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The ITEA VMAP Project
Industrial Demands and Software Standards for a Unified Material Data Interface

The development and deployment of new high-tech materials require the use of advanced virtual design and validation tools. Computer-Aided Engineering (CAE) departments in industry utilise a variety of software tools for virtual material and product design to enable virtual manufacturing parameterisation and finally for virtual product testing and evaluation. Each of these CAE tools has an internal representation for all material types. Unfortunately, in most cases these material representations are not compatible with each other and the exchange of local material and engineering information in a CAE software workflow is not standardised. This increases the manual and case-by-case implementation effort and cost. For a holistic manufacturing process design and product functionality assessment the knowledge of the material throughout the complete process is required.

The initial goal of the ITEA VMAP project (http://vmap.eu.com) is therefore to gain a common understanding and interoperable definition for virtual material models within CAE. The project will then run industrial use cases from representative manufacturing processes to ensure that:

- VMAP will generate universal concepts and open software interface specifications for the exchange and transfer of material and related information in CAE workflows.
- VMAP will create universal software interfaces for the exchange of material and engineering data including, where necessary, data translation following the open interface specification.
- VMAP will implement virtual industrial demonstrators for relevant material domains and manufacturing processes and provide best-practice guidelines.
- The innovative material interface standard concepts will be implemented into a number of leading CAE software.
- VMAP will establish an open and vendor-neutral ‘Material Data Exchange Interface Standard’ community which will carry on the standardisation efforts in the future.

The standardisation of material data interfaces in CAE will be important for all industry segments where material behaviour plays a dominant role in product and process design. Interoperable virtual material models and the seamless transfer of material and engineering data for the full CAE workflow will help industrial users to develop and produce better products in shorter timescales using more efficient manufacturing processes. Interface standards will also help the CAE software developers and vendors to realise further virtual material models which can be easily integrated in holistic design, simulation and optimisation workflows.

The VMAP consortium consists of 29 partners from six countries: Austria, Belgium, Canada, Germany, Switzerland and the Netherlands:

- Industry:
  Rikutec, Kautex Maschinenbau, AUDI, Robert Bosch, Wittmann, Philips, Sintratec, Airbus, Canadian Composites Manufacturing R&D Consortium
- ISVs:
  4a engineering, BETA, Convergent, ESI, MSC, DYNAmore, Simcon, e-Xstream
- Services:
  Hagen Engineering, EDAG, 4a engineering, inuTech, KE-works, Reden, DevControl, InSumma
- R&D:
  FhG SCAI, Dr. Reinold Hagen Stiftung, KIT/Fast, NAFEMS, TUD, RUG, M2i, UBC.

http://vmap.eu.com

Acknowledgement

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ITEA is the EUREKA Cluster programme supporting innovative, industry-driven, pre-competitive R&D projects in the area of Software-intensive Systems & Services (SiSS). ITEA stimulates projects in an open community of large industry, SMEs, universities, research institutes and user organisations.

As ITEA is a EUREKA Cluster, the community is founded in Europe based on the EUREKA principles and is open to participants worldwide

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Content

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Content

A Reference Language and Ontology for Materials Modelling and Interoperability

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Materials modelling is understood to include science based predictive methods describing any type of chemical and material at any level of granularity, i.e. electronic, atomistic, mesoscopic and continuum modelling. Methods in use today have their origins in a wide range of communities, such as computational chemistry, solid state physics, materials science, mechanical engineering etc. Application to industrial challenges typically requires integration of a range of these methods, which poses a significant interoperability challenge, not only computationally but also between experts from different communities.

The European Materials Modelling Council (EMMC) recognized the need to collate the wide range of contributions and better integrate different communities and methodologies. Interoperability of models, software and data is needed to facilitate an integrated approach to materials design and product improvement. Thus, the EMMC facilitated the elaboration of a CEN Workshop Agreement: Materials modelling – Terminology, classification and metadata to establish a reference terminology for materials modelling.

Furthermore, EMMC has been supporting the development of a general and widely applicable semantic basis for the representation of materials and their modelling: the European Materials Modelling Ontology (EMMO). The aim of EMMO is to be generic and to provide a common ground for describing materials, models and data that can be adapted by all domains.

EMMO is designed to pave the road for semantic (rather than purely syntactic) interoperability. It can be used as the foundation for implementation of standards and open interfaces connecting different codes and models based on their fundamental characteristics.

FE Solver Integration Framework

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Integrating finite element analysis (FEA) with systems engineering (SE) improve traceability, consistency, interoperability and collaboration between SE and FEA activities in multiple engineering disciplines. The first step in achieving this is a software-independent description of FEA models, which are characterized by numerical approximations of partial differential equations (PDEs) derived from physical laws, and finite elements representing unknown physical quantities. In previous work, we presented a finite element mathematics specification that is formal and understandable by most engineers. It provides all information needed for generation of shape functions for physical quantities. In this work, we propose a specification of physics used in FEA to complement our earlier mathematics specification.

We first compare existing FEA physics descriptions and their corresponding software implementations to highlight the benefits of domain-independent model descriptions used by PDE solvers. A significant drawback of PDE representations is they do not show all physical quantities from which they are derived. To tackle this, we represent the physical laws and derivations needed for FEA PDEs in machine-readable graphs. Instead of classifying physics problems by the kind of PDE used in FEA, as in PDE solver packages, we formalize problems as paths through these graphs. This increases transparency by capturing modelling decisions that are currently done on paper or electronic documents.

We combine the graph-based specification of FEA physics above with the finite element mathematics specification developed earlier to generate linear system of equations (algebraic FEA models) for solving the problem numerically. The combination will enable FEA engineers to design their own libraries (potentially automatically) if they choose, or associate existing solvers. It also generalizes mappings from physics to FEA models, a task currently repeated across specific disciplines. The framework could be standardized and integrated with SE modeling languages, improving interoperability and collaboration between systems and FEA engineers.

Coupling Process Analysis Results to Structural Simulation: Ongoing Research on Mapping and Homogenization Algorithms

C. Liebold, T. Usta, A. Haufe (DYNAmore, GER)

The rising importance of Industry 4.0 applications has made its way into the daily life of simulation engineers and the term of a "Closed Simulation Process Chain" is commonly used nowadays. With that, the demand for software tools which not only help to transfer result data from all kinds of process analysis towards structural simulation but also interpret, interpolate, and homogenize the resulting data most accurately has risen constantly. Thereby, one has to overcome the fact that various software tools being used for several simulation tasks do have non-consistent output formats; material formulations do interpret field- or history variables differently – not only between different solvers, but also within a solver itself. Furthermore, different discretization techniques are used for the different simulation disciplines, e.g. result data has to be transferred between beam, shell, thick shell, and solid elements that can be layered, stacked, fully or under-integrated.

Within this work, different averaging techniques such as Shepard's method [Shepard 1968] for scalar simulation result data will be introduced in the framework of Finite-Element (FE) result data mapping and compared to a standard closest point approach which basically transfers the values between source and target meshes. Using the linear invariant (LI) approach proposed by [Gahm 2014], various sets of tensor invariants are used to interpolate resulting stress tensors. Due to the fact that stress tensors are not a-priori positive-definite, one can rule out two of the three proposed invariant sets for the interpolation of any arbitrary tensor. Instead, it seems to be reasonable to use the Cauchy stress invariants for interpolation and to compare the results with a closest point mapping and a standard Euclidean tensor averaging approach [Usta 2018]. Nevertheless, the invariant sets are still valid for positive tensors such as fiber orientation tensors and therefore need further investigation.

Furthermore, the method has been extended, making use of the shape functions of 2D finite element meshes for a rather simulation related approach. Further methods which could be interesting for an enhanced mapping approach would be to ensure energy conservation through the thickness when transforming plastic strains from source to target mesh, as it is proposed by [Wolf et. al. 2005]. Also, the superconvergent patch recovery method [Zienkiewicz et. al. 1992] which is used to ensure stable mapping when adaptive mesh refinement is used during FE analysis could be an option as well and shall be discussed in this work.

Recommended Best Practices for Model Based Engineering's Digital Twin: Analysis and Simulation

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Model Based Engineering has a digital twin in the engineering analysis and simulation domain. During the development of a physical system (a product), several key characteristics must be defined such that they satisfy the design requirements. Substantiating the satisfactory measure of meeting a design requirement often relies on various means of verification during a physical system's development. When the physical system is manufactured it must also be shown to satisfy the design requirements by verification and validation. In most cases, the means of verification and validation involve obtaining physical measurements of key characteristics that are part of the model based design, but the definition of many of the target values of these characteristics is dependent on math and science-based analysis to predict them during development.

The fundamental theory and application of analysis-based predictions have been generated by the fusion of math and science present in the engineering vocation. Many of these analytical methods have been packaged in computer aided engineering (CAE) software, such that the process of modelling the math and science (physics) can produce predicted results that are robust, repeatable and reliable. The simulation results for a physical system are produced concurrently with the design and development of the product and continue to be produced (as-needed) throughout the lifecycle of the system. These data are used to assist in verification and validation of the physical system's performance relative to the design objectives and requirements. Defining best practices for long term archiving and retrieval (LOTAR) of engineering analysis and simulation (EAS) information has been the objective of the authors as part of the LOTAR International EAS Working Group. The means of achieving the goal of LOTAR of EAS information are also suitable for data exchange throughout the lifecycle of a product.

In its initial phases, the focus has been placed on LOTAR of structural engineering analysis of aerospace products using finite element analysis (FEA) via industry standards, such as ISO 10303-409 "Industrial automation systems and integration — Product data representation and exchange Part 409 Application Module: AP209 multidisciplinary analysis and design" (ISO STEP AP209 ed2). The use of ISO STEP AP209 is not limited to aerospace products. Other ISO STEP standards are widely used for data interchange and LOTAR (such as AP203). (International Standards Organization, 2014)

A summary of the recommended best practices is presented that will be captured in prEN 9300-600/620 "Aerospace series — LOTAR — LOng Term Archiving and Retrieval of Structural Analysis information — Part 600: Fundamentals and concepts" and "Part 620: Structural analysis information." The LOTAR International was established as a joint AIA and ASD-STAN project. While these organizations and project are focused on addressing the needs of aerospace and defence manufacturers, the best practices can be applied to any product requiring LOTAR of EAS data. These practices are also applicable to exchanging EAS data during product development.

The authors will also demonstrate a simulation of a round-trip of structural analysis performed using FEA from packaging the archived model and results data in ISO STEP AP209 ed2 to retrieving the data from archive and rerunning the analysis and validating that the results are equivalent to the original data.

Towards an ICME Methodology in Europe – Nomenclature, Taxonomies, Ontologies, and Marketplaces

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The present article provides an overview about activities towards an ICME methodology currently going on in Europe. The article especially introduces the European Materials Modelling Council EMMC as a bottom-up activity of the European materials modelling community and provide a short outline of the different working groups within the EMMC and their objectives.

One of the major objectives relates to a standardized nomenclature –the European Materials modelling ontology "EMMO" – aiming to facilitate information exchange and interoperability between a variety of models and software tools in the area of electronic, atomistic, mesoscopic and continuum descriptions of materials.

The article will indicate a possible path of interoperability between scientists, engineers and tools aiming at "engineering the material" with the FEM community more focusing on "engineering with materials" .The FEM community increasingly is interested in improving and combining simulations at the component scale also eventually even in including the use of local materials properties.

This potential path is based on an HDF5 type description of materials allowing both a statistical and a spatially resolved of microstructure data being easily exchangeable between simulations and experiments and also between simulations at different scales. Respective simulation scenarios can be deployed as workflows on simulation platforms and on future materials modelling marketplaces.

Lessons Learned from Developing a Digital Prototype Within the ARENA2036 Environment and Improvements with the New VMAP Standard

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F. Fritz, H. Finckh (DITF - Deutsches Institute für Textil und Faserforschung, GER)

In 2013, a new research campus called ARENA2036, which is the abbreviation for Active Research Environment for the Next Generation of Automobiles, has been established at the University of Stuttgart. The year 2036 accounts for the 150th anniversary of the patented version of Carl Benz's first three-wheeled vehicle with a combustion engine which led to the first serial production of motorized vehicles as we know them today. The main focus of the research campus is to investigate the rising importance of Industry 4.0 applications and in a first phase, three leading technical projects worked on topics such as lightweight design and system/sensor integration (LeiFu), new and adaptive production lines in industrial environments (ForschFab), and enhancing simulation capabilities with the definition of a digital prototype (DigitPro). The latter aimed to improve the daily life of simulation engineers by developing a digital prototype which defines a simulation data exchange platform based on a HDF5 data storage container and by improving mapping schemes to structural analysis meshes for selected process simulations such as braiding, resin infiltration, open-reed weaving (ORW), and draping of continuous fiber reinforced plastic (CFRP) materials. This should help to close the simulation process chain within the project and is now used as a basis for a subsequent 5-years governmental funded project called “Digital Fingerprint".

To develop accurate and efficient mapping and data exchange interfaces, physical relevant parameters for the different processes have to be identified in a first step. In a second step, a proper data exchange format has to be defined, since the different partners use various software solutions which output results in different formats and therefore cannot be interpreted by other software tools. In this work, it will be shown why the HDF5 format seems to be a valid storage platform for a large amount of data which accumulates when following the full simulation process chain for all different kinds of materials, components, and processes. Furthermore, a first step has been made to define a common standard for simulation result data exchange and it will be discussed, why the ITEA-VMAP project seems to consist of the better consortium to target topics such as data semantics for resulting analysis data and their interpretation depending on the physical meaning in material modeling and what steps have already been taken to define a common data exchange format. In addition it will be discussed, how the resulting VMAP standard might influence the subsequent project “Digital Fingerprint” which aims for the inclusion of all relevant data being collected along a components life time from first concepts and computer aided design via the engineering process and its virtual process simulation chain until its final usage in real applications and probable failure. Finally, an overview regarding the implementation status of the VMAP standard into the used mapping software envyo® shall be given, showing the capabilities to cover the use cases defined within the VMAP project. These examples will include a use case coupling thermal and structural analysis and a use case showing the simulation process chain for continuous fiber reinforced plastics. Furthermore, enhancements made for mapping processes within the ARENA2036 project will be discussed.

Mapping Made Easy: How the New VMAP Interface Standard can be Utilized Towards Smooth Preprocessing

A. Fassas, G. Mokios (BETA CAE Systems, GRE)

In most cases today, simulation has become complex both in terms of model and procedure complexity. Several different types of software take part in simulation procedures, to analyze the phenomenon as realistically as possible and produce reliable results. These different software types, however, do not use the same modeling parameters. For example, some of them use 3D elements, others deal with 2D elements, and others usually use different material models.

As a result, going through the steps of a simulation process, the information, including those for materials must be exchanged between the different software. To reduce errors, costs, and effort during this exchange of information, the creation of a “Material Data Exchange Interface Standard” is considered mandatory.

As part of the VMAP project, BETA CAE Systems is involved in the development of a common understanding and interoperable definitions for virtual material models in CAE. This project aims to the development of the “Material Data Exchange Interface Standard”. BETA CAE Systems has supported this format in its products, allowing engineers to apply (map) the results of a simulation on their current models, using the standard format, and proceed with their simulation process.

This presentation examines several use cases, in which exchanging information among different software, is required. In the illustrated case, we showcase how the proposed solutions support processes, such as mapping the results of a previous simulation written in the VMAP standard format on a current model, in a way that it can be used in a next simulation process step.

All steps required to transfer results from a simulation and utilize them as boundary conditions for the next simulation are performed in ANSA, with the application of the Results Mapper. ANSA Results Mapper is based on interpolation and the proper method can be selected from among several options. Enhanced with an intelligent position mechanism, the ANSA Result Mapper allows the mapping of information between models, which are not located in the same coordinate space. The transformation of the donor part can be automatically performed, with a simultaneous transformation of tensor results, like stress and strains.

Another great benefit of using the ANSA mapping algorithm is that a modification of the model’s mesh will lead to an automatic recalculation of the results, to preserve the initial values.

From Manufacturing to Performance Analysis for Composite Structures – Efficient Data Handling and Exchange

S. Müller (ESI Group, GER) T. Bergmann (AUDI, GER)

The performance of modern composite structures is substantially determined by the material handling and the involved manufacturing processes. Especially the material forming and the resin injection are known to influence the local mechanical properties and the final part geometry. Numerical analysis of both the manufacturing processes and the subsequent part performance have been found to allow for an efficient analysis of the composite part design, especially in an early design state. The predictability of the latter simulation can be improved by including the results from the different preceding manufacturing steps.

To be able to incorporate results efficiently from different sources, a common and open data exchange format is mandatory. To this end, the partially funded collaborative R&D project VMAP (A new Interface Standard for Integrated Virtual Material Modelling in Manufacturing Industry) aims to develop a vendor-neutral data storage concept.

To support this development, the AUDI AG and the ESI Group examined a continuous fibre-reinforced plastics (FRP) demonstration case, which allows to identify the requirements for the VMAP standard based on an industrial application.

The VMAP Material Data Interface Standard – A New Approach to Unify Information Transfer in Virtual Manufacturing Workflows

P. Gulati (Fraunhofer Institute for Algorithms and Scientific Computing –SCAI, GER)

The VMAP interface standard provides an open and vendor-neutral solution that can be integrated into any CAE software. VMAP standard will enable the interoperability with any other CAE software tool also supporting the VMAP standard. The goal is to support (initially) virtual manufacturing workflows which involve a diverse set of CAE tools from different vendors. The VMAP specification will be based on HDF5 API which is a widely accepted implementation platform for many IO related applications. The VMAP project will provide a first implementation of the VMAP IO library including bindings for most programming and script languages. VMAP standard consists of definitions for meta-information, unit and coordinate systems, mesh geometry and discretization, a fast growing number of element and integration rule definitions, physical result quantities, and finally also common concepts to transfer virtual material model parameters. This presentation will give a status report about the ongoing specification and implementation works and provide first information on how to use the VMAP IO library in your own code.

Acknowledgement
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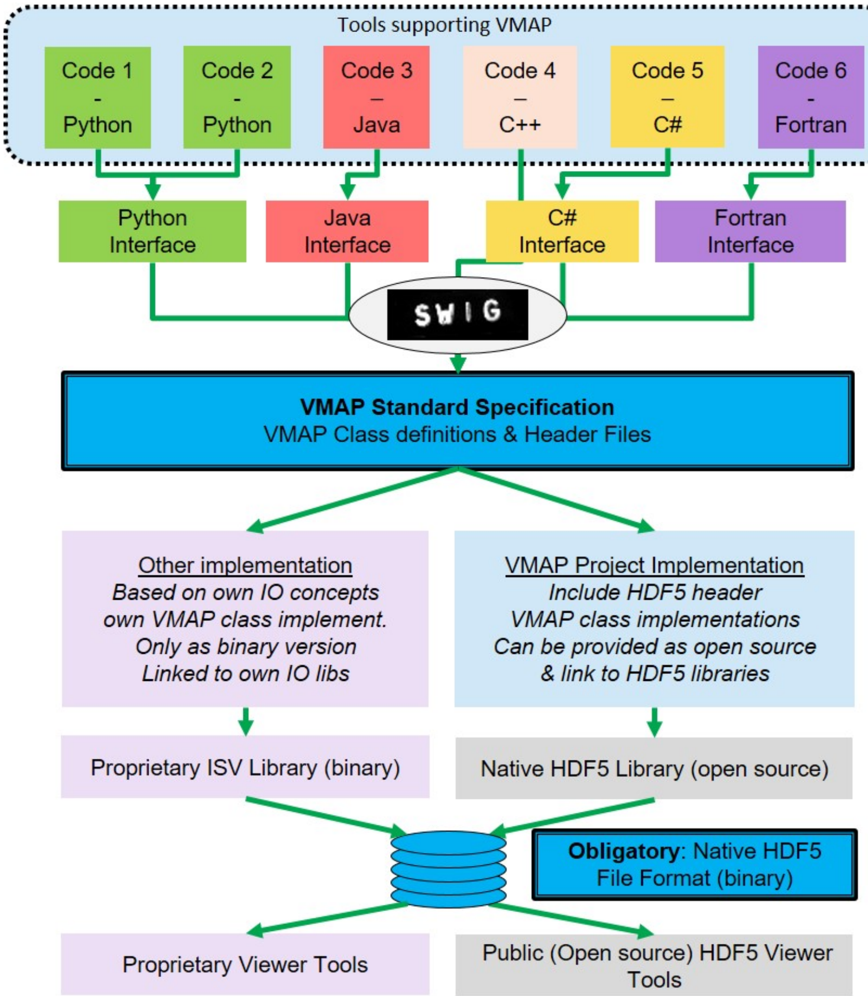

Material Data Transfer in Virtual Engineering Workflows: Application of the VMAP Standard in a Neutral Mapper Tool

A. Oeckerath, P. Gulati, K. Wolf
(Fraunhofer Institute for Algorithms and Scientific Computing – SCAI, GER)

The simulation of structural behaviour of passive safety components in automotive industry does not only depend on geometry design but is also influenced by manufacturing history. A failure of metal parts can be caused by local thickness reduction, plastic strain failure, residual stress peaks or other material properties which are the result of the manufacturing process. These local effects can limit the performance of the entire component significantly. For parts and components made of composites two influential parameters for mechanical properties are fibre orientation and fibre volume content. Both are directly affected by the draping process of the textile fabric and must be properly transferred from the deformed mesh of the draping simulation to the meshes used for infiltration and structural simulation.

The MpCCI Mapper provides a vendor neutral way for one-way transfer and data mapping of local manufacturing results in virtual manufacturing and engineering workflows. The tool bridges different barriers typically occur when linking different simulation disciplines and software packages to an integrated simulation workflow. In detail, MpCCI Mapper allows to check the geometric compliance of two simulation models by calculating the local distances between them. The (automatic) mesh alignment helps to fit the positions of two models if they are not in a non-conformal coordinate system. A robust and efficient mapping algorithm enables the transfer of any physical quantities (with nodal-, element- or shell-layer based locations) for all common finite elements and between different mesh types. The mapping works for different integration schemes, for different number of integration points in thickness direction for shells as well as combinations of solid and shell discretization for source and target model.

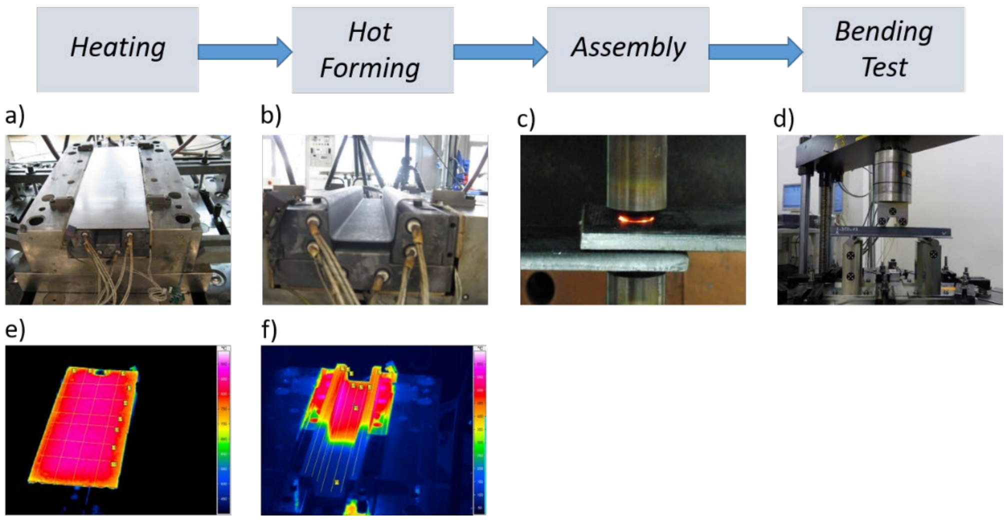

Figure 1: Hot metal forming manufacturing process chain of a 22MnB5 hat profile. After heating the metal sheet a), a hot forming step with partial cooling is performed b). A cover plate is joined to the hat profile by resistance spot welding c). Finally, a four-point bending test is done to evaluate the structural performance of the partially press hardened hat profile d). Images e) and f) show the temperature field after heating and after forming step.

In this presentation we will show how this neutral mapping tool can be utilized to transfer mechanical simulation result data between simulation codes supporting the VMAP standard as well as solver native file formats. In detail, its capabilities are demonstrated for two reference manufacturing processes in automotive industries, a hot metal forming with partial cooling of a 22MnB5 hat profile as shown in Figure 1 and a lightweight unidirectional fiber reinforced composite component as shown in Figure 2.

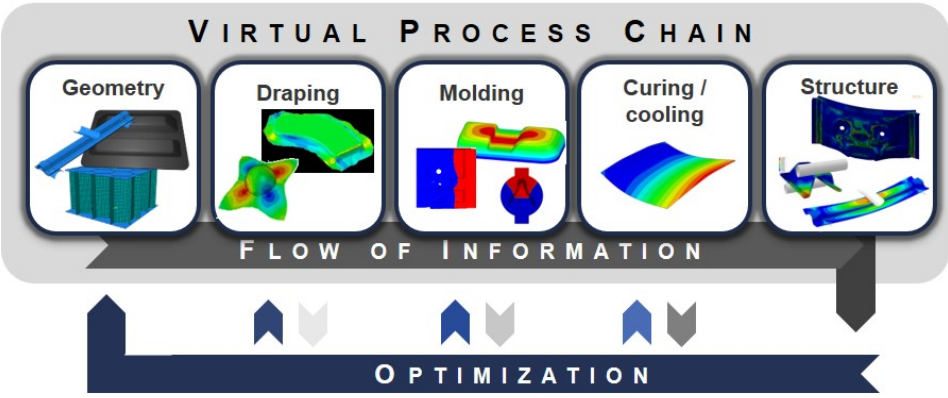

Figure 2: Virtual CAE process chain for composites (Kärger, et al., 2015). Linking geometry design, draping, molding, curing and structural simulation in an optimization process.

[1] Images a), b), d), e) and f) taken from (Hunkel, Wallmersperger, Hofmann, Wolf, & Oeckerath, 2015). Image c) taken from (Gesellschaft für Schweißtechnik international mbH, 2019).

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The ITEA VMAP Project
– Industrial Demands and Software Standards for a Unified Material Data Interface

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Project Context

The development and deployment of new high-tech materials require the use of advanced virtual design and validation tools. Computer-aided engineering (CAE) departments in industry have installed a variety of software tools for virtual material and product design, for the parameterisation of virtual manufacturing and machining processes, and finally for the virtual product test. These CAE tools have an internal representation for material types. Unfortunately, in most cases these material representations are not compatible to each other. The exchange of local material information in a CAE software workflow is not standardised and raises a lot of manual and case-by-case implementation efforts and costs. For a holistic design of manufacturing processes and product's functionality the knowledge of the complete material is required.

Goals of VMAP

The major goal of the project ITEA VMAP (http://vmap.eu.com) therefore is to gain a common understanding and interoperable definitions for virtual material models in CAE. The VMAP project will run industrial use cases from major material domains and with representative manufacturing processes.

- VMAP will generate universal concepts and open software interface specifications for the exchange of material information in CAE workflows.
- VMAP will realise (prototype) implementations for extended CAE tool interfaces and – where necessary – translation tools which follow the open interface specification.
- VMAP will implement virtual industrial demonstrators for relevant material domains and manufacturing processes and provide best-practice guidelines for the community.
- VMAP will establish an open and vendor-neutral 'Material Data Exchange Interface Standard' community which will carry on the standardisation efforts into the future.

Commercial Background and Market

The standardisation of material interfaces in CAE will be important for all industry segments where material behaviour plays a dominant role for product and process design. Interoperable virtual material models and a seamless transfer of material data history in a CAE workflow will help the industry users to develop and produce better products in shorter time and in more efficient manufacturing processes. Interface standards will also help the CAE software developers and vendors to realise further virtual material models which can be easily integrated in holistic design, simulation and optimisation workflows.

Target Innovation within VMAP

The major innovation in VMAP will be a common understanding of virtual material models, the realisation of a universal software interface for the transfer of material data workflows, and the definition of a 'Material Data Exchange Interface Standard' for CAE. The innovative material interface concepts will be implemented to a number of leading CAE tools and will be deployed in a set of industrial use cases from different material and manufacturing domains.

Modern Materials in Process and Product Design

The development of new products as well as the incremental improvement of existing products depends on the availability of suitable real materials and validated virtual material models. In a CAE design process the local properties and the overall functionality of a new product can be composed by integrating a mix of materials in a predefined way and at clearly defined positions. The material properties in the target product are influenced by the preceding material creation and the steps in the all component manufacturing processes. In each single process the material properties – for example stiffness, hardness, and viscosity– are modified and the results of these material changes have to be transferred to the next step to include the local material history.

Example 1 - High performance composites for lightweight vehicles

The transportation sector is responsible for nearly one third of the global energy demand and is the major source of pollution and greenhouse gas emissions in urban areas. There is a strong driving force for the use of new lightweight materials in order reduce the CO2 emission. Based on preliminary calculations, every 10% of weight saving will bring around a 3-5% of fuel economy which can be translated into a price reduction of 3-5 € per kg saved. High-performance composite structures promise supreme weight-specific mechanical performance, but their production process is complex with fibre deposition, resin infiltration and curing stages leading to high expenses and with the risk of faulty parts. At present, the single processes can be simulated individually, but there is still no efficient integrated virtual engineering workflow available based on industry-standard tools, which could be used to combine design, manufacturing and virtual validation of the product performance. This simulation gap causes cost-intensive development loops including high numbers of real hardware prototypes, which makes the potentially high-performance composite material economically unprofitable.

Example 2 - Blow forming solutions for robust plastic container and bottles

Extrusion blow moulding is the standard manufacturing method for hollow plastic parts like bottles, cans, fuel tanks and large containers. The engineering workflow consists of different steps, starting with the blow moulding process up to the structural design and virtual or physical testing of the article. It is widely accepted that material information (local material states like wall thicknesses, residual stresses, local strains, temperatures, etc.) should be transferred from one design or simulation process to the following ones (process simulation cooling simulation shrinkage and warpage different product analysis steps). However, the currently available export and import facilities of the simulation tools and the capabilities of transformation tools are limited and a large amount of material information cannot be passed and used in a proper way. Similar interface gaps hinder the integration of detailed material properties from e.g. molecular dynamic models (MD) or the use of real experimental data for calibration and validation purposes.

Expected project outputs

The major output of the VMAP project will be the demonstration of integrated CAE workflows with a holistic material data management in six relevant industrial areas. In each of these use cases the detailed technical results (CAE tools interconnected through the VMAP material data interface) will be shown. The strategic results of the project will be the VMAP Material Data Exchange Standardisation Initiative.

This VMAP standard will provide open and neutral specifications for the handling of material properties and parameters in integrated CAE workflows. The standard will also include a general material model concept which can be further specified towards the different material classes. Open file format definitions and (as far as needed) open-source implementations for basic VMAP-file-IO will be part of the standard.

The involved software and service partners will adapt their CAE tool to support the VMAP exchange standard. All ISVs will participate and contribute to the standard specification and will implement the ongoing standard versions in their own tools. The software prototypes will be the initial tools being compliant to the VMAP interface standard.

The industry partners will deploy the extended tools in their use cases and thus demonstrate the technical benefits of integrated material model handling in virtual design and analysis:

- The demonstrator for blow moulding will show the detailed prediction of shrinkage and warpage of plastic bottles and containers. This case will be representative for many other blow moulded articles as the material interfaces can easily expanded to other applications like virtual and also real testing.

- The composites demonstrator will show an application of the continuous virtual process chain to a practice-oriented automotive structural part. An automated and accelerated workflow for product verification as well as process and product design will be available at the end.
- Workflows for moulding of plastic components will show the engineering potential of low-cost available materials for lightweight and safety applications.
- In the additive manufacturing for components and parts Bosch will demonstrate the needs and capabilities for AM in plastics.
- Philips Consumer Lifestyle demonstrator will explore the complex response of the human skin behaviour into optimising of the products for wellness and care.
- The aerospace composites demonstrator will show how standardized information can be passed between all the relevant simulation modules for the different phases of a product development program.

All project results – VMAP standard specification, CAE tool extensions, and demonstrators – will form the basement for the strategic VMAP Material Interface Standardisation Community.

Acknowledgement

This work is funded by the German Federal Ministry of Education and Research (BMBF) via the ITEA3 cluster of the European research initiative EUREKA (Funding Sign BMBF 01|S17025 A – K).

Interface Challenges and Solution Approaches with Regard to the New VMAP Standard in a Continuous CAE-Chain for the Holistic Manufacturing Simulation of High Performance Composites

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D. Dörr (Karlsruhe Institute of Technology (KIT) / Simutence, GER)

Continuous fiber-reinforced polymers (CoFRP), distinguished by their high weight-specific mechanical properties, are ideal materials for application in load bearing components within the automotive sector. In contrast to metals, both the actual macroscopic composite material and its characteristics are determined during the multi-step manufacturing process. Depending on the component's shape as well as the parameters and boundary conditions of the process management, significant fluctuation of local fiber directions and the composition of constituents may occur inside the part [Gal19].

In order to evaluate and optimize the part's actual performance during the design phase and avoid oversized or defective structures, process simulation and its effects on the structural behavior have to be taken into account [Kae15, Kae18, Hen19]. Since the physics of the problem, the type of its numerical boundary conditions, the constitutive laws of the materials and reasonable mesh topology, typically, change from one simulation step to another, various simulation software is used for different process steps within one virtual manufacturing chain. Sequentially linking these software tools allows for transferring relevant information on the material state over different scales along this CAE-chain and thereby helps to enhance the quality of prediction. However, one significant drawback of such virtual manufacturing chains is the absence of uniform conventions and standards for the exchange of information between simulation tools. Therefore, the technical implementation of these interfaces yields bottlenecks due to the high manual effort required when setting up new CAE-chains. Tailoring CAE-chains to a specific need also results in inflexible interfaces that are hardly adaptable to different processes and/or materials. The issues described are addressed via the international research project *ITEA VMAP*, which aims at a common and standardized interface formulation for virtual material modeling.

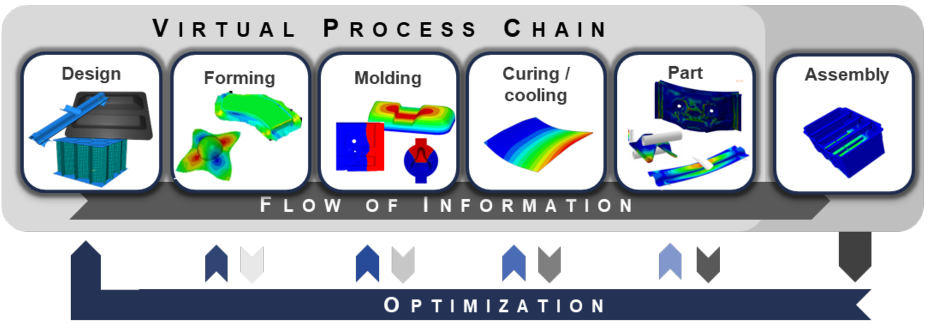

Figure 3: Virtual process chain combining design, process and structural simulation [KAE 15].

In this presentation, one of the industrial use cases within the *VMAP* project is examined: the virtual manufacturing simulation chain for the Resin Transfer Molding (RTM) process. RTM is further subdivided into three chronologically separated process steps (cf. Figure 1). First, the results of a forming simulation provide information about the dry fibers' realignment, in order to match the three-dimensionally curved shape [Doe18]. Second, this information is crucial to determine the flow propagation of thermoset resin during the infiltration simulation [Seu18]. Finally, a distortion simulation is conducted to predict possible warpage and residual stresses due to chemical shrinkage as a consequence of the resin's chemical crosslinking reaction and the thermal contraction during cooling to room temperature [Ber16]. The talk focuses on the interfaces between the individual simulation steps, their realization as well as the material data exchanged and the challenges occurring within. A first application of *VMAP* and utilization of its software library for implementing interoperable I/O-tasks with third party software is presented, by the means of the interface between draping simulation, conducted with *Abaqus/explicit,* and infiltration simulation in *OpenFoam*.

Acknowledgement

This work is funded by the German Federal Ministry of Education and Research (BMBF) via the ITEA3 cluster of the European research initiative EUREKA (Funding Sign BMBF 01|S17025 A-K). The work is also part of the research of the Young Investigator Group (YIG) “Tailored Composite Materials for Lightweight Vehicles”, funded by the Vector Stiftung.

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ITEA VMAP Project Use Case: Composites in Aerospace

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Background

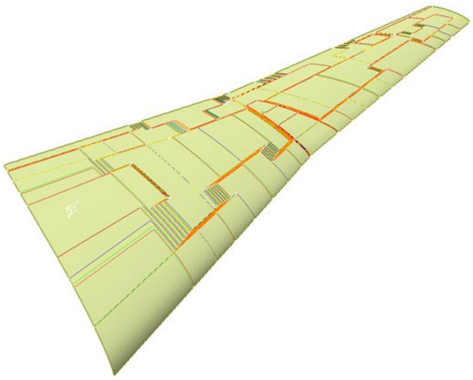
The goal of the ITEA VMAP project (http://vmap.eu.com) is to gain a common understanding and interoperable definitions for virtual material models in computer-aided engineering (CAE). The CAE tools used in academia and industry typically have internal representations of material state and properties which are incompatible with each other. This becomes a challenge for efficient process simulation as these simulations usually involve chaining simulation tools together to model the behaviour of each stage of the physical manufacturing process. As a result, companies have created complex tools and workflows to allow them to connect material state and properties at the end of one simulation to the start of the next simulation. The standardization of the exchange of this material data is ultimately the aim of the VMAP project.

Key to the success of the VMAP project are six use cases, which bring manufacturers, process simulation experts, and software providers together to provide examples of typical process modelling workflows. These use cases have been an integral part of the VMAP project from its beginning, documenting the industrial processes, identifying those simulation tools and material models used in each stage of the process modelling, and identifying the needs of each simulation chain. Over the course of the VMAP standard development, the use cases are being used to ensure that VMAP is meeting the needs of industry, and at the conclusion of the project, the use cases will be used to evaluate the success of the project at meeting these needs.

Convergent Manufacturing Technologies is the Use Case Leader for “Use Case 2.6: Composites in Aerospace”. In this case, Convergent is acting as the bridge to the manufacturer, the process simulation expert, and the software provider.

Use Case: Composites in Aerospace

Aerospace is an industry that is typically unwilling to share details of its parts, manufacturing process, and its simulation tools. Convergent has created a case study that is representative of the typical aerospace manufacturing process using a fictional composite wing skin part. This part is notional, representing a typical wing skin but it does not exist as a manufactured part. The wing skin design and its finite element representation are shown in Figure 1.



(a)

(b)

Figure 4. (a) Notional composite wing skin showing distinct layup zones, (b) finite-element representation of the wing skin and tooling for process modelling.

An idealized CAE chain for manufacturing this wing skin is shown in Figure 2. This CAE chain includes design stages because, in composites processing, the manufacturing process informs the design. In particular, the curing of the composite results in part deformation and residual stresses that are difficult to anticipate in the initial design. The tooling design is typically modified to include these effects so that the part that is produced meets the geometric and structural design requirements.

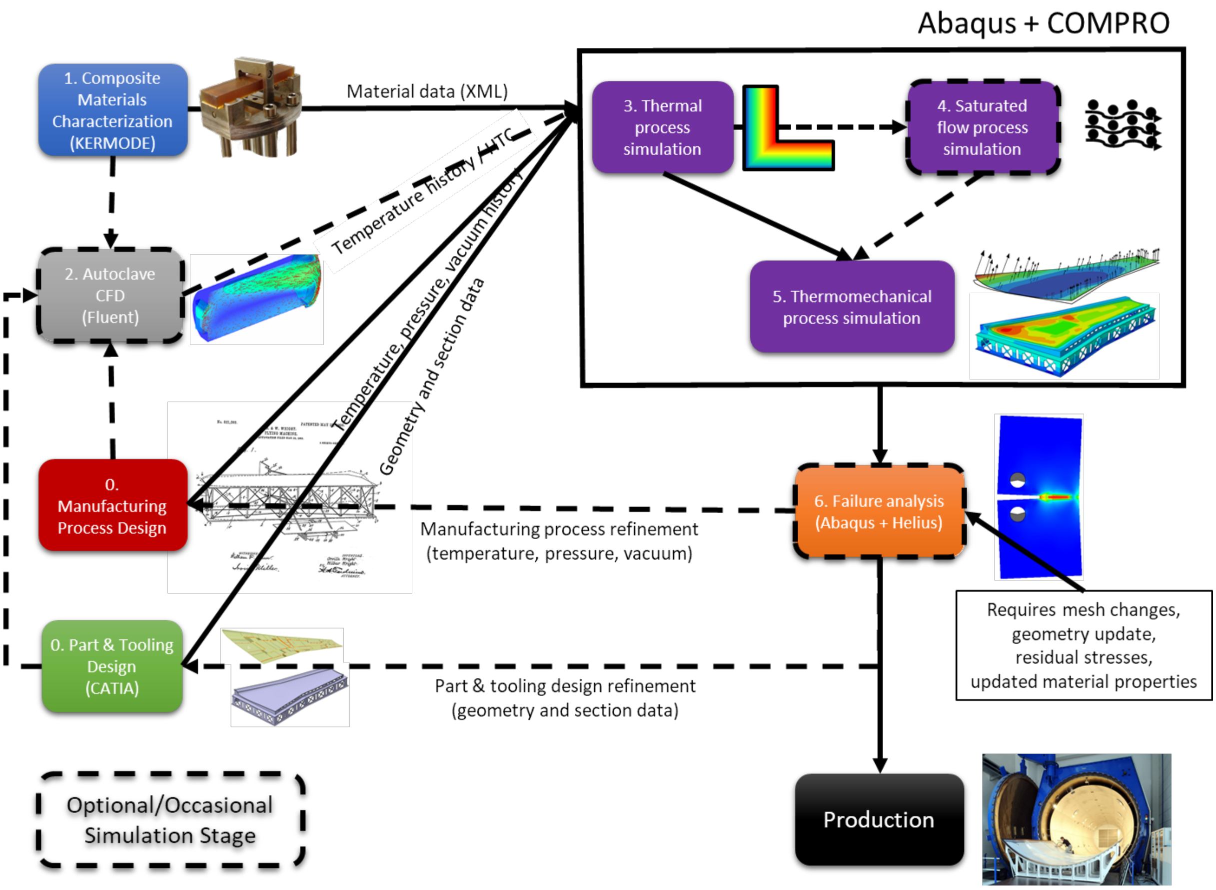


Figure 5. An idealized CAE chain for aerospace manufacturing of a carbon-fibre reinforced plastic part.

The CAE workflow in this idealized chain includes software from several vendors which perform different classes of simulations. There is design software (CATIA), material characterization software (KERMODE), computational fluid dynamics software (Fluent), finite element analysis software (Abaqus, COMPRO), and failure analysis software (Helius PFA). Geometry, material property, state data need to be transferred between each design and simulation tool, and prior to the VMAP project, these data exchanges were performed manually or with the aid of custom-written scripts. With the establishment of a VMAP standard for data exchange, and the support of the standard by the mapping and analysis software providers, this data exchange will cease to be a bottleneck in the simulation workflow.

This presentation will detail the “Composites in Aerospace” use case, explaining the use of the tools at each stage of the CAE chain, the data exchange required between the stages, and show the current state of the VMAP project as it relates to these tools and this specific use case.

The ITEA VMAP Project: How the Simulation Workflow of Blow Moulded Plastic Parts Benefits from the VMAP Interface Standard

P. Michels, O. Bruch (Dr. Reinold Hagen Stiftung, GER)

The extrusion blow moulding process is the standard manufacturing method for hollow plastic parts like bottles, cans, fuel tanks and large containers. The applicability to complex geometries in conjunction with relatively short cycle times ensures a high economic efficiency of the process. However, because of increasing quality standards and competition with alternative processing methods, companies involved with extrusion blow moulding have to continuously enhance the quality of their products. There is a big industrial need for more reliable and more efficient design methods with faster response times. Therefore, the use of CAE methods is increasingly gaining attention. Consequently, the use of simulation procedures not only reduces development costs and time, but also reduces the need for prototypes and physical tests.

One of the biggest challenges regarding the CAE workflow for blow moulded products is the high complexity which involves a lot of data transfer between the different simulation steps. Dr. Reinold Hagen Foundation based in Bonn, Germany has been working on the enhancement of the CAE workflow of extrusion blow moulded parts for many years. The standard CAE workflow involves the process simulation of the parison inflation followed by the simulation of several product tests like drop tests, internal pressure tests or top-load tests. More recent research activities are dealing with the cooling behaviour - including a CFD analysis of the cooling channels inside the mould - and the related simulation of shrinkage and warpage which is a topic of increasing industrial demand. The following figure gives an overview of the whole CAE workflow.

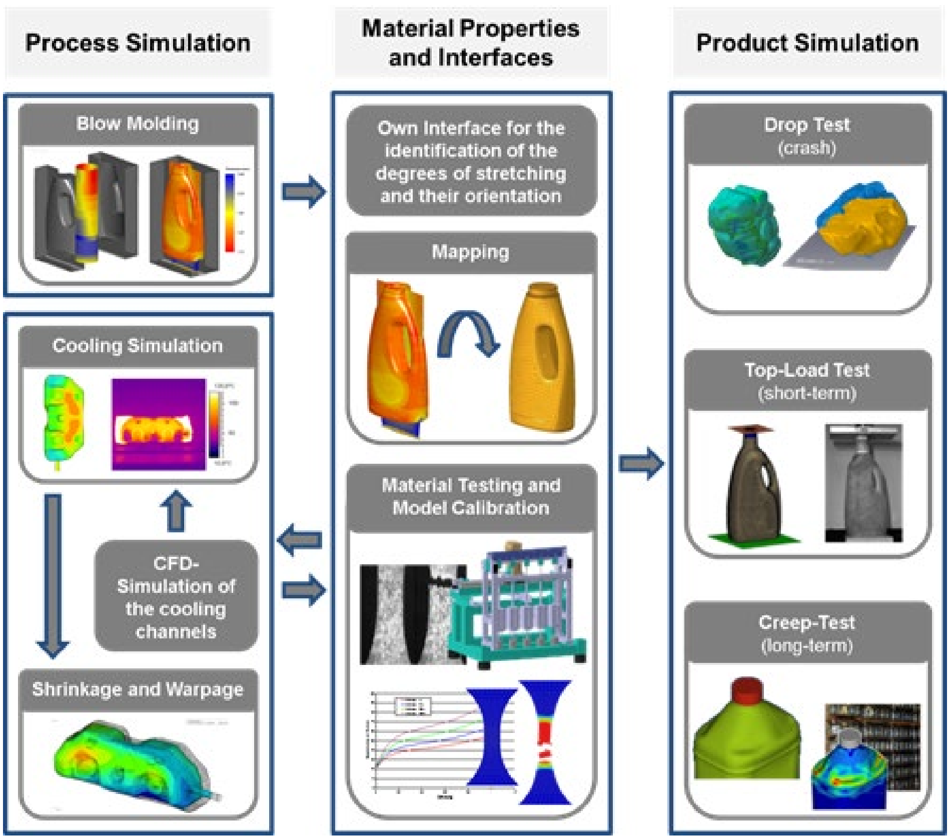


Figure 1: Simulation workflow of extrusion blow moulded products

As mentioned, the workflow involves several interfaces and data mapping between different simulation tools. A lot of research work has been carried out in the last years to consider the whole process history in the structural analysis more precisely. Because the stretching of the parison during inflation induces molecule orientations which are associated with orthotropic process dependent material behaviour, an own interface has been developed to identify the local degrees of stretching and their orientation using the results of the process simulation. Another important outcome of the process analysis - usually carried out by Accuform/B-SIM - is the wall thickness distribution which is needed by all following analysis steps. All these data have to be mapped to different structural analysis meshes, element types, and material models and correlated with data from material testing.

Currently, a standardized and partly automated CAE workflow already exists but mainly the data transfer from the process simulation to the following structure analysis steps has been considered. Beyond that there are also a lot of additional data transfer tasks between cooling simulation, shrinkage and warpage simulation and product simulation. This involves parameters like e.g. local heat transfer coefficients, the temperature field for every step in time and residual stresses. So every time the workflow is enhanced, a large amount of work is put into solving data transfer problems. The use of different simulation tools like Simulia/Abaqus, Hyperworks/Radios or Hyperworks/Acusolve makes the data transfer even more challenging.

The current workflow of blow moulded parts already utilizes first prototypes of the VMAP Standard in combination with own wrappers e.g. for Simulia/Abaqus. However, this is still associated with a lot of development effort and a partly inefficient solution for only one solver. Therefore, the simulation workflow would highly benefit from a further support of the VMAP Standard in common simulation tools. These benefits can be summarized as followed:

- The further development of the CAE workflow for blow moulded plastic parts which might involve new tools, other material models etc. will be much faster and much more efficient by the use of standardized interfaces. So the research focus can be laid rather on new simulation routines or new material models than on data transfer problems which are quite time consuming.
- Currently only specific structural solvers are used for each step in the workflow. A change of the solver is not straightforward because of proprietary tools and necessary manual adaptations. But in some cases it might be useful to use different solvers because one solver cannot always be the best choice for many different simulation tasks. Therefore, the VMAP Interface Standard could offer much more flexibility to use different simulation tools for different simulation steps.
- Furthermore, due to the better and easier integration of the process history, the use of a VMAP Standard could improve the prediction accuracy of the simulation models. Although the correlation between simulation results and physical experiments is quite high in specific cases (i.e. top load), the results can be further improved by e.g. considering of shrinkage and warpage and utilization of nonlinear viscoelastic material models. The improved virtual models will significantly improve the prediction accuracy which in turn will decrease prototype and material costs (i.e. costs for sampling, material, tool changes).

Acknowledgement

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Prediction of Warpage by Combining Plastic Flow and Structural Simulations

M. Groen (Philips Health Tech, NLD)

In consumer products there are numerous examples of products that consist of parts where metal and plastic are combined. In practice, most consumer products are produced in large numbers using mass manufacturing techniques like stamping and injection molding. If metal and plastic are combined in one part, the metal subpart is made by stamping and the plastic part by injection molding. The metal part is clamped in an injection molding die, where the plastic is injected on the metal part. The metal and the plastic have an interaction of stresses and strains, which can cause the product to change in shape after fabrication. This effect is called warpage. When the cavity of the injection molding die is an exact copy of the CAD file, the final product will deviate from the CAD file caused by the warpage. If the warpage can be predicted in the design phase, the cavity or process settings can be adjusted, to account for the warpage.

Numerical analysis can be a useful tool to look at the production process, before the product is made. In the case of metal-plastic combinations, the numerical model for the fabrication of metal parts has to be combined with the numerical model of the fabrication of the plastic parts. Metal forming requires a different type of analysis than injection molding, since the behavior of the material is different. Metal forming uses plastic deformation of the material in solid state (structural analysis), where the plastic injection molded part is produced in the liquid state (fluid dynamics). Metal formed products are packed with residual stress causing warpage and injection molded product solidifies with a certain amount of shrinkage causing warpage. When a metal part and a plastic part are combined, the warpage is caused by a combination of liquid and solid state phenomena. The aim of Philips is to use the result of a mold flow calculation in a structural calculation in MSC.Marc. This requires a transfer of information from Moldflow to MSC.Marc and is the goal of VMAP. The material information of Moldflow can be used in MSC.Marc because the flow of material is small after injection molding. The material is still liquid, but the large deformations caused by injection molding (where Moldflow is needed) are done.

The presentation will focus on the benefit of combining information of different platforms by performing a calculation of the VMAP demonstrator. Focus will be on material models for solidification of plastic the material models of metal forming, the structural calculation of warpage and the interaction of the processes leading to warpage. The model results will be compared with experimental results to evaluate the accuracy.

VMAP

Interoperability of Engineering Data within Integrated CAE Workflows

- **a defined international standard**
- **integrated import/export and translation tools**
- **supported by leading software vendors**

The VMAP standard and import/export interface tools will provide users with a vendor-neutral methodology of transferring material and engineering data between different CAE software along the whole simulation process chain.

The VMAP project will be demonstrated by different manufacturing use cases:

- extrusion blow moulding (Rikutec)
- composite light weight vehicles (AUDI)
- injection moulding (Bosch)
- hybrid modelling of consumer products (Philips)
- composite component in aerospace (Convergent)
- additive manufacturing (Bosch)

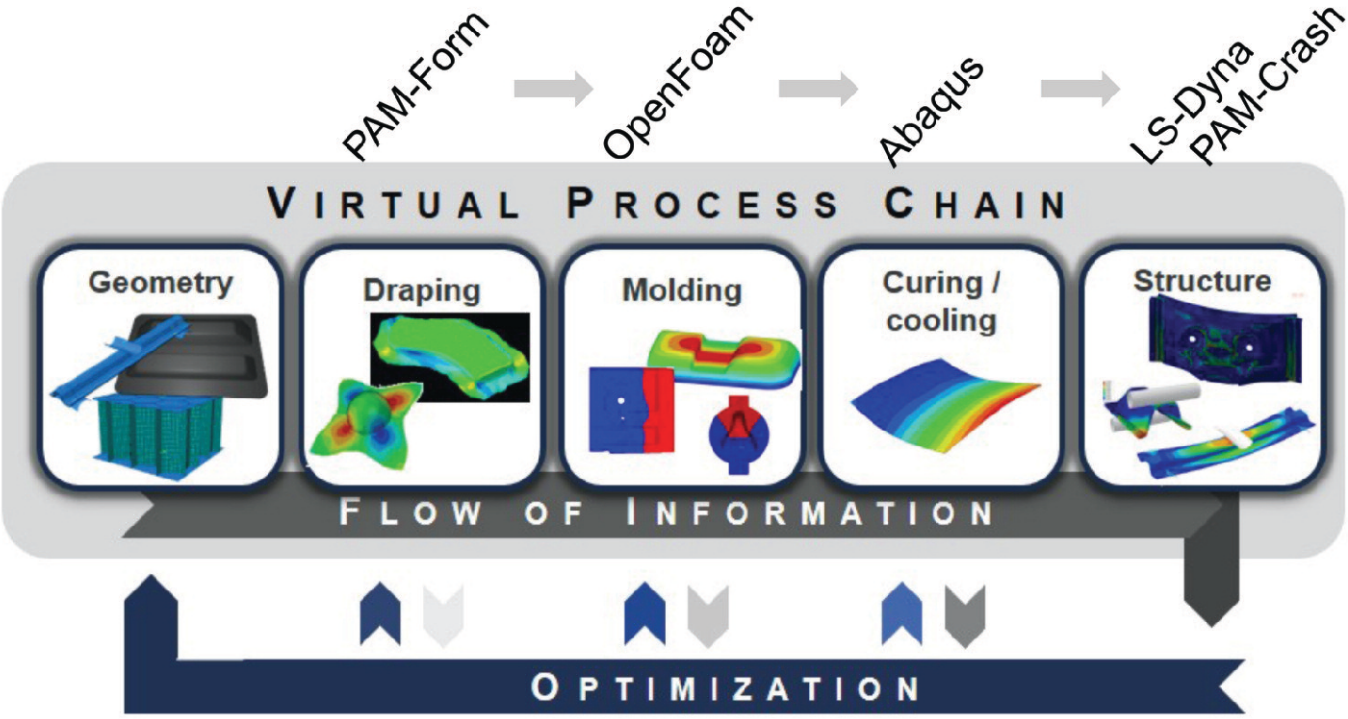
VMAP has already been directly integrated into CAE tools like MSC-Marc, MSC-Nastran, CadMould, PAM-RTM, PAM-Crash, Open-FOAM, COMPRO and RAVEN as well as independent/neutral translation tools like envyo that supports the LS-DYNA suite, Digimat, FiberMap, MpCCI and the ANSA pre-processor.

The VMAP project objectives are endorsed by Audi, Bosch, EDAG, Rikutec and Philips.

BOSCH Invented for life EDAG RIKUTEC GERMANY RIKUTEC Group PHILIPS

Use Case Example – Composite Lightweight Vehicle (AUDI)

Codes integrated in this workflow are: PAM-Form (draping), OpenFOAM (moulding), Abaqus (curing and cooling) and LS-Dyna resp. PAM-Crash (structural analysis).



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Development and validation of a CAE chain for unidirectional fibre reinforced composite components.
Composite Structures 132: 350–358, 2015. dx.doi.org/10.1016/j.compstruct.2015.05.047

VMAP Standards Community

The VMAP Standards Community has been established to drive the standards and software development effort during and after the initial project. We have held 2 web-meetings already but on 23 November 2019 we will hold a face-to-face meeting in Frankfurt, Germany.

We are open to all experts and entities who require successful VMAP standards and tools so please contact us without delay **vmap.eu.com/community**

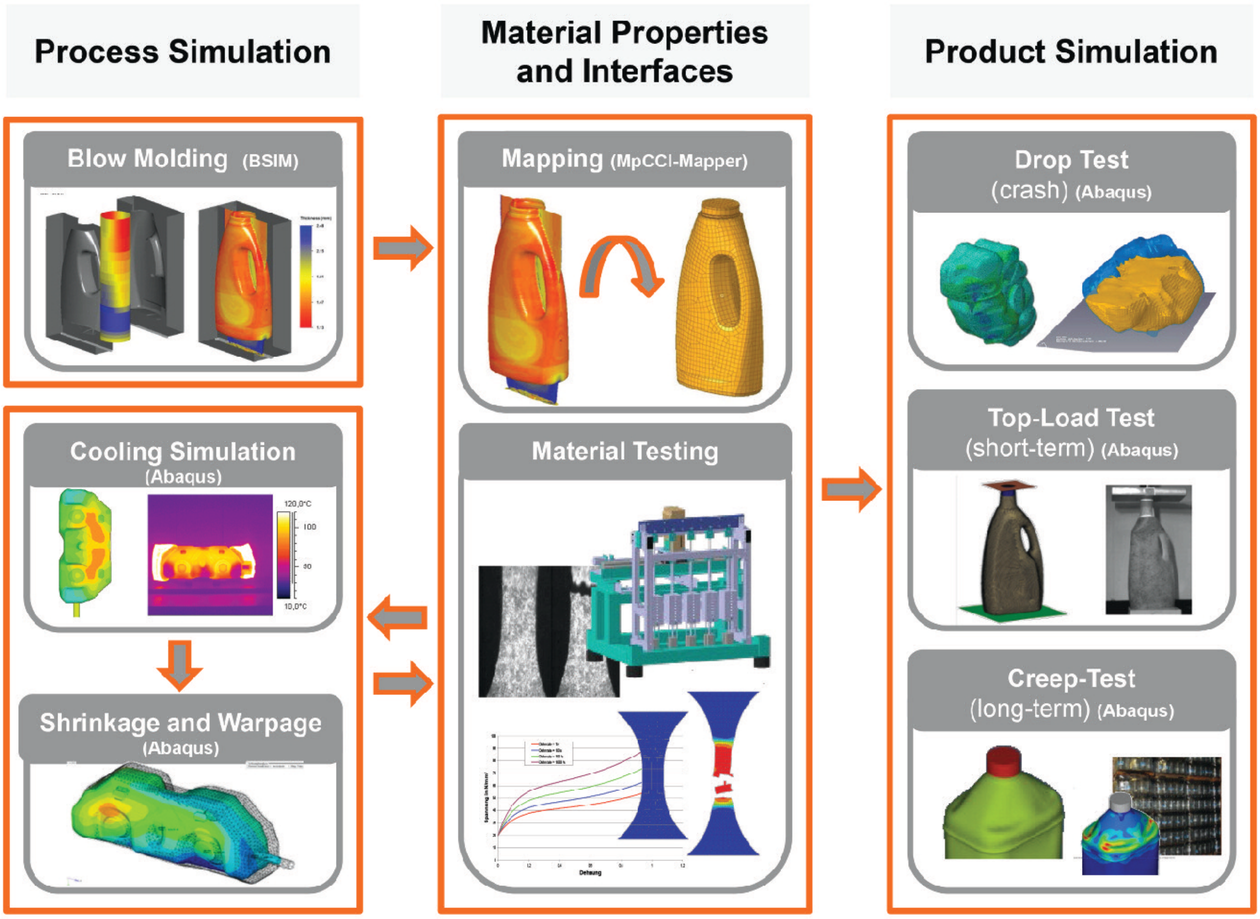
Complex workflow?
Difficult material data transfer?

The more simulation processes we look at the better the VMAP Standard will be in a shorter period. Please contact us if you would like us to examine your process and consider it in our work.

info@vmap.eu.com | www.vmap.eu.com

Use Case Example – Extrusion Blow Moulding (Rikutec)

Codes integrated in this workflow are: B-Sim (blow moulding), Abaqus (cooling & shrinkage), Abaqus resp. RADIOSS (structural performance and crash).



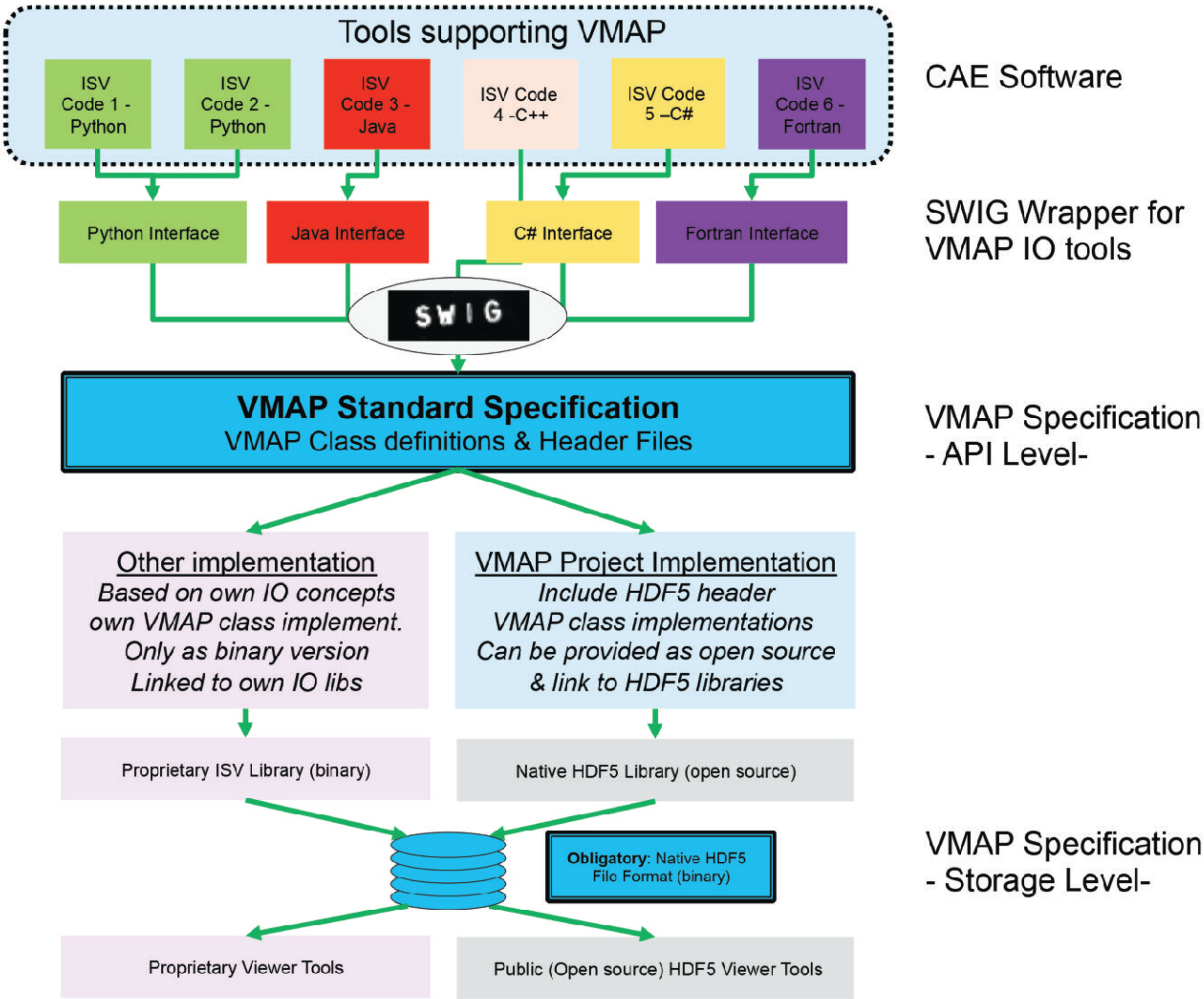
Help for Software Developers

To enable quick and efficient incorporation of the VMAP standards into any CAE software VMAP will provide a set of Input/Output software tools to write/read directly with the VMAP standard database implemented on top of **HDF5 hdfgroup.org/solutions/hdf5/**

These tools will be placed in a **SWIG wrapper swig.org** that will enable CAE software written in any programming language to directly call the VMAP IO tools.

Alternatively, Independent Software Vendors may create their own IO routines for direct and efficient reading/writing to the HDF5 VMAP standard database.

Included in the tools provided for developers will be a series of small test cases that can be used to check the functionality of any implementation.



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