PROSPECTS AND BARRIERS FOR UP-FRONT CAE-SIMULATION IN THE AUTOMOTIVE DEVELOPMENT

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SUMMARY

The European Commission funded project *AutoSIM* focuses on the identification of the best practicing and breakthrough technologies to support the European automotive industry. This three year project is coordinated by NAFEMS, the International Association for the Engineering Analysis Community. The author of this article holds the role of the technology leadership steering the project aim to identify the most promising potential breakthrough technologies of the future for the integration of simulation into the automotive development process.

Breakthrough technologies in the context of AutoSIM project are *novel or revolutionary technologies and procedures required to offer successful solutions to solve the engineering problems in the coming century*.

The project consortium – representatives of 32 Europe's leading automotive companies – was defining important technology topics with potential to become breakthrough technologies.

After a brief introduction of topics which will battle challenges as forthcoming basic tendencies for CAE-simulation within the next years, some priorities for integration of CAE-simulation into the development process will picked out and are discussed in detail. Especially the early concept and layout phases in the product development process will be discussed in this context. The reason is seen that from today's point of view several particular bottlenecks are evident during these phases.

The purpose of these remarks is to address to the most effective methods, tools and techniques to support the integration of analysis into the development process in early phases the reader. Furthermore an elaboration of essential and specific consolidated terms and concepts is visualised.

In connection with the description of the priorities, which can be localised on account of available bottlenecks at the same time, technological as well as organizational and methodical barriers become recognizable.

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Based on significant examples it is clarified which tools and methods, under the criterion of the mentioned prioritized topics, were either implemented sketchy or insufficiently depending on todays organizational lacks.

This manuscript offers therefore a concept for overcoming several of these uncovered barriers. Derived possibilities are indicator for whether to be able to close the gap to breakthrough technologies for the integration of CAE-simulation into the automotive development process with sustainable effects.

KEYWORDS

Computer-aided design process, data management, front-loading, integration of analysis, numerical simulations, simulation and modelling, upfront simulation

1: Motivation and Research Approach

Shortening of product life cycle, increasing cost pressure in the global competition and the heterogeneity of computer-aided development systems are determining the trends of today's automotive development. Steadily rising complexity of products, walking along with the product-related augmentation of information and the increasing variant variety by individualisation can be controlled – from view of the leading car manufacturers – only by improved computer-aided engineering (CAE) tools and methods, which forecast the product behaviour even earlier and even more exactly in the future.

This approach can be summarised by the notion *Upfront Simulation*. Within the large topic the European Commission funded project *AutoSIM* focuses on the identification of the best practicing and breakthrough technologies.

2: Basic Definitions and Generic Product Development Process

<u>Up-front Simulation</u>: Following the mind of Front-Loading as *a strategy that seeks to reduce development time and cost by shifting the identification and solving of (design) problems to earlier phases of product development* [12], Up-front simulation is a methodology in context of CAE driven concept design and decision making process.

<u>Virtual Prototype</u>: A virtual prototype is based on a digital model. *Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping* [13].

In addition to this virtual prototyping is a product validation method to reduce the number of physical prototypes.

A general concept of the generic product development process is shown in Figure 1.

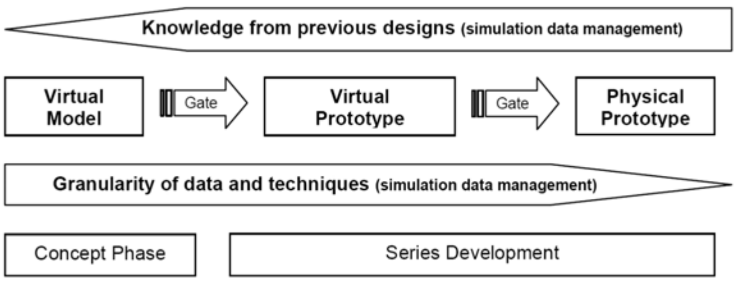

Figure 1: General concept of the generic product development process

3: State of the Art Topics

In the course of the 1st AutoSIM Technology Workshop in January, 2006 the approach of a questionnaire was suggested. In context of *integration of simulation into the automotive development process* (INTEGRATION) a list of significant topics was produced by the technology leaders of the project. All project members were invited to prioritise these questionnaire topics by

- State of Practice (SoP) gives a measure of industrial maturity,
- Technological Readiness level (TRL) indicates the state of the art or technological maturity and
- Priority Level Index (PLI) indicates the relevance for industry.

This questionnaire produced some useful results. Figure 2 gives a short explanation how to read the result interpretations of the questionnaire topics.

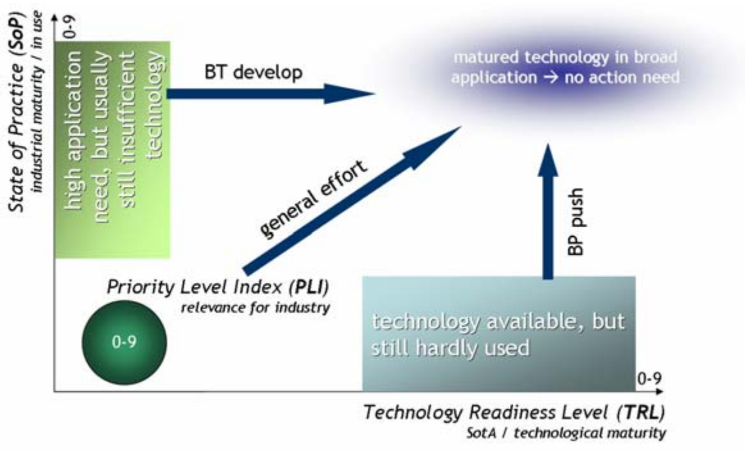

Figure 2: General grading of the survey results from questionnaires

The following figures 3-5 gives an overview about the significant topics which were mentioned in the answers of the questionnaire.

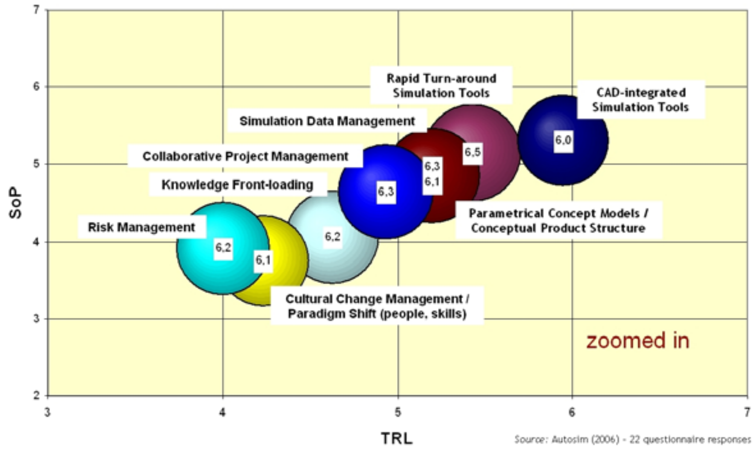

Figure 3: **Portfolio of Upfront Simulation topics with PLI ≥ 6**

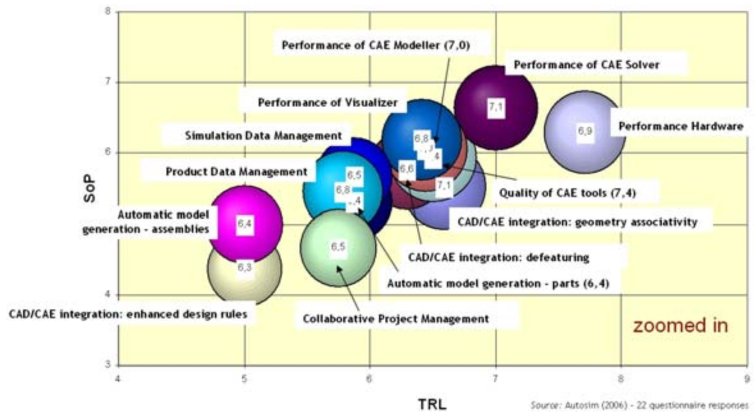

Figure 4: **Portfolio of Virtual Prototype topics with PLI ≥ 6**

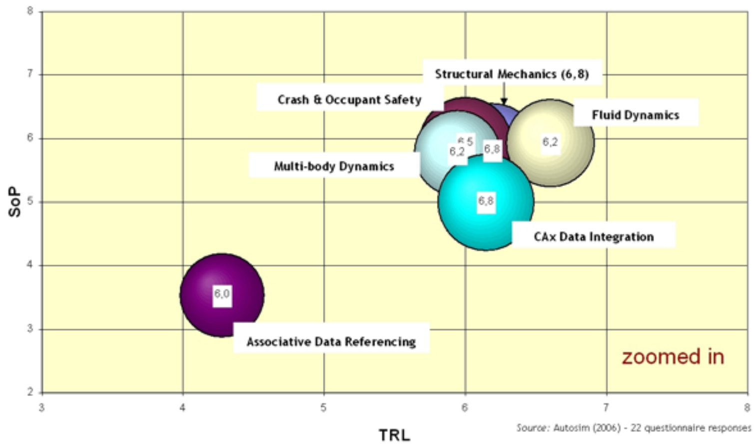

Figure 5: **Portfolio of Multi-systems Integration topics with PLI ≥ 6**

These INTEGRATION topics with a PLI more than 6 are representing a more or less significant tendency by a comparatively small number of questionnaire responses. There was a common agreement that 22 responses could not be significant enough to fix relevant topics without a wider discussion started at the 2nd AutoSIM Technology Workshop in May, 2006.

As a consensual result of this project consultation process all INTEGRATION involved project members decided that there are five significant topics to have the potential to become breakthrough technologies.

4: Breakthrough Technologies for Integration of Simulation into the Automotive Development Process

4.1: <u>Conceptual simulation models</u>

Conceptual Simulation Model is an umbrella term for terms like symbolic CAE, design grammars, parametric models, etc. Common background of these terms is that they are describing methods and models in the fuzzy front-end or conceptual pre-design phase (Figure 6).

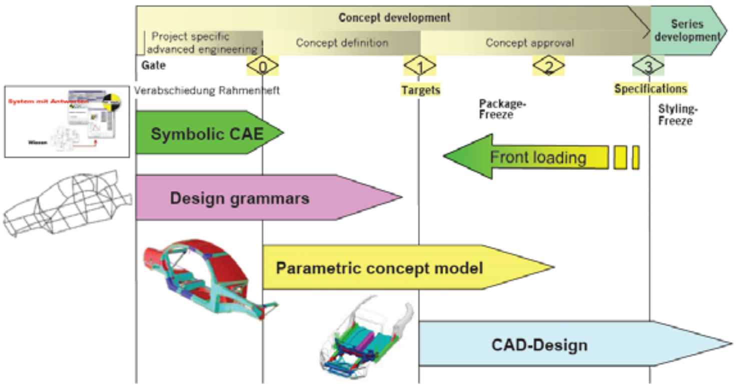

Figure 6: Conceptual Design Process [Source: Schelkle, AutoSIM, 2006]

Symbolic Computer Aided Engineering (SCAE) tools make possible the execution of feasibility and principle studies and the estimation of model influences and optimization tasks in the following development phases. This takes place via symbolic processing of mathematical relations (e.g. by Mathematica®). SCAE force the physical interpretation of a concept.

Design Grammar Tools are based on a design language for concept design [e.g. 1, 4, 6]. Related to natural languages graph-based design languages consists of vocabularies (i.e. a set of basic components), syntax (i.e. design pattern as a set of rules) and their semantic to define a conceptual design space. Design grammars force the topology finding.

Parametric Concept Models enables the convenient generation, modification and evaluation of fully parametrical CAE models by using declarative design elements [http://sfe1.extern.tu-berlin.de, Nov. 2006]. Parametric Concept Models force the geometry finding as early as possible.

Some of these tools for the compilation of conceptual simulation models have reached a high level within the last years. They are able to support the automotive development process in early phases in an efficient way.

4.2: Associative data referencing and knowledge data mining associated with data management for simulation data

Product Data are distributed on different IT-systems. A knowledge-based working environment will help to find all needed actual data in different data management systems (Figure 7).

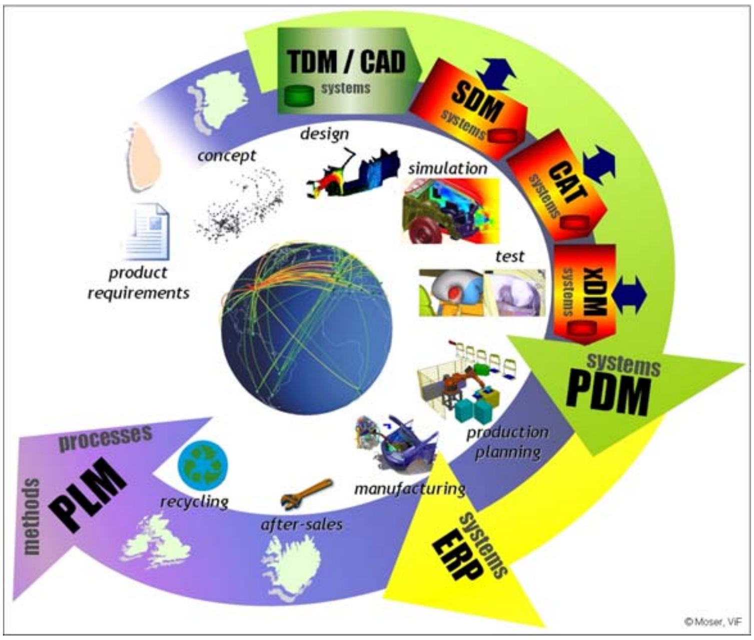

Figure 7: Product Lifecycle Management in a data and knowledge based system environment (schematic representation)

A Product Lifecycle Management (PLM) Backbone-system solution will afford this functionality by knowledge data mining. Data mining is the process of discovering meaningful correlations, patterns and trends by sifting through large amounts of data using pattern recognition technology in combination with statistical and mathematical techniques.

One solution for knowledge data mining in an integrated infrastructure could be a knowledge grid. The effective and efficient use of stored data and its transformation into information and knowledge will be a main driver in grid evolution. *The use of ontology to describe grid resources will simplify and structure the systematic building of grid applications through the composition and reuse of software components and the development of knowledge-based services and tools* [3].

As it was described in the European Commission funded project VIVACE [http://www.vivaceproject.com/content/forum1/7-1.pdf, Sept. 2005] Simulation Lifecycle Management (SLM) will become an extended part of Product Lifecycle Management (PLM) in the next years. SLM will support the management of multiple domain views of the product with a clear definition of how the cross-disciplinary product and process data relate to each other, the management of product data exchange/sharing between skills within the same domain and the management of cross-disciplinary process definitions and knowledge in order to support decision making. These aspects receive also for the support of the vehicle lifecycle more validity. In this context knowledge data mining should be also one of the most important functionalities of SDM tools in this wider SLM understanding.

Associative file management is a kind of associative data referencing. This is a forthcoming method to organize digital data. It can be seen as logical advancement of the hierarchical file management and touches down in its current form as extension on hierarchical file systems. Data are located no longer exclusively by file and listing names but – usually dynamically – by consideration of their contents and the use behaviours of the user. The usual method is the calibration of contents of a hierarchical file system with a data base. Different filters are used in order to illustrate the different data types uniformly in the data base. *An associative relationship is a relationship between or among terms in a controlled vocabulary that leads from one term to other terms that are related to or associated with it* [2]. One condition for an effective associative data referencing is the taxonomy of data.

4.3: Automatic model generation for parts and assemblies

The model generation process time on a systems or subsystems level may be as high as 80% of the total engineering simulation effort (person power). Automatic model generation has the potential to significantly increase simulation productivity and allow sparse engineering resources to concentrate on their vital tasks. *The primary aims are a shortening of the model creation process with simultaneous increase of the mesh quality* [8].

In the context of increasing adoption of design optimisation methods in the product development process, automatic model generation (re-meshing of design domain) is expected to become a necessity.

Besides producing meshes according to quality standards, automatic model generation systems should provide capabilities for de-featuring of CAD geometry, recognition and intelligent meshing of important features, and application disciplines specific modelling requirements (e.g. boundary layer modelling for CFD). It should be also capable to assemble and connect component models from separate sources. This includes the automatic joining of dissimilar meshes, bolt generation, the application of complicated distributed loads, mapping of CFD results and interpolation of data from other models.

Design languages as example are conceived to support this in a wider range [5]. The integration between CAD and the model generator is of utmost importance. *Modelling for heterogeneous systems is a complicated and complex process, which can hardly be automated* [10].

4.4: Homogeneous vs. heterogeneous model environment and platform integration

A characteristic of many technical systems is their heterogeneity. Heterogeneous systems are characterized by cooperating subsystems from different domains (mechanics, electronics, optics, etc.) [10].

Most existing modelling languages were developed for a special field of activity. They therefore have specific characteristics which support the modelling and simulation of systems from this domain particularly well. The main advantage of a heterogeneous modelling thus the possibility represents of being able to describe each subsystem with that best suitable modelling language. If a system model is modelled homogeneous, then for the description of the different subsystems of a heterogeneous system only one modelling language is needed. This proceeding offers the advantage that for execution by system simulations only one simulation tool is needed and the problems of a coupled simulation are void.

Homogeneous models strongly related to *Conceptual Models* and *Automatic Model Generation*. The combination thereof may be considered as an additional opportunity for a homogeneous model.

Another aspect on this topic is related to the CAE integration platform. Integration platform alternatives include

- CAE integration into CAD,
- Multipurpose solver CAE integration,
- CAD and solver neutral environments.

A discussion on the pros and cons of alternative CAE integration platforms in the light of an envisioned future CAE-centric product development process is e.g. provided in [7].

4.5: Multi disciplinary optimisation of complex products based on coupled simulation

To address global competition, manufacturing companies strive to produce better and cheaper products more quickly. For complex systems or subsystems in automotive industry, the design is a very complex optimisation task often involving multi disciplines, multi objectives, and computational intensive processes for product simulation.

One major bottleneck is that there are only few options for optimisation loops in early development phases. This causes in data which are not detailed enough and hardly available tools.

Multi-disciplinary (sometimes also called multi-attribute) problems that include highly nonlinear events like crash are based on response surfaces. In these techniques the most challenging task is to define a good approximation of the design space. *Multi-disciplinary optimisation is not like process automation a tool that is introduced as a task in a design project. It requires the whole design organisation, the different disciplines to act together and to follow the same rules and to apply the same techniques* [9].

Despite continuous advances in computing power, increasing complexity of analysis tools and simulation model size seem to keep pace with computing performance enhancements. In the past two decades, approximation methods and approximation-based optimisation have gained high attention. This approach approximates computational intensive functions with simple analytical models (metamodels). Optimisation methods can be applied to metamodels to search for an optimal design. This methodology is commonly referred to as metamodel based design optimisation (MBDO) [14].

In general there are two significant options to realise a multidisciplinary optimisation:

- Coupled simulation iterations alternating with different optimisation passes,
- Simulations in a specific discipline with optimisation loops followed by simulations in a further discipline.

Especially complex systems/products (with huge models, many parameter relations, etc.) requires more than one optimisation loop to find the optimum. Therefore it is particularly important that in the concept phase the tendencies of the substantial optimisation directions can be already recognized.

The not automatically possible changes of topology represent a substantial limit of past systems and limit thereby their optimisation potential on only parametric changes. *The use of rule-based design languages in the vehicle concept design allows, for example, the manipulation of parametric and* *topology in just one, uniform graph-based pattern* [5]. An essential progress whose practical spreading can be forced during the coming years is thereby reached. Coupled Simulation may be seen as a pre-requisite for multi-disciplinary optimisation. There is an increasing need for multidisciplinary simulations in various research and engineering fields. Fluid-structure interaction, magneto-hydro dynamics, thermal coupling, plasma computations, or coupled manufacturing processes define only a subset of potential multi-physics applications. Computational engineering offers efficient methods and tools to simulate fluid mechanics, structural analysis or electromagnetism, for example. Rising requirements for the accuracy of simulations and increasingly complex technical problems require the coupling of simulations.

This is the only way in which interactions of technical and physical processes can be represented in precise mathematical-numerical models. Coupling between simulation disciplines may be accomplished by direct (tightly coupled) or sequential (loosely coupled) methods. Tightly coupled systems are potentially more precise, but represent a closed solution. Loosely coupled systems allow for integration of best of breed applications for various disciplines. In most cases not a single (proprietary) simulation system can provide all necessary features but coupling of the most suitable codes for each discipline will enable more flexibility and simulation quality to the end user.

MpCCI (Mesh-based parallel Code Coupling Interface) as an example has been developed at the Fraunhofer Institute SCAI in order to provide an application independent interface for the coupling of different simulation codes [http://www.scai.fraunhofer.de/mpcci.0.html, Aug. 2006].

5: Barriers against the achievement of these Breakthrough Technologies

5.1: Cultural change

The envisaged paradigm shift from a CAD-centric to a CAE-centric product development process will have an effect on the people involved into that process. It is of vital importance for a successful implementation of required changes to the product development process and associated methodologies that people affected by the change will be involved and will buy-in as early as possible.

There was a large change in the understanding of the role of a designer resulted with the development of CAD tools with extensive functionalities. Diversified skills of designers and engineers become more and more importance by supporting the development process with computer aided tools.

Detailed CAE simulations may be the bottle neck in the development process [11].

That applies to design grammars too. They seem to be important and have enough potential but the short term oriented automotive industry probable will not try out this paradigm shift in the next 10 years - although there were no topology changes in the last 10-20 years.

5.2: Globalisation

On the one hand there will be fewer suppliers in the year 2015 than today but they will be more networked [15]. Similar simulation data are stored at different organisational units. On the other hand the proportion of virtual development methods will increase up to 80%. Therefore, the communication between used systems for the virtual vehicle development will become increasingly more complicated.

5.3: Average number of CAE-tools and models

Today's average number of CAE-tools is more then 40 in the automotive industry. *Furthermore there are at least 14 or 16 different CAE-simulation models in use by an automotive OEM* [16]. Especially the second fact is a big INTEGRATION bottleneck.

6: Conclusion

The reduction of simulation models to less then ten must be one of the major aims by the next years. In addition to that all relevant vehicle parameter have to be summarized by an engineering data backbone.

One of the most effective approaches to force the integration of simulation into the design process will be a powerful simulation data management tool. Linked with this fact there are two questions: *Which tool functions will link between Product Development Management (PDM) and SDM?* One definition could be: processes and data management are part of SDM while PDM shows a snapshot of actual data in the development project. *Which methods will support next generation simulation data management tools?* This question was discussed in chapter 4.2.

Standardisation of processes will be one of the most important factors and responsibilities by developing tools to support the integration of CAE-simulation in the future. Today the risk to make mistakes is high for the most parts of the development process cause there are less or different standards. The aim should be: creative users with standard processes.

Therefore not least organisational changes are necessary. Not only simulation specialists can solve the complex system requirements in the future. A CAE-user needs more and more an overall view and a corresponding education (e.g. as a systems engineer).

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REFERENCES

[1] ANDERSSON, Kjell - A Vocabulary for Conceptual Design - Part of a Design Grammar; IFIP WG5.2 Workshop on Formal Design Methods for CAD, Tallinn 1993

[2] Guidelines for the Construction, Format, and Management of Monolingual Controlled Vocabularies; National Information Standards Organization, ANSI/NISO Z39.19 – 2005, NISO Press, Bethesda, Maryland, U.S.A., 2005, ISBN 1-880124-65-3

[3] CANNATARO, Mario; COMITO, Carmela - A Data Mining Ontology for Grid Programming; 1st Workshop on Semantics in Peer-to-Peer and Grid Computing at the 12th International World Wide Web Conference, 2003

[4] FITZHORN, P. A. - Formal Graph Languages of Shape; Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM); Vol. 4, No. 3, pp. 151-164, 1990

[5] HAQ, Manan; RUDOLPH, Stephan - EWS-Car: A Design Language for Conceptual Car Design; VDI-Papers Nr. 1846, pp. 213-239, Verein Deutscher Ingenieure e.V., VDI-Verlag, Düsseldorf 2004

[6] HAQ, Manan; RUDOLPH, Stephan - A Design Language for Generic Space Frame Structure Design; 1st IFIP TC-5 Working Conference on CAI, Ulm 2005

[7] HOFFMANN, Michael - Integration of Simulation into the Development Process. Requirements and Realization Scenarios; 2nd AutoSIM workshop, Sonnenhausen, Germany, 4-5 May 2006

[8] SCHELKLE, Erich - Simulation; Grazer SafetyUpDate 2006, EASi Engineering GmbH, Graz, 20-21 June 2006

[9] SCHRAMM, U. - Optimization Technology in Design – Trends, Direction, Gaps; 6th World Congresses of Structural and Multidisciplinary Optimization; Rio de Janeiro, Brazil, 30 May - 03 June 2005

[10] SCHWARZ, Peter - Modellierung und Simulation heterogener technischer Systeme; Technischer Bericht, Fraunhofer Institut für Integrierte Schaltungen Erlangen, Außenstelle Entwurfsautomatisierung, Dresden 2002

[11] SCHWEIGER, Raimund - CAD-integrated Numerical Simulation in the Early Design Stage: Benefits, Requirements, Examples; NAFEMS Seminar: Integration of Numerical Simulation into the Development Process, Wiesbaden, Germany, 17-18 Nov. 2003

[12] THOMKE, Stefan; FUJIMOTO, Takahiro - Front-Loading Problem-Solving: Implications for Development Performance and Capability; PICMET '99 Conference, pp. 234-240, Portland 1999

[13] WANG, G. Gary - Definition and Review of Virtual Prototyping; Transactions of the ASME, Journal of Computing and Information Science in Engineering, Vol. 2, no. 3, pp. 232-236, Sept. 2002

[14] WANG, G. Gary; SHAN, S. - Review of Metamodeling Techniques in Support of Engineering Design Optimisation; ASME Transactions, Journal of Mechanical Design, 2006

[15] Future Automotive Industry Structure (FAST) 2015 - Study by Fraunhofer Institutes and Mercer Management Consulting, Stuttgart-Dortmund-Munich 2004

[16] SCHELKLE, Erich - Up-front CAE Simulation – Just a Catchword or Already a Fact of Modern Automotive Engineering? 3rd AutoSIM workshop, Lisbon, 23-24 Nov. 2006