EARPA Task Force Modelling & Simulation Repositioning Paper into Methods and Tools for Virtual Development and Validation (MT4V)

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About EARPA

Founded in 2002, EARPA is the association of automotive R&D organisations. It brings together the most prominent independent R&D providers in the automotive sector throughout Europe. At present its membership counts at present 55 members, ranging from large and small commercial organisations to national institutes and universities.

1 Introduction

1.1 Overview

The actors of European road transport research commonly share an ambitious vision of a sustainable and inter-modal transport constantly improving safety and comfort while reducing emissions combined with largely reduced greenhouse gas emissions to limit the impact on climate change. The challenge is to reduce the dependency on fossil fuels without sacrificing efficiency, comfort, and compromising mobility[1].

In contrast to the traditional vehicle design process successfully applied over many years, the new challenge is to consider the vehicle as part of its intelligent environment (system of systems). Vehicles have to be designed as connected, cooperative, and automated, inside internet of the things[2].

The **digital transformation** is reshaping the transportation industry, and the automotive sector in particular. Highly connected vehicle functions such as advanced driver assistance, cooperative integrated safety systems, cloud-based comprehensive energy management, intuitive and safe HMI, visualization enhancement and automated driving functions are driving next generation mobility. All these functions have to work **correctly, reliably, fault-tolerant, and safely in any situation (24/7 availability) and in any weather conditions** in order to protect people, the environment, and in addition to save energy resources.

The **cross-cutting value of methods and tools for virtual development and validation** plays a crucial and vital role when aiming for a green, safe and high-quality transport system through a competitive European industry sector. Indeed, the global vehicle manufacturing industry is ever more capitalizing on modelling and simulation as a **means to frontload the design challenges into the virtual stage**. Both the mechanical and the mechatronics system performance must meet increasingly challenging customer demands, while reducing the production costs and shortening the time-to-market.

[1] EC, Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, 2011 and its extensions.

[2] EC, Declaration of Amsterdam on connected, cooperative, and automated vehicles, April, 2016.

1.2 Vision and mission

Methods and tools for virtual development and validation covering uncertainty quantification of simulation models (high-fidelity, multi-physics, multi-domain, scalable, real-time capable…) are seen as essential and critical activities by industry and academia for a successful product ramp-up.
In order to reduce development and testing costs mainly driven by hardware variants and physical testing, a shift towards accepted virtual methods is strongly required. The ultimate industrial goal is to be able to apply **qualified/certified methods and tools** for **early design decisions** and **virtual commissioning / approval**.

Ultimately, the EARPA task force MT4V envisions:

- to facilitate the use of advanced simulation technologies
- to cover emerging automotive trends such as high performance computing and artificial intelligence in terms of virtual development and validation methods and tools, taking into account their future use in control algorithms, applied in vehicles via cloud connections or powerful on-board ECU's.
- to improve technology and knowledge transfer between engineering practitioners (academia towards industry) within the automotive industry.
- to identify potential breakthrough technologies which could have a profound effect on the use of virtual development and validation techniques for automotive applications.
- to identify technology gaps and areas where research activity is needed.
- to bundle universities and research organizations to support Europe's automotive industry
- to constantly be aware of the state-of-the-art of the five axes of the task force

1.3 Objective

The task force aims at driving forward methods and tools for virtualization and virtual approval by bringing together the key players in research and development in Europe. Our main goal is to reinforce the introduction of virtual approaches and to facilitate the paradigm shift towards digitalization, independent of the application and the industrial domain. The task force encompasses five key axes shown in figure 1.

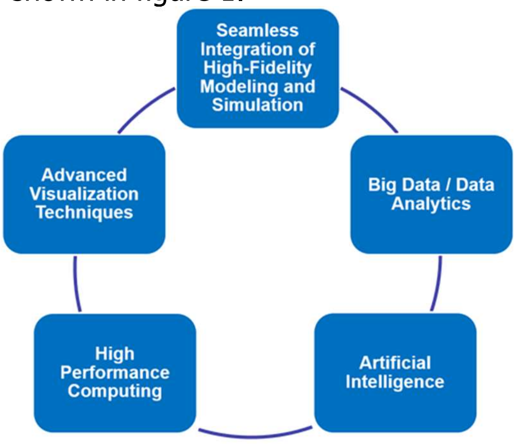

Figure 1: The five research, development and innovation axes of the MT4V task force [Source: EARPA].

2 Relevance and importance of the topic to European industry

Methods and tools for virtual design and validation ("virtual homologation") are highly required to shorten the development and production cycle and, consequently to strengthen Europe's position as high technology location on a global scale. The EARPA TF MT4V significantly contributes by deploying disruptive virtualization methods and tools for the efficient digital development of highly complex, connected, safe, and software-intense mobility technologies with respect to the whole life-cycle.
Currently, the state-of-the-art of validation methods and tools is not sufficient anymore.

The EARPA TF MT4V has put its major focus on virtual development and validation of highly connected systems (in-vehicle and ex-vehicle) taking into account the current lack of methods and processes to manage progressively increasing complexity to foster Europe's position with respect to engineering methods and tools.

3 Research priorities of the MT4V Task Force

In the following, the five main MT4V research challenges for European R&D&I in road transport are introduced and discussed.

3.1 Seamless integration of multi-scale/-domain/-physics high-fidelity modelling and simulation

Associated research challenges

- The presence of electrical and electrified components in future hybrid and fully electric powertrains leads to a broad range of development and optimization challenges related to their functional behavior as part of the entire system (cf. high-fidelity modeling and simulation).
- Fast and efficient sub-system integration into an entire powertrain system on both functional and control related level requires the availability of suitable high fidelity plant models for the mechanical, thermal and electrical domains as well as for the involved conventional and e-components.
- In order to ensure seamless re-use of sub-system and physics based component models from previous development phases, highly flexible and modular modeling techniques are required supporting the right model fidelity level needed for successful handling of the specific development tasks.
- Due to the largely increased number of components and sub-systems in future powertrains and hence the increased number of degrees of freedom and increased complexity of inter-component interactions, data driven models need to be replaced by physically based models.

Research priorities

- Generic technologies for seamless data exchange, coupling and co-simulation of purely virtual and mixed virtual / real multi-domain system models
- Scalable system-level physical models and parametric model order reduction approaches for derivation of real-time-capable multi-disciplinary plant models for use in MiL/SiL/HiL environments
- Tools and methods for automated parameterization of system-level models based on detailed multi-physical modelling results and experimental data

- Modeling and simulation tools and methods for detailed multi-physical analysis and optimization of electric components with respect to performance, thermal and NVH behavior

3.2 Big data research in the automotive industry

Research challenges
The key research challenges in big data research applied in the automotive industry revolves the four Vs of data: "Volume", "Variety", "Velocity" and "Veracity" with a proposed 5th V being "Value". The big data case in the automotive industry refers to all 5, as well as to the type of task that is called to tackle. Research challenges in this area are tightly related to challenges in artificial intelligence (AI), high performance computing (HPC), and cloud computing. Furthermore, the automotive industry has to manage several dimensions: **big data in development, cloud data (e.g. backend),** and **dynamic big data** (in-vehicle online data analytics, cognitive data processing).

Research priorities
- Knowledge/data representation, storage and communications standards and semantics as well as architectures and platforms for the effective combination of computing algorithm (e.g. AI-based) and HPC in the context of big data projects in the automotive industry.
- Methods and tools for providing explanation, visualisation and validation methods based on the analysis of big data. This includes standards for the virtualisation of prototyping and the simulation of various aspects of automotive design, manufacture and operation.
- New techniques for the effective analysis of various automotive data formats, including image analysis, objects and situation recognition, spatio-temporal data analysis, planning and decision support.
- Suitable methodologies, tools and techniques to automate and speed up the analysis and modelling of automotive problems that involve large amounts of heterogeneous automotive data applied to safety- and time-critical problems (mixed criticality), such as intelligent drive assistance and in-vehicle performance optimization.

3.3 Artificial intelligence in automotive industry

Research challenges
The increased automation in the design, production, and operation of automobiles and the introduction of computing systems in most industries including planning and logistics, provides many opportunities for the use of AI-based techniques, tools, and systems. In most application areas in the automotive industry, there are no standard models and frameworks for knowledge representation, reasoning paradigms and evaluation and validation. The embedded nature of many AI enabled components, the complexity, volume and speed of data and the complexity and timeliness of the problems to be dealt with, all pose serious research challenges.
There is a strong research need for the development of capable virtual testing and prototyping platforms modelling data of different provenance and granularity and the deployment of machine learning techniques and systems. The application of AI techniques in planning and logistics requires combination with traditional optimisation and planning techniques.

The introduction of automated driving, platooning techniques, and integration of various types of transport modes create research challenges that are stretching the ability of AI models to deal with complex and uncertain situations and systems.
Vehicle automation requires the use of AI techniques for the personalisation of driver and passenger experience and for the effective communication of status and requirements in a human-focused way.
A specific research challenge in AI is transparency, explanation, and validation of AI techniques.

Research priorities

- Developing knowledge/data representation standards and semantics as well as architectures and platforms for the effective combination of AI techniques with mathematical modelling and simulation technologies to solve and optimise increasingly complex problems in the automotive industry.
- Extending and enhancing AI techniques and algorithms to operate effectively with embedded intelligent agents and systems collaborations and dealing efficiently within the big data challenges and opportunities presented in modern vehicles, traffic infrastructure, and across transport and logistics modes.
- Developing intelligent user interfaces for designers, manufacturers and operators, including personalisation, recommendation and security in a user-centric way.
- Developing methods and tools for providing explanation, visualisation and validation aware intelligent methods that can justify actions and provide decision support for informed human-centred decision-making.

3.4 High performance computing

Research challenges

Even though HPC has meanwhile many applications in the automotive industry, there is still a lack of methods, tools, and processes to seamlessly integrate HPC into the automotive development and validation cycle, e.g.:

- Progress in HPC tightly linked to hardware, software, and algorithms
- Complexity increased for hardware systems, sophistication of software tools, HPC numerical analysis, algorithms & applications
- Customizable software, HPC ecosystem, (open source & commercial)
- Support for application codes on heterogeneous systems
- Storage & visualization
- Optimal and suited computing approaches (grid, cloud/fog/edge, parallel vs. distributed)

Possible HPC applications include

- Hybrid vehicle powertrains need completely new approach to optimization of ICE role as a primary mover.
- Electrification of vehicle powertrains introduces a new dimension into the virtual prototyping, namely requirement like efficient vehicle energy management for optimal range, comfort and safety.
- Fluid structure interactions (FSI) has many important applications in the automotive industry, such as external aerodynamics, aero-vibro-acoustics and water crossing and intrusion, passenger comfort (HVAC), defogging, engine lubrication, and NVH.

- ADAS and future automated driving functions will require millions and millions of kilometers for the qualification and the homologation of such complex smart systems depending on unlimited scenarios and conditions.

Research priorities

- Bring the prospect of AI into both pre- and post-processing of simulation data using a well-understood set of algorithms to accelerate the discovery of most important factors that lead to an optimized and reliable product design.
- Create a HPC framework that integrates into the established CAE processes by interjecting a data mining step using a guided pattern discovery application suited to the task at hand.
- Improve HPC and the dynamic node-balance for multi-scale mesh adaptive (i.e. automatic 'shell-solid' remeshing) technique's performance as well as improve existing scalability for increased complexity models integrating high fidelity CFD (LES, DNS), complex chemistry, and multi-domain models.
- Improve 'meshless CFD' technique's computational performance, and fluid structure interaction capability with deformable structure, in particular for small volume such as water intrusion simulation in real operational condition, powertrain lubrication, complex airbag modelling, and full airbag equipped vehicle body structure models.

3.5 Advanced visualization techniques: Visualization and virtual reality techniques

Research challenges

The democratization and the convergence of augmented reality and virtual reality have the potential to become the next big disrupting immersive interactive computing platform. It can reshape the way doing things. Co-visualization of all data (structured and unstructured) related to the hybrid digital twin model representing the vehicle, passengers, road users and infrastructure will be increasingly necessary to assess complex mobility configurations.
New visualization capabilities will be required to handle requirements for human-in-the-loop, and associated interactions with the virtual prototype based on real time simulation based on model reduction and pre-computed simulations. For data analytics, advanced data visualization techniques for volume rendering of scatter plot point data will be required.

Research priorities

- Convergence of different technology such as integrated augmented reality and virtual reality, to ensure the all kind of interactions with the virtual prototype.
- Access to data analytics and advanced links with data mining and machine learning 3D immersive interactive visualization with access to hybrid digital twin models with associated data (structured and unstructured)
- Enable engineer's desk-side exploration of simulation results through consumer-grade immersive virtual reality device support (Oculus Rift, HTC Vive)
- Explore cloud approaches to enable 'anywhere you go' exploration, analysis and decisions on multi-domain results.

4 Cross-domain impact (beyond automotive)

The MT4V TF is aware that methods and tools for virtual development and validation are not limited to the automotive industry. The shift towards virtual approval influences and impacts all relevant application domains including other transportation sectors (rail, avionics, maritime…), health, production, maintenance, farming, infrastructure, and energy.

5 Drafting team

- Fouad El-Khaldi (ESI Group)
- Stefano Fontanesi (UNIMORE)
- Tomaz Katrasnik (University of Ljubljana)
- Reinhard Tatschl and Andrea Leitner (AVL)
- Jan Macek and Oldrich Vitek (CVUT)
- Ibon Ocana (CEIT)
- Miltos Petridis (University of Brighton)
- Daniel Watzenig (Virtual Vehicle)

For further information, please get in touch with our contact persons of the MT4V Task Force

Daniel Watzenig
MT4V TF Chairman

E-mail: daniel.watzenig@v2c2.at
Phone: +43 316 873 9069

Ibon Ocana
MT4V Secretary

E-mail: iocana@ceit.es
Phone.: +34 943 212800

More information at our website: www.earpa.eu