property Based Model (PBM) was developed to represent a car body in a common language. In this paper the effect of different product architectures on the development process is presented.

To minimise development costs and time, different system architectures require different development processes. Three types of system architecture are identified using Design Structure matrices (DSM): integrated, distributed and mixed (Partly integrated and partly distributed.) It is shown that the type of interface defines the type of architecture.

Integrated systems are characterized by their complex and un-defined interfaces, which couple them together tightly making their global performance dependent on sensible interaction between their components, leading to the need of an iterative design process. In the car body example, components interact spatially with each other and forces are transferred between them, creating deflections and at high force levels, e.g. in a crash situation the components deform plastically and new spatial interactions are created, which have to be managed adequately. Re-designing a component is therefore a complex task; all the interactions have to be respected if the overall performance is to be preserved.

Distributed systems, on the other hand, are characterized by their well-defined interfaces, coupling them together in a more predictable way. In the example, active systems with components such as sensors, actuators and data boxes interact with well-defined standardized interfaces. Spatial interactions seldom occur between sub-systems. Therefore, changes in a distributed system are relatively easy: As long as the interfaces are respected the design freedom is huge.

Many systems are a mix of integrated and distributed architectures, as, for example, the chassis system. These systems are built from clusters of interacting components that are coupled by interfaces giving mostly sequential design tasks but sometimes also parallel, although each individual sub-system or component cluster includes an iterative design loop.

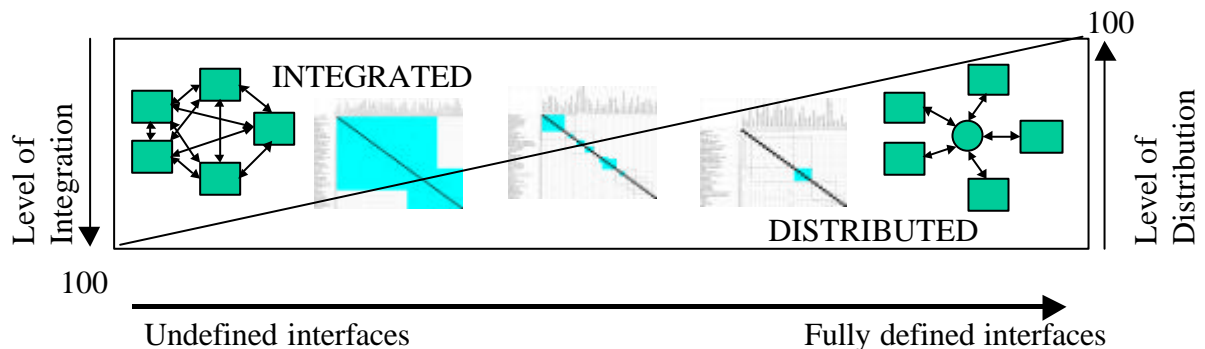


Figure 7. Relation between level of interface definition and level of distribution and integration.

Development costs rise faster with the rise in the number of components for an integrated system than for a distributed system; for products made of many components the difference in development costs can be significant.

6.3 Paper D

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ADRIAN a program for evaluating the stiffness of joints and its application in the development process.

The development process proposed in papers A and B, based on the use of a PBM, specifies easy-to-use single purpose tools to check the mechanical performance of the PBM's organs during both concept development and detail design. This paper specifies how to evaluate the mechanical behaviour of the joint organ, one of the organs used in the PBM. It also presents a single purpose easy-to-use tool, ADRIAN, developed for integration with the CAD tool used at Volvo Car Corporation. ADRIAN requires a minimum of experience with analysis for beginners while permitting advanced users to override default values in making more advanced analyses.

Development of complex mechanical structures such as car bodies is an iterative process between design and analysis. In car body development these two stages are done in different departments, making the loops between design and analysis slow and costly. One way of speeding up the development process is to make these loops smaller and thereby faster. By letting the design engineer/drafter can make preliminary mechanical analysis them self. This not only makes design loops smaller, but they can also be made in parallel thereby speeding up the development process while at the same time exploring more solution alternatives. To support this development process, two easy-to-use tools have been made, one of which, ADRIAN, is presented in this article. The first tests of ADRIAN in an industrial environment showed that technical issues such as analysis stability and speed are satisfied, and that the target group, the design engineers without experience of analysis, found it easy and valuable to use, which is equally important. With ADRIAN, two design alternatives for a joint were examined in a fraction of the time necessary using general-purpose finite element tools. The strategy to put most of the user interaction in the CAD environment was shown to be correct.

The combined use of the superelement method and the presented dynamic joint method completes earlier methods. Especially when the geometry of a joint makes it difficult to find a unique centre. Furthermore, the dynamic joint method has an experimental counterpart enhancing the use of quantitative benchmarking of competitors' joints.

The joint stiffness values presented in the HTML page permits comparison with local requirements, and the eigenmodes shown in ANIMATOR show weak areas in the design. The basic usage of ADRIAN can be learnt in a short time by any design engineer. Furthermore, putting the analysis results on an HTML page facilitates communication of the results. A pilot study of ADRIAN in the design process has been launched at VCC with a restricted number of design engineers. The result of this study will serve as input for a full introduction of the software.

The joint evaluation program, ADRIAN, together with the beam evaluation program, DAMIDA, comprise an efficient toolbox for car body development during the detail design stage.

7 Conclusions

The objective of this research has been to develop methods and tools for development of complex mechanical structures from concept to detail design as applied to car bodies.

It has been found that in the industry today design and analysis activities are separated in the product development. A process has been developed to integrate computer support and analysis in the development process, thus speeding it up. The importance of concepts is addressed and a standardised language based on three organ types (beams, joints and panels) has been made to break down and quantify concept performances. Concept selection has been addressed with care not to impose an off-the-shelf method, but to identify the needs of the particular situation. To achieve a fair concept selection process, all concepts are put on the same level of maturity with the aid of optimisation.

An analysis tool has been developed, tailor made according to broken down concept performance (organs) and enhancing the presented process. The main feature of the tool is the possibility to move part of the analysis from simulation experts to design engineers, thereby increasing simulation usage in product development. The first test of the developed tool has been successful; the targeted user found it easy to use. The overall purpose is to arrive at a *simulation-driven* design, based on requirements broken down to local level rather than a *simulation-verified* design.

8 Future work

8.1 Joint measurements

An experimental method supporting the joint element in the product model is under development and will be further examined in the future. It is a dynamic method for joint stiffness evaluation.

8.2 Improved concept selection

The concept selection will be treated in more depth and requirement breakdown with target cascading is under discussion.

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