VMAP

Virtual Material Modelling in Manufacturing

D1.7 State Of The Art

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Edited by: Fraunhofer SCAI - Priyanka Gulati

List of Authors

4a Engineering	Bernhard Jilka
	Peter Reithofer
Wittmann Battenfeld GmbH	Filipp Pühringer
MSC Software Belgium S.A.	*undefined*
Convergent Manufacturing Technologies Inc.	Anthony Floyd
Audi AG	Tim Bergmann
Dr.Reinold Hagen Stiftung/Hagen Engineering GmbH	Olaf Bruch
	Patrick Michels
DYNAmore GmbH	Christian Liebold
	Tolga Usta
EDAG Engineering GmbH	Lukasz Lasek
ESI Software Germany GmbH	Sebastian Müller
Fraunhofer SCAI	Andre Öckerath
	Klaus Wolf
	Priyanka Gulati
inuTech GmbH	Giannoula Mitrou
	Niels Sondergaard
Karlsruhe Institute of Technology (KIT)	Constantin Krauß
	Luise Kärger
Kautex Maschinenbau GmbH	*undefined*
NAFEMS Deutschland, Österreich, Schweiz GmbH	Gino Duffett
RIKUTEC Richter Kunststofftechnik GmbH & Co. KG	Daniel Grotenburg
Robert Bosch GmbH	Joachim Strauch
	Matthias De Monte
Simcon kunststofftechnische Software GmbH	Liyona Bonakdar
	Max Mades
Delft University of Technology	Jilt Sietsma
DevControl B.V.	Cor de Vries
In Summa Innovations b.v.	Maarten Oudendijk
KE-Works	Bastiaan Beijer
Material innovation institute M2i	Anouar Krairi
	Jesus Mediavilla
MSC Software Benelux	Pieter Vosbeek
Philips	Harm Kooiker
	Jan Siegersma
Reden BV	Edwin Lamers
	Lambert Russcher
University of Groningen	Anthony Vakis
BETA CAE System International AG	George Mokios
	Thanasis Fassas
e-Xstream engineering	Laurent Adam
Sintratec	Christian von Burg

Abstract

This document describes the State of the Art analysis of technologies, modelling and interfaces, which will be relevant for the VMAP project. Since, the state of the art was already provided as part of the project proposal. This document details the state of the art from the beginning of the project till the end of the project, what has been learnt so far including the new issues that have been identified.

After an introduction to this document an overview of interface. This is followed by the technologies which are needed to implement the VMAP stanadrd interface. Finally, the use cases and the state of the art per use case is discussed in detail.

Abbreviations

CAE	Computer Aided Engineering
FEM	Finite Element Methods
FEA	Finite Element Analysis
SWIG	Simplified Wrapper and Interface Generator
API	Application Programming Interface

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Chapter 1

Introduction

Computer aided engineering (CAE) departments in industries are using different varieties of software tool for material simulation in parameterisation of virtual manufacturing and machining processes and in product tests. All CAE tools have an internal representation of the material data and in almost all the cases these material representations cannot be used by another CAE tool. Although, the exchange of data is paramount to a successful CAE workflow process, there aren't many standardized formats for data exchange. This leads to a case-basis implementation accounting for huge amount of effort. The standardisation of material interfaces in CAE is therefore vital for all industry segments where material behaviour is central to product and process design. Hence, the ITEA VMAP project aims to gain a common understanding of, and interoperable definitions for, virtual material models in CAE. VMAP aims to:

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

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. VMAP Consortium encompasses multiple domains of manufacturing world, hence having a comprehensive atmosphere for developemnt of a standard. Table 6.1 summarizes the contributing partners and their contributions, as they are reflected in the first version of the document.

Organisation	Country	Role in Project
4a engineering GmbH	AUT	expertise in plastic and composite materials, mechanical material characterization, material modelling and simulation method development
Audi AG	GER	as an automotive OEM AUDI has advanced experience in using modern materials in its product design - within VMAP, AUDI will especially focus on composite materials and parts
BETA CAE Systems International AG	CH	BETA is a CAE software house and will provide its enhanced software simulation solutions to end-user AUDI and EDAG in their workflows
Convergent Manufacturing Technologies Inc.	CAN	ISV and engineering services provider for Composite parts in Aerospace Industry
Delft University of Technolgy	NLD	Knowledge provider
DevControl B.V.	NLD	(Industrial) Software development
Dr. Reinold Hagen Stiftung	GER	R&D: Independent non-profit research institute in the area of plastic engineering with a focus on extrusion blow moulding and mechanical engineering
DYNAmore GmbH	GER	Software development to chain simulation process together
EDAG Engineer GmbH	GER	Advanced experiance in virtual product development for a wide range of customers (OEMs and SMEs) by using a huge number of different CAE codes and software packages
ESI Software Germany GmbH	GER	Development of virtual prototyping solutions
Fraunhofer SCAI	GER	Fraunhofer is provider of vendor neutral interfaces for data transfer in CAE workflows. A standardised 'material data interface' will help to extend the applicability of its tools
Hagen Engineering GmbH	GER	Provider of commercial engineering services in the field of the development of plastics parts and blow moulded articles, reaching from small bottles to large containers. Customer support along the complete development chain of blow moulded product

In Summa Innovation b.v.	NLD	Positioned in the area of simulation execution and related validation activities. Knowledgable in simultaion processes
inuTech GmbH	GER	Experience in CAE and in interfacing software tools related to CAE. inuTech develops and markets the Diffpack Product Line for numerical modeling and solution of Partial Differential Equations (PDEs)
Karlsruhe Institute of Technology (KIT)	GER	The Institute of Vehicle System Technology (FAST) at KIT has long-term experience in composite process and structural simulation. Based on this background, KIT provides material models and interface requirements
Kautex Maschinenbau GmbH	GER	Providing text data and experimental results
KE-works	NLD	Solution provider, CAE workflow integrator
Materials innovation institute M2i	NLD	M2i connects industrial needs on material related technologies with academic research. Resulting models describing material behaviour have to be adopted by industry and integrated in software applied by industry
MSC Software Belgium S.A.	BEL	MSC Software Belgium (e-Xstream) is a CAE tool provider and will provide its enhanced software solutions to end-user Robert Bosch GmbH in their workflows
MSC Software Benelux	NLD	Deliver FEM software to simulate through process modeling
NAFEMS Deutschland, Österreich, Schweiz GmbH	GER	NAFEMS is the International Association for the Engineering Modelling, Analysis and Simulation Community
Philips	NLD	Industrial end-user
Reden BV	NLD	service provider in virtual prototyping, virtual testing, multi physics, tool developer
RIKUTEC Richter Kunststofftechnik	GER	Industrial end-user (SME) who will deploy the developed CAE workflows for its product and process design
Robert Bosch GmbH	GER	Industrial end-user
Simcon kunststofftechnische Software GmbH	GER	Simcon supports with its injection molding simulation software suite the value chain from the design phase until serial production
Sintratec	CH	AM Machine Manufacturer (Polymer Laser Sintering)
University of Groningen	NLD	R&D provider

Wittmann Battenfeld GmbH	AUT	Wittmann Battenfeld GmbH offers all kind of injection moulding machines and technologies and is a specialist for the variothermic technology as well as for foamed parts (Cellmould technology)

Table 1.1: Contributing partners, fields of expertise and contributions

Chapter 2

Related Projects & Technologies

2.1 Introduction

This chapter explains the related EU Projects which have focussed towards material models and other industrial standards which are being used by some industries in specific domains.

2.2 Related Research Projects

Project Name	Cooperative Programme	Time Period	Technical focus	Relationship
RedPro	Germany BMBF FH-profUnt	2010 - 2013	extrusion blow moulding (EBM), experimental determination of material data, finite elemente simulation (FEM) of shrinkage and warpage	FE models for shrinkage and warping
MatRes	Germany Chek.NRW	2012 - 2015	EBM, experimental determination of process depending material data, Virtual Testing (FEM)	Process depending material props
ReBauVES	Germany BMBF FH-profUnt	2015 - 2018	EBM, material data determination: experimental and by the use of molecular dynamics simulation, FEM with focus on time dependent (viscoelastic) material behaviour, process depend. mat.-model.	Process depending material models

Fortissimo	EU FP7	2015-2016	Fh SCAI and KIT work on a prototype workflow for RTM components to be used on dedicated HPC systems with focus on remote access and automating of a simple workflow.	workflow can be used in VMAP as initial solution
TC² RTM CAE/CAx	Germany / Baden-Württemberg	2011-2014	Development of a continuous virtual process chain for RTM structures, using MpCCI.MapLib to transfer relevant computational data. The CAE chain is not automated nor universally formulated.	workflow can be used in VMAP as initial solution
Arena2036	Germany BMBF	2013-2017	Focus on intelligent lightweight design with function integration, efficient manufacturing processes and related digital prototypes.	Use experience on interfaces
CompTab	Germany, BMWi-LuFo	2011-1014	A continuous tool chain was developed in cooperation with the aerospace industry.	Use experience on interfaces
MAI Hiras + Handle	Germany BMBF	2014-2017	Development of a motorcycle rear swinging fork made of different composite materials/types; consideration of automatization as well as the manufacturing process.	Experience and selective usage of typical use cases
ULWAK	Germany BMBF	2011-2014	Development of a lightweight train structure with multi material design.	Use experience of use cases
Press Perfect	RFCS	2012-2015	Comparing 3 types of stainless steel and develop predictive models for the 3 type of multi stage production routes.	Use material date, demos and models

MAI Design	Germany BMBF	2012-2015	Composites: construction methods, consistent process simulation chain, structural simulation, testing, engineering.	Use interface format concepts
MAI Form	Germany BMBF	2014-2017	Material development, simulation and forming of thermoplastic composites	Use interface concepts
MAI qfast	Germany BMBF	2012-2015	Comparison (Benchmark) of various materials and processing routes for one demonstrator product supported by FE analysis during design and evaluation of hardware tests	Material data and the values can be used as starting point

Table 2.1: Related collaborative research projects.

Other Standards in the industry are discussed below.

2.3 STEP - STandard for the Exchange of Product model data

ISO 10303 (ISO, 2000) is an International Standard for the computer-interpretable representation of product information and exchange of product data. Its official title is: Industrial automation systems and integration — Product data representation and exchange. It is known informally as **"STEP"**, which stands for " **St**andard for the **E**xchange of **P**roduct Model Data". The objective is to provide a neutral mechanism capable of describing product data throughout the life cycle of a product independent from any system. STEP AP209 ed2 is one such standard for sharing, exchanging and long term archiving of engineering design and multi-disciplinary simulation data (Figure 2.1) [1].

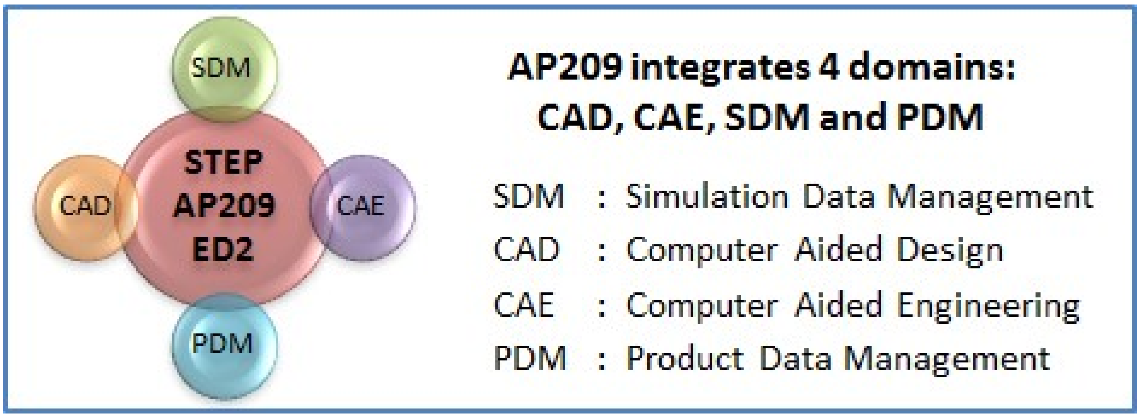

Figure 2.1: AP209 Main concepts [1]

STEP AP209 ed2 – Application Protocol: Multidisciplinary analysis and design Formerly known as Part 209:2001 – Application Protocol: Composite and metallic structural analysis and related design is concerned with sharing, exchange and long term archiving of data between the iterative design and analysis stages of product life cycle. The disciplines covered by AP209 are Structured Finite Element Analysis, Computational Fluid Dynamics and Kinematic Analysis (Figure 2.2) [1]

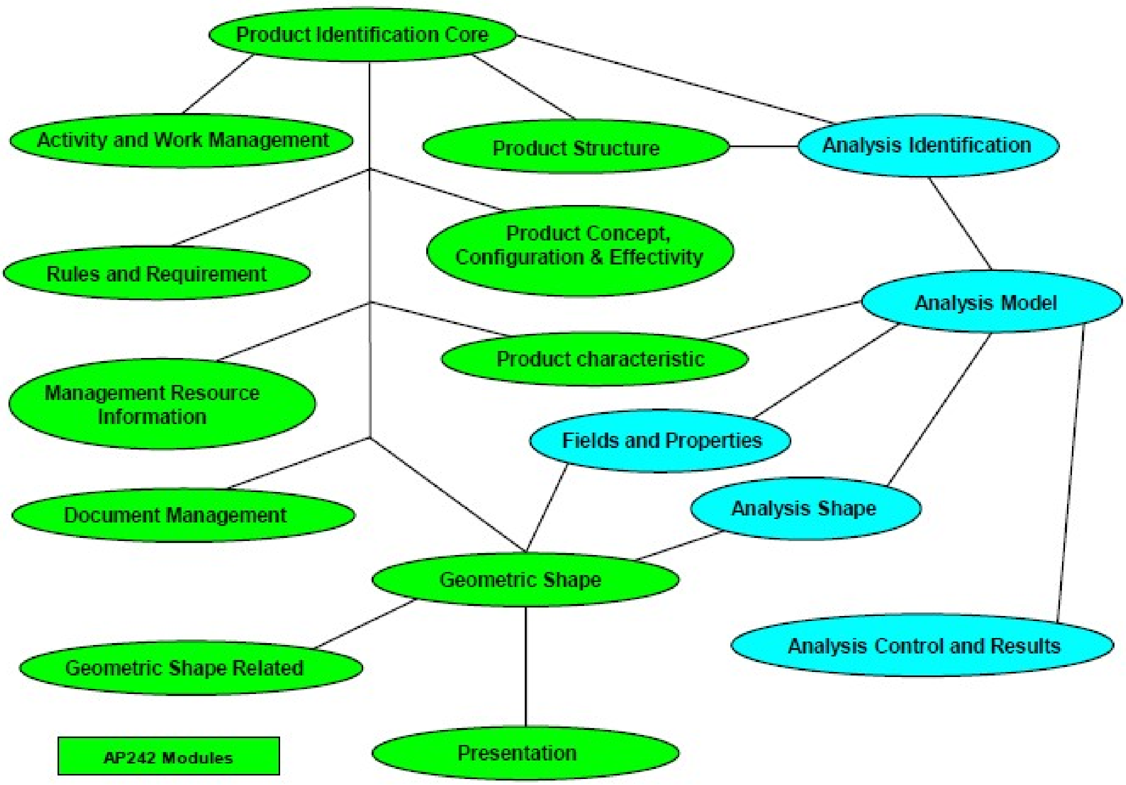

Figure 2.2: AP209E2 High Level Overview – Data Planning Model [1]

2.4 LOTAR – LOng Term Archiving and Retrieval

The objective of LOTAR International is to develop, test, publish and maintain standards for long-term archiving (LTA) of digital data, such as 3D CAD and PDM data. The LOTAR project consortium consists of user companies from around the world. Member companies include Airbus, BAE Systems, Boeing, EADS, Eurocopter, General Dynamics, Lockheed Martin, SAFRAN, Sandia, and others [2].

LOTAR Composites Workgroup

- The objective of the LOTAR Composites Workgroup is to develop, publish and maintain standards designed to provide the capability to archive and retrieve CAD 3D composite structure in a standard neutral form that can be read and reused throughout the product life cycle, independent of changes in the IT application environment originally used for creation. This workgroup has extensively used the ISO 10303 Information models, AP203 "Configuration-controlled design" and AP209 "Composite & metallic structural analysis & related design" standards [2].

LOTAR EAS: Engineering Analysis & Simulation Workgroup

– EAS WG launched in December 2014 is developing capabilities for archiving, retrieval and reuse of valuable engineering simulation and analysis assets. They also rely closely on ISO STEP AP209 ed2 “Multidisciplinary analysis and design” [2].

2.5 EMMC – The European Materials Modelling Council

The EMMC elaborates methodologies and supports the development and implementation of open, widely endorsed metadata schema for interoperability and standards based on the **European Materials Modelling Ontology (EMMO)** framework [3], EMMO covers all aspects of material modelling : behavior, governing physics law, mathematical representation in a solver and post processing data.

2.6 Current Trends

Until last year, while VMAP was still under its early development stages, either there was no data transfer or sotware vendors & industries were spending a lot of man-hours to develop software specific transfer tools. This approach is not only time consuming but also inefficient. Additionally, some large companies like Philips use experimental methods to test the new processes since there is no possiblity to simulate this on software tools. This incurs cost and takes years before a process becomes part of a process chain. However, if we consider that there is a standard data storage format available in the industry, then any relevant software tool can be used to run a required simulation and then the results can be transferred to the next tool using the VMAP data storage format. This would cater to multiple manufacturing industries as a quick solution to simulate a process chain instead of spending huge amounts of money and time over experimental tests.

Chapter 3

VMAP Standard for CAE Interoperability

The ITEA VMAP project, see details in Appendix A, aims to gain a common understanding of, and interoperable definitions for, virtual material models in CAE. Using industrial use cases from major material domains and with representative manufacturing processes, new concepts are being created for a universal material exchange interface for virtual engineering workflows.

3.1 Problem Statement

Computer aided engineering (CAE) departments in industries are using different varieties of software tool for material simulation in parameterisation of virtual manufacturing and machining processes and in product tests. All CAE tools have an internal representation of the material data and in almost all the cases these material representations cannot be used by another CAE tool. Although, the exchange of data is paramount to a successful CAE workflow process, there aren't many standardized formats for data exchange. This leads to a case-basis implementation accounting for huge amount of effort. The standardisation of material interfaces in CAE is therefore vital for all industry segments where material behaviour is central to product and process design.

3.2 Proposed Solution - VMAP Standard

The concepts generated within the VMAP project will be concretised in an open software interface standard and implemented in a number of software tools. The advantages of integrated material handling will be demonstrated by six industrial use cases from different material categories, manufacturing domains and industry segments. In brief, VMAP will:

- generate universal concepts and open software interface specifications for the exchange of material information in CAE workflows.

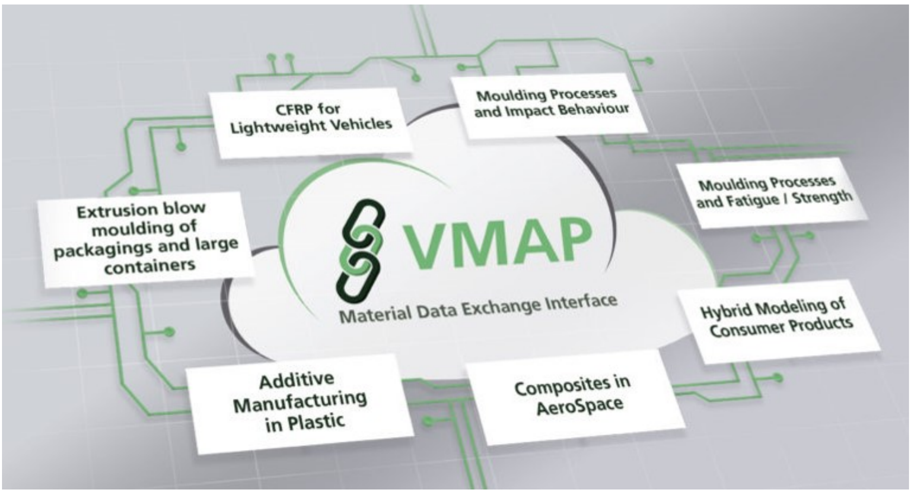

Figure 3.1: Industrial Use Cases will show the need and benefits of a standardised Material Exchange Interface.

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

3.3 Challenge

Overall, some efforts have been made in regard to bringing standard file formats or standard specifications to the industry, the penetration of such standards has been limited to a few specific industries, mainly aero-industry (see Chapter 6). The standardizing of storage formats has been paramount to the Aero-industry because it is essential to use data in the long term. Changing data formats over the years would have been a huge financial and technical blunder for this industry. However, other manufacturing markets might not need data for long term archival, they definitely need it for interoperability among various softwares. With a wide range of application specific CAE tools in the market, the need for a common standard, which allows use of any software the user wishes, has become primary if not indispensable. Hence, VMAP Standard is a step forward in the standardization of output file formats. With multiple partners, it was possible to gather varied use cases from different domains of the manufacturing industry, thus assisting in a comprehensive development of the standard.

Chapter 4

Requirement Analysis for VMAP

The VMAP consortium involves more than 30 companies from all over Europe and North America. This includes the 10 manufacturing industries and the rest are CAE software developers. All the members of the consortium offer different industrial use cases, hence making VMAP a wholesome standard covering a vast variety of materials used for manufacturing. Based on this vast majority of use cases, some of the critical requirements for VMAP are listed below:

1. VMAP should contain result information in detail.
2. VMAP should contain all data necessary to map the results.
3. VMAP should be capable of storing transient analyses.
4. VMAP should be able to use any of the standard unit systems.
5. VMAP files should be useful for both batch and automatic execution modes.
6. VMAP should be capable of storing custom coordinate systems, both local and global.
7. VMAP should be useful for all known operating systems.
8. VMAP files should be accessible with the help of free/open source tools.
9. A service and support community should exist, even after the project ends.
10. Software maintenance should be carried out on a regular basis.

These are few of the very basic requirements, which form the building blocks of VMAP. These critical requirements and many others formed the basis of VMAP and led to a standard which covers the geometrical and material domain in CAE.

Chapter 5

VMAP Software Architecture

This chapters explains the VMAP software architecture (Figure 5.1), briefly going through all the layers. The further chapters then focus on each layer in detail.

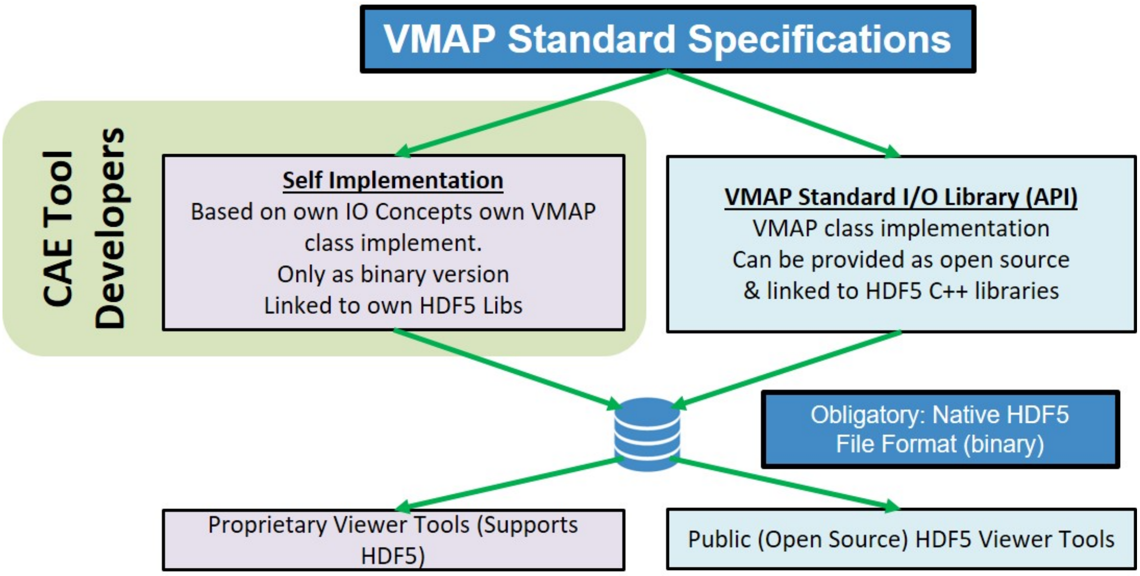

Figure 5.1: VMAP Software Architecture

VMAP Standard Specifications are at the core of the software architecture. VMAP offers two possibilities for any user. First, is to use the VMAP Standard Specifications via the VMAP Standard I/O Library (API) built in C++. The second option is to implement your own VMAP I/O classes using the VMAP Standard Specifications. The only obligation is to use the native HDF5 file format as the output. HDF5 file format is an optimal and apt output option for VMAP because HDF5 Viewer is an open source tool, just like VMAP Standard Specifications are open source. Section 5.3 explains HDF5 Technology in detail.

The VMAP Standard I/O Library or **VMAP Standard API** is explained in detail in chapters 3 & 4 in Standards Document. The option to implement your own VMAP

I/O Library is explained with schematic diagrams in chapter 6.

5.1 VMAP Interface to CAE Tools

Almost all CAE tools offer API, these API are used by ISVs to build codes. ISV codes written in C++ can be directly linked to the 'VMAP Standard API'. ISV codes written in Python, Java, C# or FORTRAN utilize the 'VMAP Standard API' through a language specific interface. For Python, Java and C# such a language specific interface can be automatically generated using the **Simplified Wrapper and Interface Generator (SWIG)**(Section 5.2). For FORTRAN the language specific interface is possible but must be written manually. Figure 5.2 shows the extended software architecture.

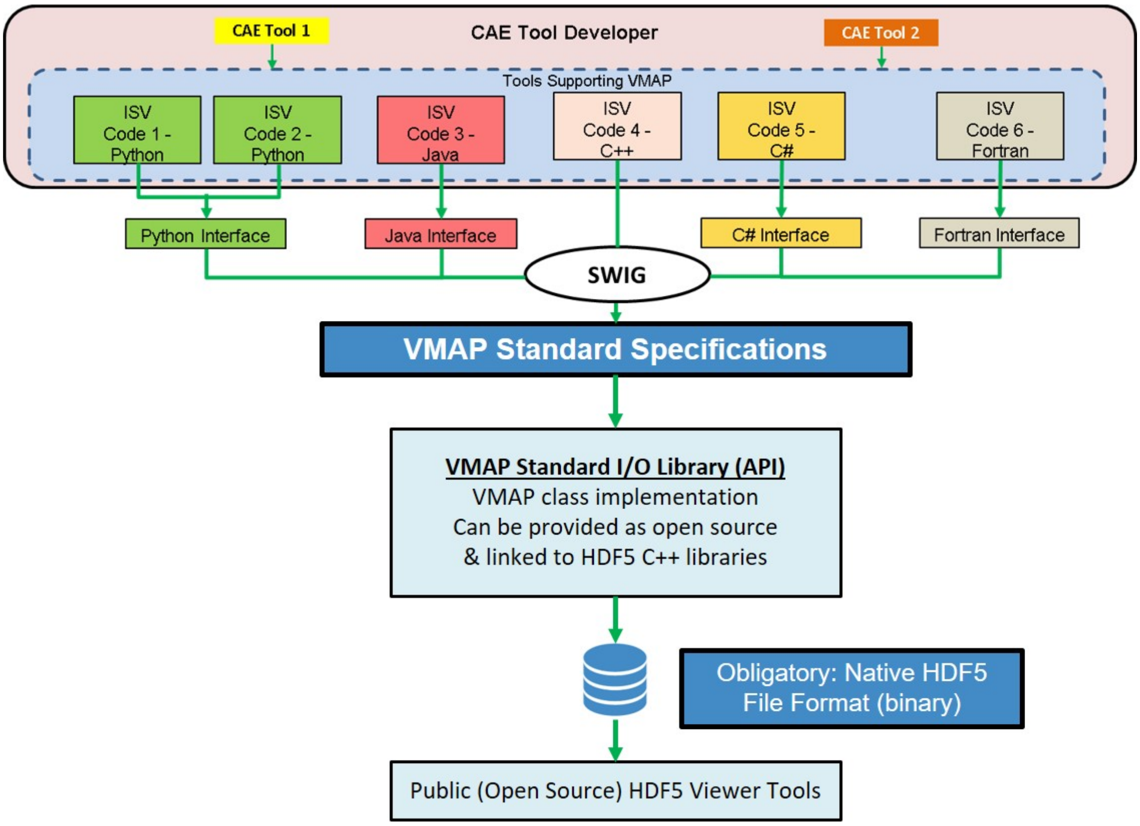

Figure 5.2: Extended VMAP Software Architecture

The VMAP Standard API and its role in a chain CAE simulation process is represented in (Figure 5.3). The image shows two simulations, Blow Moulding simulation carried out using Code A and Cooling simulation carried out using Code B. The cooling simulation requires the output result of the blow moulding simulation. Such a situation arises very often in the industry, where results of one simulation are required to carry out another simulation. Since, there are multiple CAE tools (Codes) available in the market, each time a combination of tools is used a new specific converter needs to be developed. This is where VMAP Standard comes into the picture, with all CAE tools providing VMAP Standard format as one of the output options, the specific converters will become unnecessary. VMAP Standard will facilitate reusability and thus, time saving. Since VMAP Standard is currently in development phase, the converter is replaced by an external VMAP converter. As the standard is completely formalised, the VMAP Standard API can be directly integrated into the CAE tool.

CAE tools which additionally require a Mapper to map data from Simulation Model A to Simulation Model B, can also have the Mapper integrated with the VMAP Standard API.

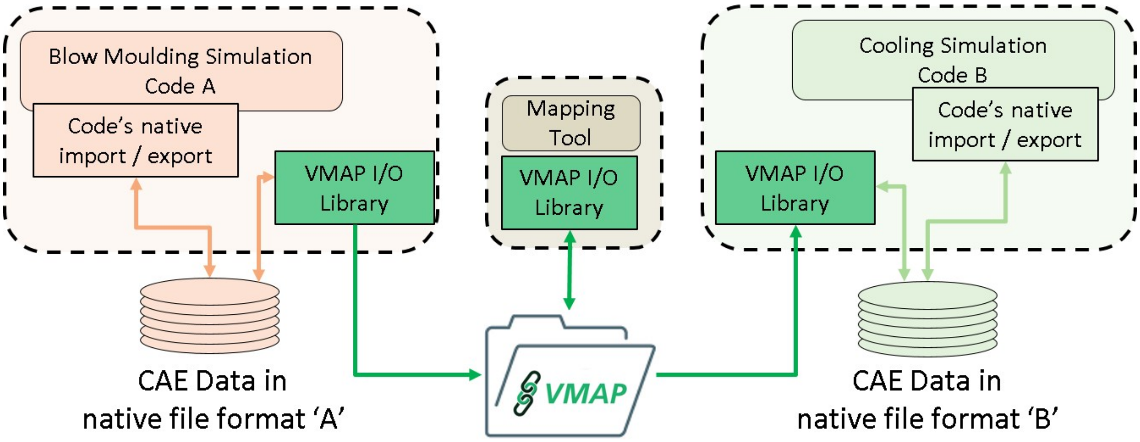

Figure 5.3: VMAP Standard API in CAE chain simulation process

5.2 SWIG

SWIG is a software development tool that connects programs written in C and C++ with a variety of high-level programming languages. SWIG is used with different types of target languages including common scripting languages such as JavaScript, Perl, PHP, Python, Tcl and Ruby. The list of supported languages also includes non-scripting languages such as C#. SWIG is most commonly used to create high-level interpreted or compiled programming environments, user interfaces, and as a tool for testing and prototyping C/C++ software. SWIG is typically used to parse C/C++ interfaces and generate the 'glue code' required for the above target languages to call into the C/C++ code [4]

5.3 HDF5 technology

The VMAP interface and transfer file relies on the HDF5 technology. The Hierarchical Data Format (HDF) implements a model for managing and storing data. The model includes an abstract data model and an abstract storage model (the data format), and libraries to implement the abstract model and to map the storage model to different storage mechanisms. The HDF5 Library provides a programming interface to a concrete implementation of the abstract models. The library also implements a model of data transfer, an efficient movement of data from one stored representation to another stored representation. The figure below illustrates the relationships between the models and implementations. This chapter explains these models in detail.

The Hierarchical Data Format version 5 (HDF5), is an open source file format that supports large, complex, heterogeneous data. HDF5 uses a "file directory" like structure that allows you to organize data within the file in many different structured ways, as you might do with files on your computer. The HDF5 format also allows for embedding of metadata making it self-describing.

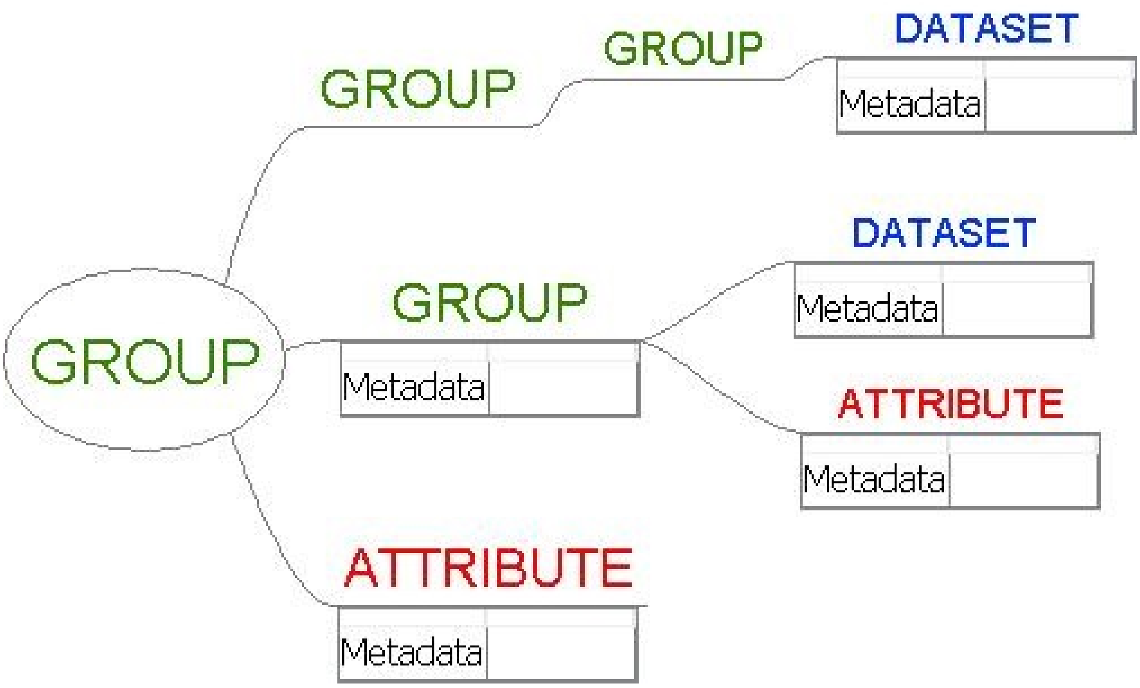

Figure 5.4: HDF5 file format

Chapter 6

VMAP Use Cases

This chapter describes the seven VMAP use cases created to demonstrate the VMAP standards being used within industrial simulation workflows in different sectors.

UC.1	Blow Forming
UC.2	Composite for Lightweight Vehicles
UC.3-1	Injection Moulding – impact
UC.3-2	Injection Moulding – foaming
UC.3-3	Injection Moulding – creep
UC.4	Additive Manufacturing
UC.5	Plastic Metal interaction
UC.6	Composites in Aerospace

Additional input file information is provided in digital form, please contact the VMAP Standards Community via the website.

6.1 Use Case UC.1 Blowforming

Sector: Extrusion blow moulding

6.1.1 Description and Final product

Integrated simulation and optimization workflow for blow moulded plastic parts considering geometry changes because of shrinkage and warpage.

The product range of extrusion blow-moulded plastic parts ranges from thin-walled packaging products like bottles or cans, to highly stressed technical parts like fuel tanks or intermediate bulk containers (IBC), see Figure 6.1.

Figure 6.1: Blow moulded components

6.1.2 Process description

The CAE workflow of blow moulded products cover the manufacturing process, as well as the product behaviour of the final part (structural analysis), see Figure 6.2.

The process simulations give information e.g. about the wall thickness distribution and the shrinkage and warpage, which significantly influences the product properties of the final part. Therefore, all the information regarding the process history (e.g. temperatures, residual stresses, or wall thickness) needs to be stored and transferred between the different simulation steps. In combination with high advanced material models, this integrative simulation approach makes it possible to predict the product properties of blow moulded parts with a very high accuracy.

Simulation Steps	Custom Interface	VMAP Interface
Blow Moulding Simulation		
transfer	yes	yes
Custom Code		
transfer	yes	yes
Cooling Simulation		
transfer	yes	yes
Shrinkage & Warpage		
transfer	no	yes
Product simulation		

Table 6.1: Blow Moulding: Status & Progress

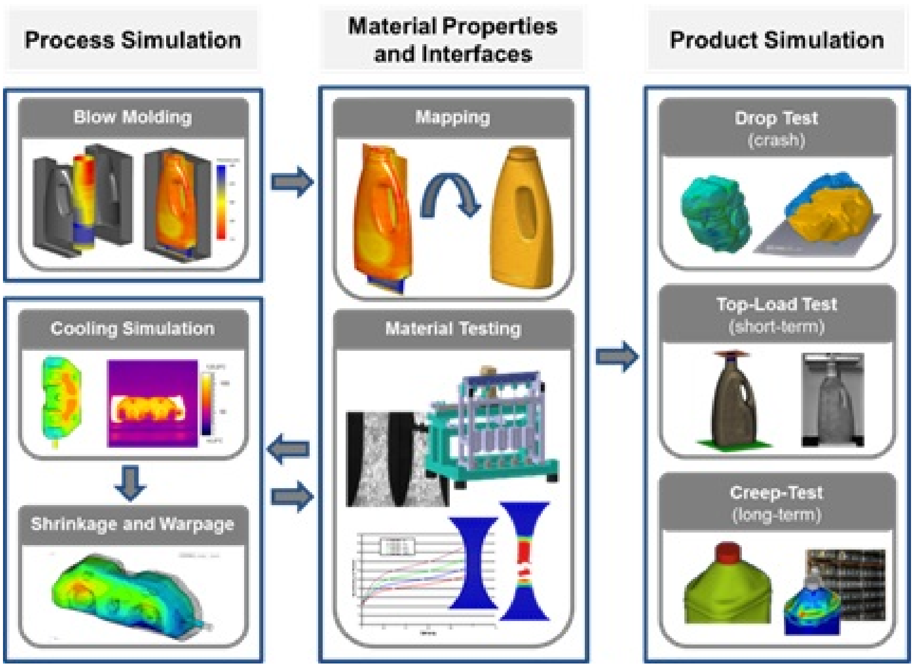

Figure 6.2: Simulation process workflows - Blowforming

6.1.3 Process requirements and advantages

The product performance of blow moulded parts is highly influenced by the process conditions. Therefore, the whole process history (e.g. local wall thickness, temperatures, residuals stresses, principal strain etc.) needs to be transferred between several simulation stages also involving different solvers and meshes.

The benefits of a standardized and self-acting virtual process chain are significant shorter development times and considerably more precise simulation models.

6.1.4 Simulation issues prior to VMAP

The main issue and challenge concerning a more realistic simulation in combination with a less time consuming CAE workflow is the lack of standardized interfaces. So it‘s currently difficult e.g. to use alternative solvers for different simulation.

6.1.5 User benefits/business case

More accurate simulation methods allow higher product performance of blow moulded plastic parts with less material consumption and shorter cycle times. Due to standardization and automation of the CAE-workflow, time consuming data transfer between different simulation stages can be avoided. In addition, the accuracy of the simulation models will be increased because the whole process history is taken into account. Furthermore, the automated data transfer makes the whole simulation process more user-friendly.

6.2 Use Case UC.2 Composites for Lightweight Vehicles

Sector: Automotive lightweight technology

6.2.1 Description and Final product

Integrated simulation and optimization workflow for an automotive composite manufactured by the established Resin Transfer Moulding (RTM) technology to produce complex shaped composite parts.

An automotive underfloor structure made of continuous fiber-reinforced polymers (CFRP) is shown in the Figure 6.3 below.

Figure 6.3: Simulation process workflow - Composites for Lightweight Vehicles

6.2.2 Process description

The CAE workflow is shown in Figure 6.4.

Resin Transfer Moulding (RTM) is an established technology to produce complexly shaped composite parts. The figure below shows a standardized CAE workflow particularly from the view of high-performance composites in structural relevant automotive applications. The CAE chain shall efficiently combine all essential simulation steps and enable an integrated product development considering all relevant manufacturing effects and finally provide an integrated structural optimization over multiple simulation steps.

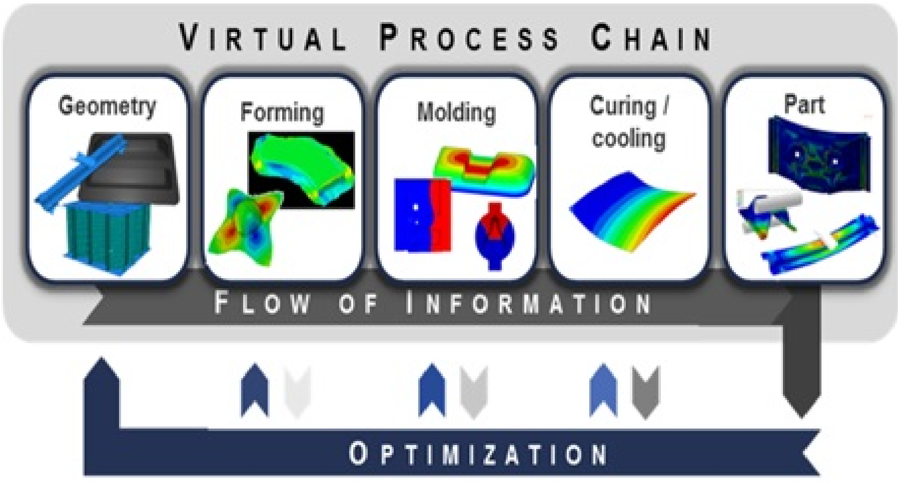

Figure 6.4: Simulation process workflow - Composites for Lightweight Vehicles

Simulation Steps	Custom Interface	VMAP Interface
Draping/Forming		
transfer	yes	yes
Infiltration/Molding		
transfer	yes	yes
Distortion		
transfer	no	yes
Structural		

Table 6.2: Composites for Lightweight Vehicles: Status & Progress

6.2.3 Process requirements and advantages

Results of forming simulation are required as initial conditions for subsequent simulations. This can help in reducing efforts for the development of product and reduce error in the part design evaluation.

6.2.4 Simulation issues prior to VMAP

The main issue and challenge is the mapping of the layered material including the transfer and mapping of fibre orientation, volume and density. The other difficult issue is the stress equilibrium after mapping has been carried out from the solid mesh to the shell mesh.

6.2.5 User benefits/business case

Standardized data interfaces within virtual workflows are able to reduce both the manual effort required for setting up or adapting virtual manufacturing chains and the related error-proneness. This is due to fewer custom helper tools and/or scripts, all involved parties speaking the same language with regard to modelling related terms, and more definitions are specified in an explicit form. From an end user's perspective those features contribute to achieve accelerated TTA of a product or solution, to reduce costs during development and increase the added value for possible costumer. Thereby, competitive advantages can be gained.

6.3 Use Case UC.3-1 Injection Moulding – Impact

Sector: Injection moulding of fibre reinforced materials

6.3.1 Description and Final product

For Short- and Long-Fibre Reinforced Thermoplastics (SFRT and LFRT) an integrative simulation will be performed. The transfer of the process induced fibre orientation as well as of further results of the injection moulding simulation (e.g. melt and weld lines) into structural explicit simulation will be researched. Especially the influence of simple to advanced approaches on prediction of energy consumption will be compared.

Injection moulded parts subjected to impact are shown in Figure 6.5.

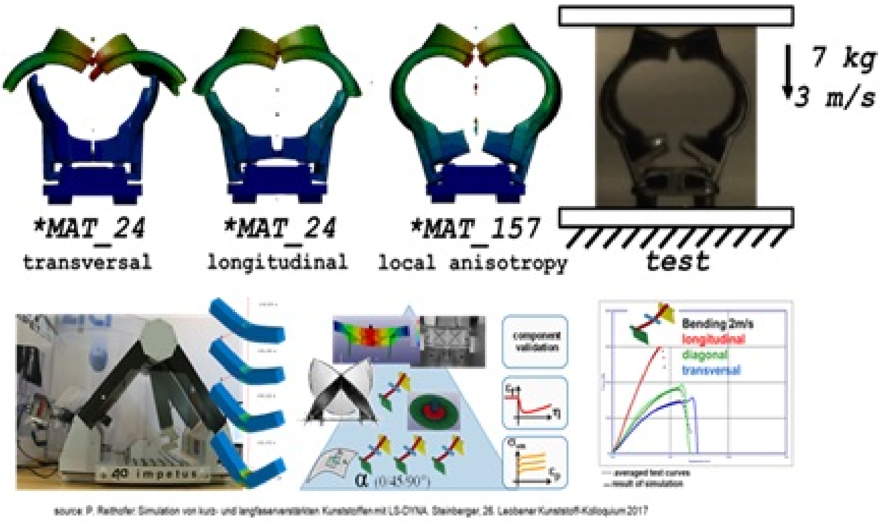

Figure 6.5: Injection Moulded Parts - Impact

6.3.2 Process description

The CAE workflow is shown in Figure 6.6.

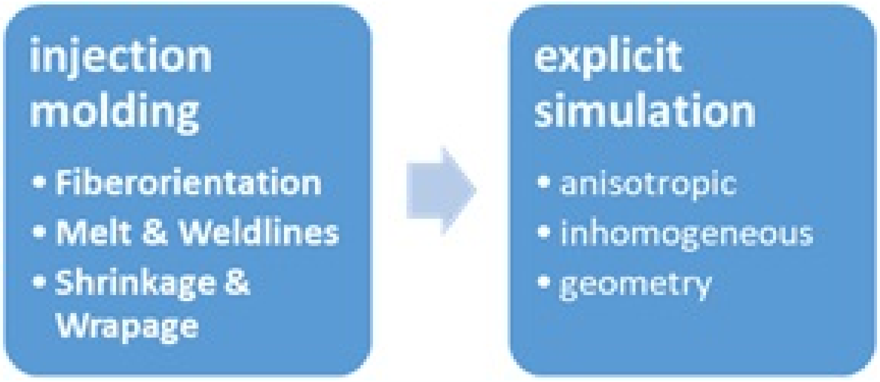

Figure 6.6: Simulation process workflow - Injection Moulding - Impact

Simulation Steps	Custom Interface	VMAP Interface
Injection Moulding		
transfer	yes	yes
Mapping		
transfer	yes	pending
Explicit Simulation		

Table 6.3: Injection Moulding - Impact: Status & Progress

6.3.3 Process requirements and advantages

From the injection moulding simulation (using Moldflow) the following information is required:

- fiber orientation,
- melt and weldlines,
- shrinkage and warpage.

From the impact simulation (using LS-DYNA) the following information is required:

- anisotropy,
- inhomogeneousness,
- geometry.

6.3.4 Simulation issues prior to VMAP

The main issue and challenge is the transfer and mapping of fibre orientation, volume and density and the transfer of custom result types such as porosity, bubble distribution, etc.

6.3.5 User benefits/business case

More accurate simulation methods allow higher product performance with reduced product development times.

6.4 Use Case UC.3-2 Injection Moulding – Foaming

Sector: Injection moulding of foamed components

6.4.1 Description and Final product

For foamed parts an integrative simulation will be performed. The transfer of the process induced bubble distribution and dimension into structural simulation will be researched. Some examples of injection moulded parts subjected to foaming are shown in Figure 6.7.

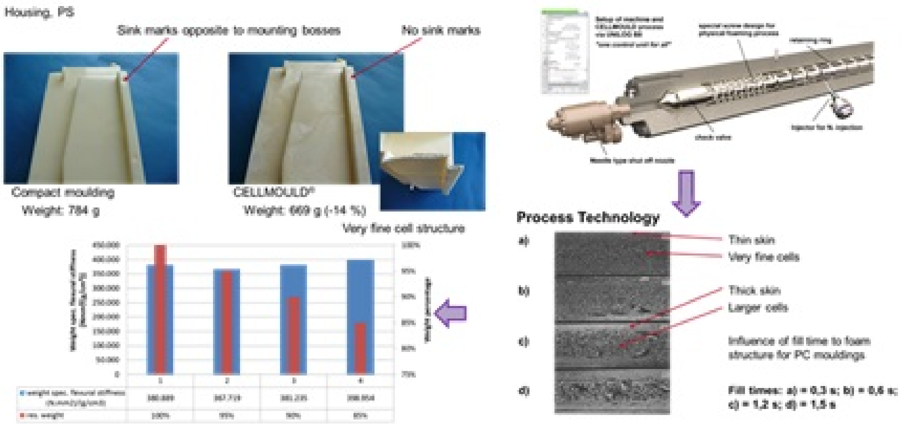

Figure 6.7: Injection Moulded Parts - Foaming

6.4.2 Process description

The CAE workflow is similar to that shown in Figure 6.8.

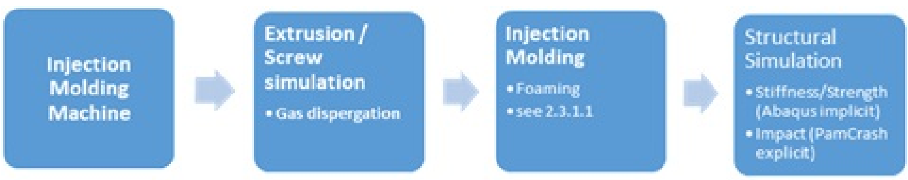

Figure 6.8: Simulation process workflow - Injection Moulding - Foaming

Simulation Steps	Custom Interface	VMAP Interface
Injection Moulding Machine		
transfer	yes	yes
Mapping		
transfer	yes	pending
Structural Analysis		
transfer	yes	pending
Strength Computation		

Table 6.4: Injection Moulding - Foaming: Status & Progress

6.4.3 Process requirements and advantages

From the injection moulding simulation(CADMould) the following information is required:

- process induced gas volume,
- bubble distribution.

From the foaming simulation the following information is required:

- density,
- bubble volume.

6.4.4 Simulation issues prior to VMAP

Without the knowledge about the gas volume and bubble distribution, the mass reductions in a part cannot be estimated correctly. The estimation of local mass reductions is necessary for the development of light weight products.

6.4.5 User benefits/business case

More accurate simulation methods enable lighter products due to better exploitation of material capabilities. A major benefit is the reduced product development time.

6.5 Use Case UC.3-3 Injection Moulding – Fatigue

Sector: Injection moulding of fibre reinforced materials

6.5.1 Description and Final product

As for the previous fibre-reinforced thermoplastics an integrative simulation will be done. The simulation chain will be validated on two fibre-reinforced parts, see 6.9

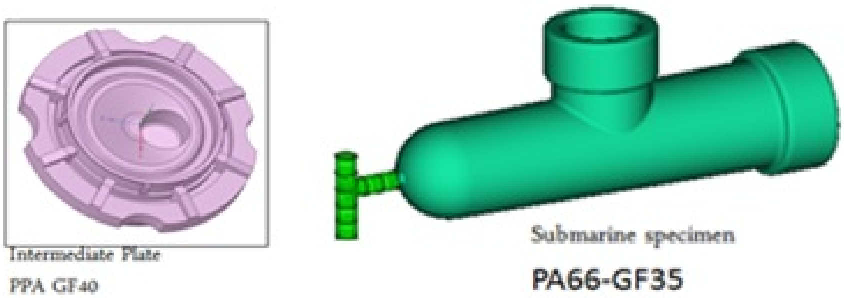

Figure 6.9: Injection moulded Components - Fatigue

6.5.2 Process description

The CAE workflow is similar to that shown in Figure 6.10.

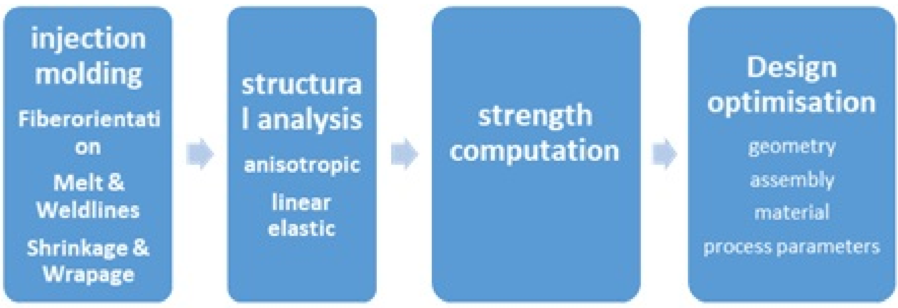

Figure 6.10: Simulation process workflow - Injection Moulding - Fatigue

Simulation Steps	Custom Interface	VMAP Interface
Injection Moulding		
transfer	yes	yes
Mapping		
transfer	yes	pending
Structural Analysis		
transfer	yes	pending
Strength Computation		
transfer	yes	pending
Design Optimization		

Table 6.5: Injection Moulding - Fatigue: Status & Progress

6.5.3 Process requirements and advantages

From the injection moulding simulation (using Moldflow) the following information is required:

- fiber orientation,
- melt and weldlines,
- shrinkage and warpage.

From the structural analysis simulation the following information is required:

- stresses/strains,
- energy field,
- element/integration point volume,
- element/integration point coordinates.

From the fatigue simulation (using FEMAT) the following information is required:

- lifetime,
- damage,
- safety factor.

6.5.4 Simulation issues prior to VMAP

The main issue and challenge is the transfer and mapping of fibre orientation, volume and density and the transfer of custom result types such as porosity, bubble distribution, etc.

6.5.5 User benefits/business case

The consideration of weld lines position and quality along the virtual product development workflow will substantially increase the accuracy of reliability predictions in the design of injection moulded plastic parts. Further, the simplification of the workflow itself will allow its adoption at a very early product development phase (A-sample). A better exploiting of the material capability will result in on-the-edge products allowing Bosch to extend its share in the market of exhaust gas treating systems for commercial vehicles. The workflow developed will be further rolled-out to other business unit at Bosch, as industrial applications, household goods, power tools and electric drives.

6.6 Use Case UC.3-4 Injection Moulding – Creep

Sector: Injection moulding of fibre reinforced materials

6.6.1 Description and Final product

Establish an integrated simulation and optimization workflow for injection moulded plastic parts to consider deformation dependent design optimizations.

6.6.2 Process description

The CAE workflow is similar to that shown in Figure 6.11.

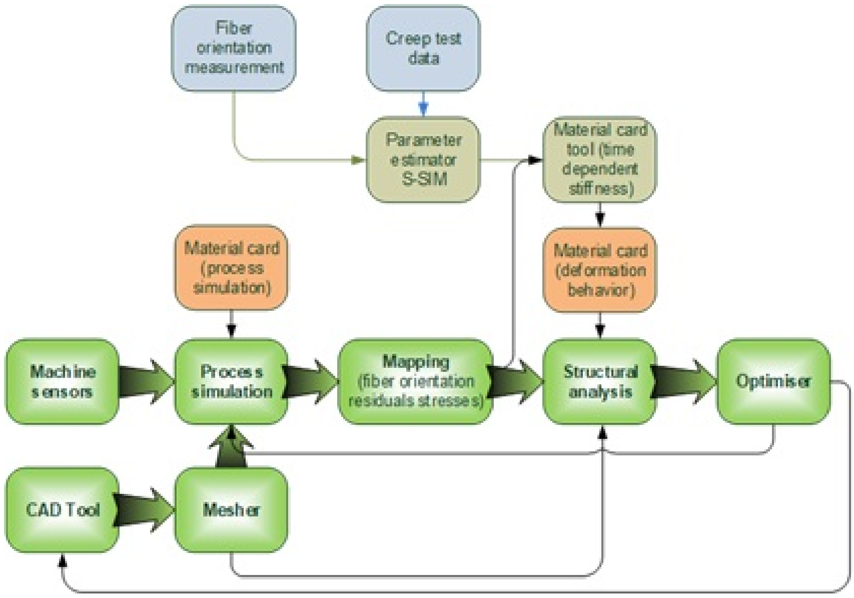

Figure 6.11: Simulation process workflow - Injection Moulding - Creep

Simulation Steps	Custom Interface	VMAP Interface
Injection Moulding		
transfer	yes	yes
Mapping		
transfer	yes	pending
Structural Analysis		

Table 6.6: Injection Moulding - Creep: Status & Progress

6.6.3 Process requirements and advantages

From the injection moulding simulation (using Moldflow) the following information is required:

- fiber orientation,

- melt and weldlines,
- shrinkage and warpage.

From the impact simulation (using LS-DYNA) the following information is required:

- anisotropy,
- inhomogeneousness,
- geometry.

6.6.4 Simulation issues prior to VMAP

The main issue and challenge is the transfer and mapping of fibre orientation, volume and density and the transfer of custom result types such as porosity, bubble distribution, etc.

6.6.5 User benefits/business case

A substantial simplification of the simulation workflow for assessment of creep deformation in short-fiber reinforced plastic parts will enable the introduction of such simplified integrative simulation chain in the virtual product development of steering product for automotive applications. Thanks to the increased accuracy in prediction of mechanical performance, more structural design elements will be made of reinforced plastics, contributing to lighter products and reducing manufacturing costs. These aspects will contribute to extend Bosch's market share in the highly competitive sector of electrical steering systems.

6.7 Use Case UC.4 Additive Manufacturing Plastics

Sector: Additive Manufacturing of plastics parts

6.7.1 Description and Final product

Establish an integrated simulation and optimization workflow for additive manufactured plastic parts (exemplified for SLS process) to optimize the building process, the part design and the parts function. Ensure first time right production. An example of an additive manufacturing part is shown in Figure 6.12 as represented in the Digimat-AM software-

Figure 6.12: Additive Manufacturing - Plastics

6.7.2 Process description

The CAE workflow is shown in Figure 6.13.

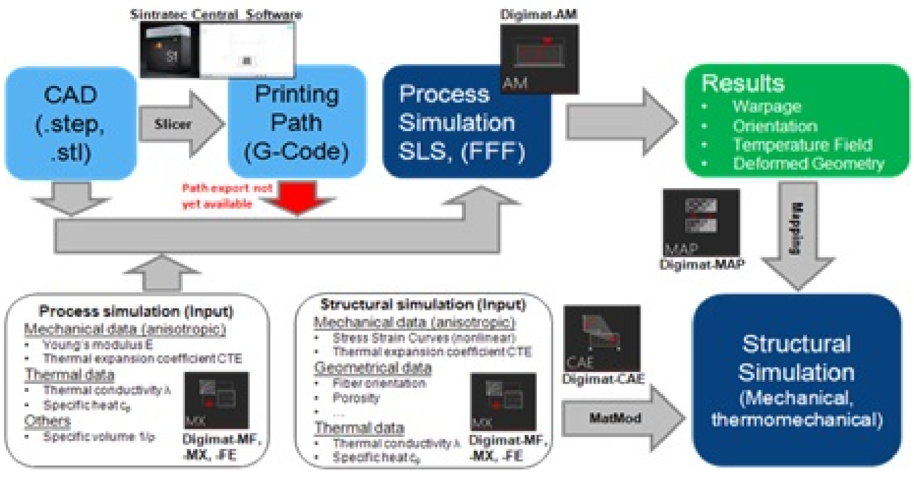

Figure 6.13: Simulation process workflow - Additive Manufacturing

Simulation Steps	Custom Interface	VMAP Interface
Printer Pre-processing		
transfer	yes	pending
Process Simulation		
transfer	yes	yes
Structural Simulation		

Table 6.7: Additive Manufacturing: Status & Progress

6.7.3 Process requirements and advantages

The product performance of blow moulded parts is highly influenced by the process conditions. Therefore, the whole process history (e.g. local wall thickness, temperatures, residuals stresses, principal strain etc.) needs to be transferred between several simulation stages also involving different solvers and meshes.

The Benefits of a standardized and self-acting virtual process chain are significant shorten development times and considerably more precise simulation models

6.7.4 Simulation issues prior to VMAP

The main challenge is the transfer of time dependent boundary conditions from printer to simulation.

6.7.5 User benefits/business case

The created CAE workflow for virtual product development of 3D printed plastic parts will be a key enabler for achieving "First-time-right production" with selective laser sintering technology. The resulting benefits for small series, as customized sensor housings and support parts for production lines, are higher part quality (less warpage, improved mechanical performance) and drastically reduced product development times as well as manufacturing costs. Further, the newly developed interface between Sintratec printers and Digimat AM will enable the implementation of more advanced printing strategies, allowing for fully exploiting the potential of 3D printing in terms of lightweight and optimized topology for specific applications.

6.8 Use Case UC.4 Hybrid Modelling of Consumer Products

Sector: Additive Manufacturing of plastic parts

6.8.1 Description and Final product

Philips seeks to further improve its production processes and the performance of its products.The product considered is the shaver shown in Figure 6.14.

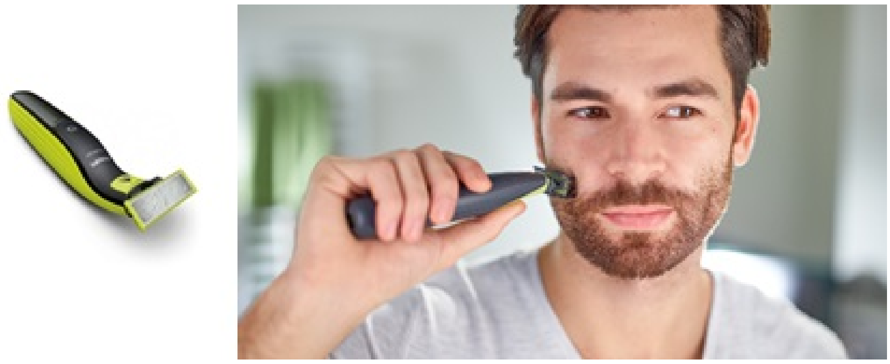

Figure 6.14: Shaver product and use.

6.8.2 Process description

The CAE workflow is shown schematically in Figure 6.15.

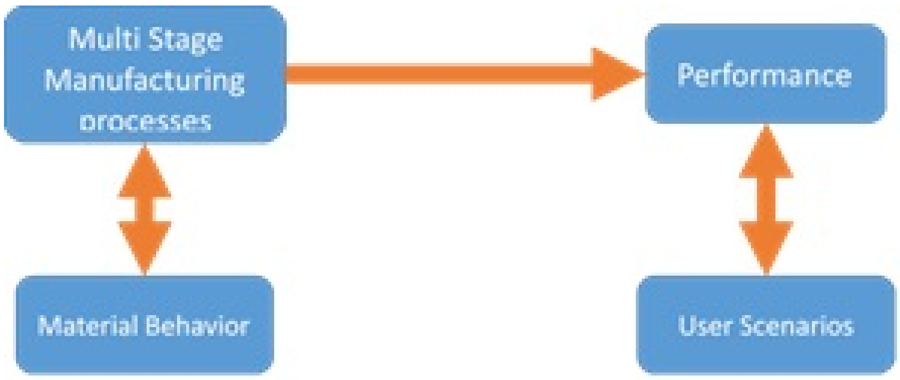

Figure 6.15: Simulation process workflow - Hybrid Modelling of Consumer Products

Simulation Steps	Custom Interface	VMAP Interface
Step 1		
transfer	yes	yes
Step 2		
transfer	yes	yes
Step 3		
transfer	no	yes
Step 4		

Table 6.8: Consumer Products: Status & Progress

6.8.3 Process requirements and advantages

To cut time-to-market and increase the speed of innovation, Philips and its partners aim to achieve a virtual process chain. Each partner in the consortium brings its unique knowledge and expertise to achieve the separate steps along the virtual development chain.

6.8.4 Simulation issues prior to VMAP

Currently, a complete virtual process chain is not realized due to difficulties in transferring results from solution A to B.

6.8.5 User benefits/business case

Combining the metal and plastic domains into a single simulation chain gives a more realistic prediction for the warpage of the hybrid plastic-metal product. Currently, experimental iteration cycles are needed to design a flat hybrid product with minimal warpage. These unavoidable iterations are not only cost-expensive but also time-expensive, as the costly physical moulding tooling needs to be adjusted manually for all iterations. Removing these manual adjustments has the potential to improve the overall efficiency of the design of the manufacturing process. VMAPs interoperability for that reason will deliver a business case for Philips, and in broader view for all other industrial parties that develop products making use of interacting manufacturing processes that cannot be described without CAE-interoperability.

6.9 Use Case UC.5 Composites in Aerospace

Sector: Composite manufacturing for commercial aerospace

6.9.1 Description and Final product

Virtual autoclave manufacturing for commercial aerospace parts. End-to-end simulations, design, and optimizations including material characterization, process simulation, shape optimization due to process-induced deformations, and process optimization for thermal compliance and processing defects.

The product considered ia a large, one-piece aircraft wing skin made from polymer matrix composites (carbon-fibre reinforced plastic), see Figure 6.16.

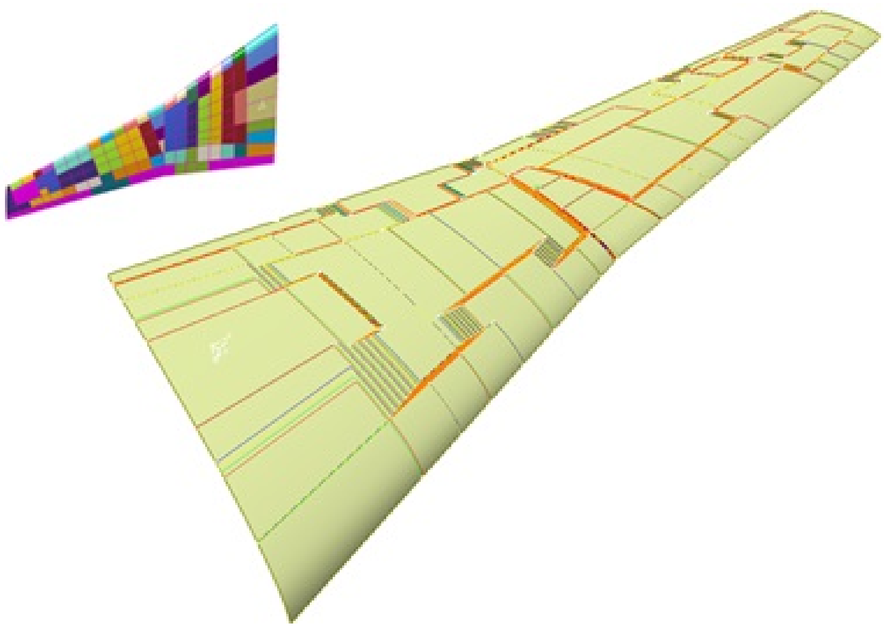

Figure 6.16: One-piece aircraft wing.

6.9.2 Process description

Virtual autoclave manufacturing for commercial aerospace parts, see workflow schematic Figure 6.17. End-to-end simulations, design, and optimizations including material characterization, process simulation, shape optimization due to process-induced deformations, and process optimization for thermal compliance and processing defects.

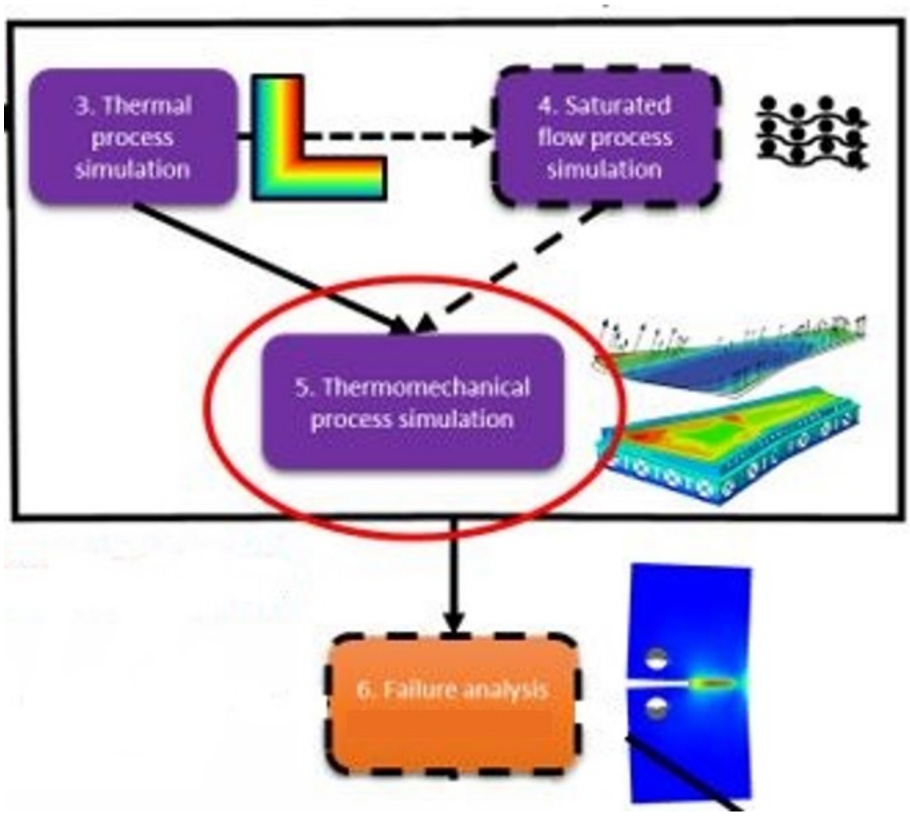

Figure 6.17: Simulation process workflow - Composites in Aerospace

Simulation Steps	Custom Interface	VMAP Interface
Thermal Analysis & Cure Simulation		
transfer	yes	yes
Saturated Flow Simulation		
transfer	no	yes
Thermo-mechanical Simulation		
transfer	no	yes
Failure Analysis		

Table 6.9: Composites for Aerospace: Status & Progress

6.9.3 Process requirements and advantages

The product performance of blow moulded parts is highly influenced by the process conditions. Therefore, the whole process history (e.g. local wall thickness, temperatures, residuals stresses, principal strain etc.) needs to be transferred between several simulation stages also involving different solvers and meshes.

The Benefits of a standardized and self-acting virtual process chain are significant shorten development times and considerably more precise simulation models

6.9.4 Simulation issues prior to VMAP

Many different physics are considered in the process chain, and the simulation requirements for each step are quite different. The computational fluid dynamics simulation requires a different mesh and boundary conditions than the thermo-chemical simulation, saturated flow, and stress/deformation simulations. The mesh required by the failure simulation is different again. Throughout the whole virtual process chain, boundary conditions, deformations, material state, and other process variables change in time. These changes must be communicated to each of the simulation stages. At the moment, there is no easy way to do this.

6.9.5 User benefits/business case

Use of the VMAP library in CAE tools commonly used in aerospace applications will reduce the time and effort required to perform analyses of different complexities and in different analysis domains. It is not uncommon for such analyses to involve several different software tools, each with their own file formats and data transfer capabilities, and often a significant amount of time is spent transferring data between these software packages. With specific focus on process simulation of composites manufacturing, material properties such as degree of cure, viscosity, modulus, and fibre orientation must be tracked in the laminates over time, and these histories need to be used in different domains. The VMAP standard allows this data to be transferred between these packages efficiently and accurately, reducing the overall analysis setup time and minimizing errors caused by manually transferring data between software applications. Time savings for complex, multi-stage analyses could be as much as 30%.

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