The Role of Digital Twins in Automotive R&D for Rapid Prototyping and System Integration

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Abstract

The automotive industry is undergoing a significant transformation as the focus shifts toward connecting, autonomous, shared, and electric vehicles (CASE). These technologies promise substantial improvements in vehicle safety, efficiency, and comfort, but achieving higher levels of automation poses new challenges for deep learning-based algorithms in driver assistance and automated driving functions. Validation and verification remain challenging due to the difficulty of generating and executing a sufficient quality of ground truth for all possible corner cases. The challenges are exacerbated when the vehicles are expected to learn and adapt to highly dynamic environments or when the validation is to be done in meaningful real-world scenarios. Simulation environments are required to generate ground truth, and their reliability must be assessed before evaluating the functionality of the AD systems within that simulation. The approach presented is called “Digital Twins of Vehicles and Driving Environments.”

Digital twins promise to become indispensable in vehicle development and production. The digital twin concept has its origin in product lifecycle management and sees wide application in fields such as aerospace and the manufacturing industry, where a high initial investment is necessary. In the automotive industry, digital twins are expected to monitor the state of a vehicle, such as its components, system performance, and risk-related developments. In digital twins of the driving environment, off-board components are also considered, including surrounding vehicles/pedestrians, current and future road and traffic infrastructure, and external sources of information/influence. Currently, vehicle OBD systems, roadside cameras, and other sources of information are employed in assistance systems for safety-critical functions such as hazard detection and traffic jam warning. After-market services, studying traffic behavior, or influencing it will become relevant when highly automated driving is realized. As a digital image of the object of interest, digital twins require high-fidelity simulations to be useful.

Keywords: Digital Twin Technology,Automotive Prototyping,Virtual System Integration,Model-Based Systems Engineering (MBSE),Real-Time Simulation,Cyber-Physical Systems,Data-Driven Development,Rapid Design Iteration,Digital Vehicle Models,Hardware-in-the-Loop (HiL),Software-in-the-Loop (SiL),Vehicle Dynamics Simulation,AI-Enhanced Modeling,Integrated Development Environments (IDEs),Continuous Engineering.

1. Introduction

The automotive industry is undergoing a technological, organizational, and social transformation. This paradigm shift is driven by newly emerging trends and the digital transformation of industries. Technological trends include electrification, digitalization, automation/functional safety, connectivity, and data-driven solutions. A complexity explosion comes along with these trends, related to a continually increasing number of combinations of different architecture options, vehicle configurations, and software variants. Current tools as parsers for analysis, filtering approaches, and data summarization and visualization methods are needed. The adoption of dedicated tools will be either proposed or investigated in short prototypes for analysis approaches on their feasibility for the automotive industry. Together with the effects of the trends, the interplay of global players and increased time to market demand an earlier assessment of the solution space. This increases the need for flexibility, interdisciplinary collaboration, and efficient exploitation of hybrid physical expertise as well as domain knowledge, e.g., in Design for X environments, which offer only a limited global view on possible effects that individual changes could have on such systems.

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During both the requirements and specification phases, rapid technology prototyping allows a flexible implementation of concepts and functionality. Successful approaches offered in the tech industry include hackathon-style events to unify, partly parallelized, implementation stages and invite fresh ideas from outside, with the temptation to rethink standards. While handling basic complexity classes more easily by main-volume applications based on state-of-the-art solutions, these solutions can become "blind" to the current architecture. Automotive development in compliance with regulations to avoid physical hazards and operations is continuously increasing in complexity and cost.

In dynamic systems with multi-discipline, multi-scale, and reconfiguration systems, the "digital twin" (DT) concept can help reflect the physical system, enable the understanding of future behavior (including what-if scenarios), and support remote management capabilities. Data availability and the emergence of methods from other industries make the approach ripe for application in the automotive domain. In order to lower the risk and the development and evaluation efforts for DT, this special aspect aims at identifying, developing, and advancing holistic platform-independent abstraction methods for the implementation of efficient, flexible, and reusable automotive DTs.

1.1. Background and Significance Digital twins (DTs) also referred to as digital avatars, are virtual copies of objects, processes, or systems that update in real time based on data streams from their original counterparts. They originated in product design but are currently most used in prediction and monitoring applications. The automotive sector was among the first sectors to use DTs, but the focus was mainly on monitoring. This paper provides a state-of-the-art overview of DT maturity related to recording and enabling applications and outlines directions for future work.

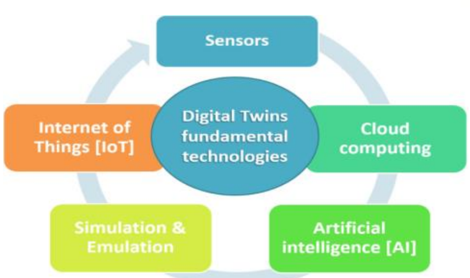

Fig 1: Digital Twins in the Automotive Industry.

Initially, the automotive and associated sectors created 3D models of vehicles for design and product visualization. The megatrends towards adding connectivity, autonomy, and electrification to vehicles rapidly increased the complexity of the vehicle system. As a response, local simulation and mirroring efforts were integrated, assembled, and connected, leading to the invention of so-called "virtual proving grounds" mirroring the world. Further extending the applications of DTs to include system enabled demanded substantial improvements in processing capabilities and bandwidth. Today, the automotive sector is digitizing a holistic understanding of the system and implementing artificial intelligence (AI) legislation to keep drivers consistently in the loop. In the recent past, automotive sector representatives argued for machine learning black box explainability to be mandated, with a lengthy body of knowledge on XAI methods being past reviewed for style by graduate students.

There is hope that this legislation could spur EU efforts or otherwise limiting efforts in other regions to leapfrog on maturity in the understanding of DTs. However, digital twins around drivability and a behavioral understanding of the driver are still early-stage with few prototypes built and a limited knowledge repository. Current research includes the creation of refined vehicle interactions with surroundings, capturing and interpreting intentions and driving styles, aggregating purposes, and ranking intentions given priorities. Initial explorations with a view to DRIVING would be suitable. Immediate issues include architectural engineering and design, real-time, heterogeneous processing, interpretative and probabilistic reasoning, scalable and robust integration of language and vision, thwarting attacks, and replaying past objections.

2. Concept of Digital Twins

Digital twins (DTs) enable virtual representations of a physical product, allow for their development and continual enhancement to improve the product's performance even after deployment and use. A DT comprises one or multiple digital twin instances (DTIs) that can cooperate. DTIs exchange data and optimize a vehicle collectively in a digital twin aggregate (DTA). Following , four phases of the product life cycle exist, during which a vehicle is improved or otherwise optimized by a DT: during the design and development of the product, during the operational phase where the vehicle is used in the field, in

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the operational assessment phase, and in the service phase encompassing maintenance and repair. To optimize the vehicle in design and development, the digital twin for the product (DTP) is the prominent DT type. Once the vehicle is built and used in the field, a digital twin instance (DTI) is employed to improve operational efficiency and availability. In the context of the operational assessment phase, data scientists or fleet managers analyze data and alter settings of the DTI to avoid violations of driver or operator tolerances and regulations. Engineers that operate on modelling and simulation tools in the service phase characterize searches for the best repair actions and tweak parameter settings of the DTI.

A DT is defined as a digital representation of a physical product, which can exist as a single instance, as a product variant or family, or as an aggregated instance. Individual instances of a DTI are typically paired with individual instances of the physical counterparts. A DT is enabled by various technologies, for the automotive industry, five technologies are identified to facilitate the development and coexistence of digital twins. As a result of developments of these key enabling technologies, vehicles are augmented by an increasing number of sensors and electronic control units (ECUs), and a plethora of safety systems are built in vehicles, some of which also utilize sensors. Examples of such safety systems are advanced driver assistance systems (ADAS) and automated driving systems (ADS). Wireless communication capabilities allow sharing the vehicle's state and position with other vehicles (V2V) and/or with other infrastructure components.

2.1. Definition and Overview Digital twins (DTs) have emerged as an exciting area of research within the automotive domain, garnering significant attention in both academia and industry. As they allow for continuous monitoring of a physical entity in a virtual space, this technology has enabled a recent shift towards a more virtual and simultaneous design of vehicles and systems. While there is no universally accepted definition for a DT, they are typically defined as a virtual representation of a physical asset, process, and/or system, with which a connection has been established to periodically exchange information for diverse purposes.

As a technology/application domain, DTs have been found in a variety of applications, such as those for product lifecycle management, manufacturing, and health monitoring. The main objective of a DT is to generate a virtual model of a physical object to simulate its functionality and/or behavior. Conventionally, in the literature, DTs have been considered as consisting of three elements: a physical entity, a virtual entity, and a channel that links these two entities. The physical entity, or physical twin (PT), is the physical object to be modeled. The virtual entity, or digital twin (DT), is a mathematical model of the PT. The channel, usually using sensors, communication links, etc., is called a digital twin prototype (DTP), which can transfer information from the PT to the DT and vice versa. This digital twin concept has attracted attention in multiple domains as it allows creating and refining a virtual counterpart of a physical product before the physical product exists.

This digital twin (DT) concept has attracted a lot of attention in many domains, and its interest is spreading within the automotive domain as well. As a result, existing DT technologies and frameworks are being studied and new ones are being developed. In this work, the design of a digital twin of a learning-enabled autonomous vehicle is presented along with the results obtained from its application. The design and application of the digital twin pertain to multiple disciplines and therefore require seamless integration of a set of tools. A digital twin prototype is created using the PAVE360-VSI digital twin platform and the Ethernet protocol to seamlessly integrate and interconnect the models and simulators of a vehicle model in Amesim, an environment model in Prescan that specifies the road path, the sensors, and the driving scenario, and a perception module, based on the YOLOX algorithm, which can detect and classify traffic signs. In addition, a learning-enabled steering controller is implemented in the Robot Operating System for lane keeping, and a controller for the speed governor is developed in Simulink.

2.2. Historical Development Over the past twenty years, computer technology has made huge progress concerning performance and efficiency. On the level of automotive engineering, this progress enabled the usage of data-driven approaches, advanced analytics, and machine learning in digital twins and other engineering applications. Therefore, there are enormous opportunities for future digital twin applications in the automotive domain. However, due to the company specifics and the historical development of the digital twin technology, various automotive companies are at various stages of development regarding digital twin

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applications. In fact, the following maturity levels can be distinguished, with illustrative examples:

1. Application of data-driven digital twins to assist human engineers and technologists: At this level, fleet data is aggregated in a data lake and data-driven approaches are applied for engineering, analytics, or operational purposes. Typical questions addressed are: Is my vehicle on time for preventive maintenance? Which root cause could potentially be responsible for the spreading of a fault?

2. Advanced usage of data-driven digital twins to partially automate data-driven processes: Engineering and process control tasks that were addressed manually during the earlier development stages are automatized enabling data-driven engineering based on fleet data. Typical questions addressed are: What is the probable root cause of a new previously unseen fault? How to best calibrate my controller, hypothesis, or setting for the next tests following the fleet data analysis?

3. Potential usage of data-driven digital twins for near-future products: Advanced analytics, data mining, and root cause analysis are set up and proven robust against time-drifting data. However, their application is currently limited to a certain part of the data or business case, settings, or vehicles. As often engineering and processes need to be modified to be applied there, there are currently no feasible plans for the implementation. Typical questions addressed are: Can I predict the system output or fault signal of my previous production domain with unexplained drivability complaints?

Equ 1: Prototyping Acceleration Rate (PAR).

$$\mathrm{PAR} = \frac{T_{baseline} - T_{DT}}{T_{baseline}} \times 100$$

- $T_{baseline}$: Time to develop a physical prototype without a digital twin
- T_{DT}: Time to develop using a digital twin
- Measures the time savings achieved through digital twin use.

2.3. Technological Foundations

The concept of Digital Twins (DTs) gained significant attention in both academia and industry during the last few years. Typically defined as a virtual representation of a physical asset, process, and system; a DT refers to the virtual mask of an object, which can be a physical object, a system, or a process in the real world. Various aspects of that object can be visualized in the virtual space to serve a diverse purpose. DT applications have been found in several domains, like product lifecycle management, manufacturing, military, healthcare, supply chain management, construction, civil engineering, and transportation. The main objective of a DT is to generate several virtual models of a physical object to simulate and visualize some behaviors of the object in the virtual space. These models can be created based on the design stage, manufacturing stage, or the operational stage. Conventionally, DTs involve three elements; a physical entity (the real object of the DT), a virtual entity (the corresponding virtual object of the DT), and a channel that links (or connects) these two entities and transfers/communicates information.

The digital twin concept enables designing, creating, and refining a virtual counterpart of an asset or instrument before the actual physical version of the counterpart exists. By doing this, the whole creative and integrated process can be scrutinized and re-evaluated before the cumbersome attempt of manufacturing the physical entity. Digital twins are increasingly applied in the automotive domain, mainly in automotive R&D.

3. Applications in Automotive Industry

Digital Twin Technology, as a powerful, versatile tool for integrating and exploiting disparate results emanating from previous system development processes, is successfully gaining a foothold in the automotive and aerospace industries. Possible benefits include reduction of assembly test duration time, operational improvements using aggregated fleet data, and virtual integration approaches agnostic to the underlying physical architectures. These visions bear similarity to the Digital Twin Concept, a cross domain term but still an unstandardized concept.

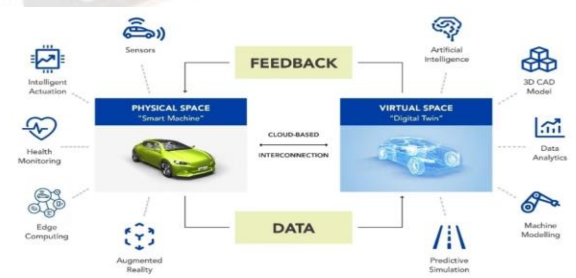

Fig 2: The use of Digital Twins in automotive engineering.

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The Digital Twin (DT) has been proposed as the virtual counterpart to a physical peer. DTs can be defined as observables that form an abstraction of the physical system and restrain a non-trivial model to generate instances of possible involvement in time. In the ideal case, given the physical world states, a DT could predict the physical world's future state with arbitrary precision. Artificial Intelligence approaches in the context of DTs are understood as utilizing a digital twin form but which don't form an applicable definition for all DTs. For enhanced understanding, DTs can be classified into Digital Twin Process (DTP), -Instance (DTI), and -Aggregate (DTA) and hierarchical relationships are classified according to this understanding. DTPs with single vehicle modeling and representation don't exhibit an option for aggregating results to a common base for flat fleet sided optimization.

Based on processes governed by a functional decomposition the DTP is used during the design phase, while the DTI is applied during operations, whereas the latter DTI was an additional system development effort due to overarching interests, the former setup does. However first steps, e.g. working DTI, exist. The vehicle level instance works as standalone and is currently ill-integrated with existing process flows or tool chains. Ad hoc approaches utilizing Excel, or specific Queries address the gap between simulation knowledge and understanding or implementation. Whereas input bandwidth is restricted to just process parameters, these candidates offer no support in knowledge transfer without additional effort, though the implementation in Java offers the potential for coupling and shielding existing approaches.

3.1. Design and Development Digital Twins (DT) have gained significant attention in both academia and industry. Typically defined as a virtual representation of a physical asset, process, and system, a DT serves diverse purposes. More specifically, it has been used to design, test, verify, monitor and maintain such systems. Due to its emerging popularity and flexibility, a rich bouquet of definitions of a DT as a formal abstraction has been proposed in both academic and industry domains. DTs originated in several ancient designs and fabrication fields conducting off-line performance predictions primarily focused on design and operations. Thereafter, a plethora of embedded systems and cyber-physical systems in various domains gleaned, integrated, and returned huge quantities of on-line data, leading to the emergence of data-driven programming and maintenance based on a DT. The rapid advancement of such DTs led to many domains coming to integrate learning-enabled components into new designs, leading to a wide variety of new challenges regarding programmable and inherently uncertain properties unmatched between a physical counterpart and its virtual representation. Therefore, new digital twins are actively developed to address these challenges, in turn fostering advances in DT integration and standards.

In general, DT applications have been found in the domains of product lifecycle management, manufacturing, cumulation and use, and traffic monitoring. Debates on the role, types, challenges, standards, frameworks and tools of DTs have continuously evolved and endured. Such DTs consist of a model of an asset, primarily a physical object, a model of the environment, and a description of the surrounding environment. The main objective of a DT is to generate virtual/digital models of physical objects to simulate their behaviors. Conventionally, three elements are involved: a physical entity, a virtual entity, and a channel that links these two entities directly or indirectly. The digital twin concept enables creating and refining a virtual counterpart before the physical one exists. If the digital system meets certain criteria, the physical product can be manufactured and linked to its DT using sensors, actuators, and communication channels.

3.2. Manufacturing Processes Building on the idea of the digital twin as a proactive and independent model of a physical system, the modules methods and tools team is investigating if preconditions put in place by the suppliers of the digital twin and the physical systems meet the requirements for bi-directional exchange. This work has been initiated in the automotive sector and is expected to be extended to other sectors, e.g. in a public-private partnership with aerospace companies. Case studies are performed with digital twins of a hybrid power module and selected manufacturing processes. Methods and tools for the modeling of the structures, functionality and behavior of the physical system in question are presented and the possibility of an automated generation of the twin's model is discussed. Furthermore, the modeling of design scenarios with the digital twin and methods for model-based performance validation are introduced. The objective of this paper is the conceptual description of a digital twin of a production process, its data structure, and application areas such as simulation, analysis, process monitoring, and control. The planned scenario is that

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the digital twin model for a production process is created by suppliers based on an appropriate data structure which can be utilized by originally the equipment using manufacturer, suppliers of equipment's components, integrators of equipment into new machines, system integrators or customers of equipment upgraders. Ideas for further developments that can improve the digital twin and its application possibilities are also discussed.

3.3. Testing and Validation Testing and validation in the Automotive industry follows strict standards, providing a reliable framework for the analysis of vehicle specifications. The vehicle specification might change in spite of this reliability. Upstream, during requirements engineering, design changes might affect or conflict with the existing tests. Downstream, when tests need to be implemented in a new environment to simulate the system, they might over-specify the implementation or integrate into the system incorrectly. Digital Twin (DT) technology can be promoted to minimize the effort needed to fix these problems.

A digital twin of the test allows analysis to be conducted on the test specification, and, because it is executable, it provides an automatic translation to the new test formats. Functionality can be ported unchanged, but test parallelism may be lost, so synonyms are introduced for built-in sleep functions that are inexpressible in the new environment. In addition to a quick design entry point for engineers developing tests, this work also provides novel suggestions for future research avenues for better support of testing of increasingly complex systems.

The detailed analysis of test specifications is based on observations from functional testing. Abstraction to focus on key points when porting tests to new environments is achievable. Adopting soft information pointers helps avoid continual lengthening of tests, a common problem in the automotive industry as complexity increases. The efficiency of any of these approaches is still open to further research exploration as technology matures. DT technology is maturing, and every day new tools feature better analysis and visualization capabilities. In the same spirit, the automotive industry is integrating more and more with the commercial gaming software industry, which is developing more advanced development environments.

4. Rapid Prototyping with Digital Twins

Industrial automation tasks are becoming increasingly complex. As a response, the scale of machine and system design is also increasing. However, the time and adroitness with which machines are set up are taking to very long. There is a growing demand for Data, Simulation, Virtualization and Digital Twin-based Robotics, Automation and Industrial Automation System Design in order to tackle these challenges. Accordingly, there is a need for solutions and frameworks to be able to develop such automation systems. The main objective of this work is to elaborate on a reference architecture for a data, simulation, virtualization and digital twin-based robot using industrial robotic arms and other components that can be set up as complex systems. Also focusing on the approach of creating a virtual robot in simulation software is outlined. Finally, a data sharing and collaborating system was implemented through which data can be shared and utilized between several user clients and IIIoT devices. Designed to feasibly expand in scope and complexity, the system can orchestrate, monitor and record learning tasks without the need for further programming. The visual interactive environments of the environments enable supervised and unsupervised learning tasks alike.

The components and capabilities of the systems (robotic arms and software) are presented in detail together with some use case demonstrations showcasing the capabilities of the proposed system. Future works will explore some additional aspects of the reference architecture, along with other software and hardware components that will provide opportunities for further research and development. The overall aim is to develop and provide solutions, frameworks and tools for data and simulation based robotics, automation and systems engineering.

4.1. Benefits of Rapid Prototyping The rough prototyping of the systems involved in ADAS provides several important benefits, including quicker validation and verification via simulation workbench, faster turnaround testing, and cost-effective development by running simulations rather than hardware tests. Rapid prototyping is the fast creation of early interference models of a product by CAD. With their many toolchains available, the cloud environment provides efficient rapid development and testing of algorithms and models. The rapid prototyping of ADAS projects can be

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done in two stages: desktop applications of AGVs without embedded control and hardware-in-the-loop simulation. Utilizing software-in-a-loop frameworks provides faster cross-platform deployment of models with less redundancy. The flexible implementation of control, length of different traces, and PC resource management extends coverage testing beyond that of ISO26262. The development of individual safety parts and adopting a modular system safety solution significantly reduce the EPC of product development.

Inspired by the 4th industrial revolution, the automotive industry faces significant challenges in terms of vehicle software updates over the air. Automotive software and system integration can be considered as two sides of the same coin. Vehicle system conceptualization and architecture analysis guide the division of complex software systems into simpler and manageable parts. Vehicle system standard interface policy including the TS21434 communication, safety, and security standard, and the ISO26262 ASIL requirement decides the software systems being developed by original equipment manufacturers (OEM) and suppliers. The development and testing of the software system are continuously performed in the simulation environment. A clear vehicle characteristic description and risk analysis guarantee a smooth system integration.

Fig 3: Benefits of Rapid Prototyping.

4.2. Case Studies This section discusses the use of digital twins in rapid design iterations for R&D of electric powertrains and automotive systems at TI Automotive. Rapid design iterations require a simulation and test environment that can support integrated prototypes from the software developer to the vehicle system integrator. A digital twin is a computational representation of physical phenomena and systems that enables automated, high-fidelity simulations and tests during rapid design iterations. Two case studies from TI Automotive are presented. The first case study discusses the automotive digital twin and rapid prototyping MSM which implements a scalable MBS formulation that can simulate and test a variety of full real-time system configurations of mechanical systems. The second case study discusses how the digital twin and development of rapid prototyping TI/SABA have enabled the development of multiple software stacks for e-mobility in producing Quality on-time prototypes for system integration on vehicles. Potential future work is suggested on improving the integration and operability of digital twins further, enabling wider-ranging audience interest in the acquired benefit of automated simulations and tests.

Development processes in automotive and other applications have become more complicated due to the advent of multiple complex systems in a vehicle, such as electrical and software systems. With the need to ensure the safety and security of these systems, testing to acquire quality has become increasingly difficult. Nowadays, most quality acquirings are primarily 'done' using test on physical prototypes which typically requires a substantial number of professional human resources. Digital twins provide a bridge between the computational and physical worlds by enabling the virtualization of physical systems. The responsibility of TI Automotive is to offer products to convert GVE power supplies into GVE loads. New electric products, including electrical aspects and software stacks, as well as mechanical and thermal aspects, are continually developed to have current products expanded and the work done much easier and more efficiently.

Equ 2: System Integration Efficiency (SIE).

$$\mathrm{SIE} = \frac{N_{successful}}{N_{total}} \times 100$$

- $N_{successful}$: Number of system integrations completed without rework
- N_{total}: Total integration attempts
- Indicates how digital twins reduce integration errors via virtual validation.

4.3.

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Challenges and Limitations Digital twins offer significant promise for automotive rapid prototyping and remote integration, although some challenges exist. These limitations are typically more easily addressed through improvements to underlying software stacks. Digital twins are software-heavy applications which are dependent on extensive software stacks but may rely on standards for the interfaces between their components, as is the case with the . Therefore, the first challenge encountered was in transforming an existing proof-of-concept twin into a deployable application. Although some improvements were desirable, this phase's primary outcome was getting the prototype to work and making it deployable. Future work on enhancing this application would benefit from first assessing the entire stack with respect to key software engineering principles, and only then working through the necessary software and configuration changes in a systematic manner. A secondary issue is planning maintenance cycles. This was partly anticipated during the deployment phase by including code comments, documentation on intended use and an external interface description. However, what came as a surprise was the migration of dependencies from one version to another, which broke multiple assumptions in the development. It might be wise in the future to establish an external periodic code review process with accessible documentation first.

A limitation in the twin-based approach of testing a system was that availability of test hardware at the time of testing was not guaranteed. To remedy this issue when initiating development, a resource unit working on sample-based estimation of cut-sets and validating the worst-case guarantees of the twin were employed. Although this choice allowed finding pathology counter-examples and debugging the model, it unfortunately could not guarantee coverage for the whole state space due to memory issues. Perhaps a different partitioning strategy, employing edge-weighted graph partitioning techniques, or sampling the state space from within the frameworks of tools like MLTL-MuR, could remedy this .

5. System Integration in Automotive R&D

The successful joint operation of vehicles in open traffic requires the consideration of multiple stakeholders, strict compliance with laws and regulations, and a high degree of cooperation between all traffic participants. The ability of vehicles to communicate with each other (V2V) as well as with the road infrastructure (V2I) exposes them to additional potential attack vectors that are not present in the case of human-guided vehicles. To prevent potentially catastrophic traffic crashes and breaches of privacy, open-safety standards specifying acceptable levels of safety must be met. However, in contrast to process innovations in safety-critical hardware, the hazards, measures, and requirements for primarily software-related innovations remain largely unexplored. In addition, with software transparency being not an option due to the high level of complexity and proprietary knowledge inherent in deep-learning-based systems, automated validation will prevent many breakthroughs and broad-market operations from happening.

There are a number of concepts for a reflection-analysis approach that raise a plethora of ethical and legal issues concerning liability, accountability, and the assignment of risks. This is why solutions to the challenges of ensuring the security and safety of digital twins in intelligent transportation systems should be based on both systemic validation and physical validation, where systemation can produce both validated virtual twins that can be observed and controlled via physical twins, which, due to their confinement to a physical dimension and full observability, can be further analyzed. As part of an interdisciplinary collaboration between computer science, traffic psychology, and innovation management, an illustrative case study with real execution time controllers and physical vehicle-in-the-loop platforms will exemplify this co-engineering approach through which both safety and operability concerns can effectively be addressed.

5.1. Role of Digital Twins in Integration The majority of published Digital Twin work relates to low-level vehicle components, sensors, actuators, and controller design, arguably providing too little of a holistic focus on high-level approaches at the vehicle or fleet level. Almost equal shares of DTI by category are aimed at monitoring, predictive, prescriptive, and area DTIs. Additionally, the DTInitiative's Industrial Deep Dive identified a high-level gap in current DTI research topics not extending beyond engineering-focused design tasks and the effort to move flow modeling into the operational realm. ACTUATOR proposes to build on these insights into gaps for the development of focused future work within this part. ACTUATOR intends to research a design-and-build Digital Twin Vehicle, aligning closely with the Vehicle Design criteria mentioned in the DTInitiative Industrial Deep

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Dive. The goal is to enable the design phase entry of novel AI-based and physics-based R&D approaches that encompass the entire V&V chain from design to production, testing, and complementary field-testing based on data. This is expected to be pivotal for shortening the first full-vehicle build cycle from today's… years to an innovation-disrupting month or such.

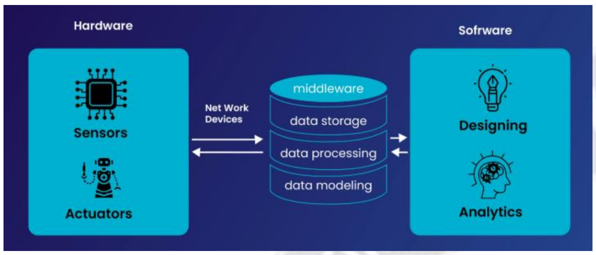

Fig 4: Digital Twins in Integration.

In deployment and operation, the DT use emerges from various published research settings, from on-tool diagnostics & maintenance to generative capabilities and fleet-routing models, to name a few. Some attempts to study autonomous vehicle behavior in traffic also avail of already publicly available DTs. The majority of published detailed use cases tend to be mostly at the component level and focused on monitoring and predictive capabilities. While DTs at this level remain crucial for the operability and safety of existing and upcoming vehicles, such focused and low-level R&D does not fit ACTUATOR's high-level priorities and spread ambition for the use of DTs in R&D sandboxing and as SI schools. ACTUATOR proposes to arrange a focused research workshop at this level as the initiation of developing a comprehensive DTI inventory road mapping at the Vehicle and Fleet Design levels.

5.2. Interdisciplinary Collaboration

Digital Twins (DTs) can revolutionize vehicles' development and integration, enabling interdisciplinary collaborations by gathering, processing, and exchanging diverse and massive data. DTs replicate detailed aspects of vehicle components' physical properties, bringing intelligence to the R&D process. Therefore, this comprehensive digital representation of a vehicle or a vehicle component is the user selected vehicle DT. The vast range of information and data produced and collected from the high-fidelity virtual twins, simulation tools, and various IT infrastructures, can fit under the broader term digital environment of the vehicle DT. Such environments can enhance collaborations between the automotive industry and sensor suppliers, software and hardware tools providers. A digital environment reference architecture encompassing different layers, blocks, and components is elaborated. Such an architecture comprises various simulation tools, test automation tools, data storage, and vehicle braking simulation and data relevancy determination tools and processes.

The trends in vehicle development, which vehicles become more complex and intertwined; systems become highly integrated and relevant, require fundamental research on comprehensive digital replicas of the vehicle and the vehicle components. A detailed representation of various aspects of the components would help to ensure proper design and implementation of even the newest vehicle features. High-fidelity models can also provide representative explanations of the pure physics of the brakes. A digital person DT is elaborated, enabling objectivity, fidelity, diversity, and extendibility fib. The person model comprises multi-domain facets covering kinematics and dynamics, biomechanics, perception, cognition, and behavior modelling. The extensive cooperation and interaction of these facets can be a target of research developments and extensions and newly defined hypotheses. An example application is shown, stemming from assumptions developed under the broader concept of a person DT aimed at the driver behavior modelling for ADAS and AD system assessment. This generic concept can benefit different sectors beyond the automotive industry. Understanding how humans become efficient and intelligent is jointly interesting for other engineering and mechanical domains alike.

5.3. Real-time Data Utilization

Real-time data from vehicles is crucial for various applications in automotive research as it can enhance simulation capabilities, optimize development processes, and improve system integration. In addition to the lifecycle management of commercial fleet vehicles, there are additional approaches where data from owned vehicles can be utilized in the vehicle manufacturer's favor. The manufacturer can gain insight into real-world use statements of functions that they have developed, or in the case of component manufacturers, an idea of whether a supplied component works as desired throughout the entire vehicle and in long-term operation. The applications span several areas of technology, including the development of assistance systems and functions, the modeling of undesired preconditions of critical vehicle states, and the optimization of integration tests in heterogeneous hardware and software environments.

To develop assistance systems that can act on certain vehicle states during operation, the development to a potential use case is often time-consuming and costly, requiring an extensive off-road simulation of necessary critical scenarios and a vehicle-in-the-loop validation. With a well-designed modeling procedure, such requests can involve the creation of appropriate abstract classic simulations and simulations optimized for high fidelity. By utilizing new possibilities for collecting data in the vehicle, these operating states can become accessible and prepared for further actions. This enables the manufacturer to be more agile in selecting and deploying integration use-cases without manually simulating nearly all critical scenarios again, saving hundreds of hours of development time.

6. Impact on Innovation and Efficiency

Thanks to digital twins, innovations in automotive R&D can be created more easily and efficiently. Until now, innovation processes have required the use of time-consuming physical prototypes. With digital twins, that can be overcome. During the development of a new R&D element, the construction, validation, and testing of a physical prototype can escape. Instead, it is capable of building a digital prototype consisting of a functional model over the x-steps, the test set-up with environment and MATLAB/Simulink over the x-steps, and the vehicle dynamics simulation over the x-steps. For the validation, it enables parameters of the functional model that the hardware would need to observe for the real-world testing to be varied with different scenarios. When the model passes the requirements, then the test setup would only need to be built in the environment; thus, the test can be run within days after the construction of the digital prototype. By the help of consistent and fast tests, engineers can build more innovative components instead of improving existing ones. As long as the extra length of a new data path is covered either by a fast digital test or parallel runs, engineers can think outside of the box. As each test no longer takes a physical prototype into account beforehand, in searching for solutions the vehicle dynamics engineers can run the test set of crossing over passes instead of going round with typical digital experiment solutions for each class of road over time-consuming 300-steps merge learning simulation, suspending their long durations. The selectivity of the approach targets fatal and dangerous corner cases and helps set-up a log of vehicle-related corner cases that would not ever demand R&D resources in the physical world. It also captures fixed-data defects from manufacturers that can possibly elongate forever in the real world as engineers cautiously cover advanced corner cases with simulations. For R&D companies, the time length of each test is no longer an issue and each test resembling the Digital Twin is just as convenient and affordable in terms of hardware and time length as those simpler tests; features that initially work so well with a physical prototype can be instantly applied to the digital scheduling & scenario generation system without any reform on hard- or software components. Notice that as the Digital Twin is a far more complex system with abundant corner cases to consider, besides gaining robust corner cases with perfectly set constraints, engineers can also use intuitive criteria or even near-sighted information that would lead to a huge number of expected failures in a referential setting.

6.1. Innovation Acceleration

In the age of accelerated and agile development, an up-to-date digital twin greatly reduces the cost of changes, while allowing for early verification of alignment with concurrent references. The continuous interaction between physical sensors and control, as well as plane perspectives, minimizes discrepancies and allows easily matching benchmarking requirements.

In the new vehicle development process, up to five concept vehicles of different configurations and different experimental setups need to be developed, built up, and tested. While modelling the physical platform is simplified through a well-defined build-up procedure, modelling the software-based functionality and behavior creates far more challenges. The capabilities of digital signal processors and other software-controlled components, as well as the autonomy of the functionality, are still expanding with steep progress and diversity.

Managers, engineers, and scientists need to think of new solutions to fulfill requirements today and address upcoming issues tomorrow. A reference vehicle model improves state-of-the-art software implementation far easier and safer. Reusing such well-documented and instrumented reference technological vehicles increases the speed of delivery and reduces the technical risk associated with solving today’s problems and tomorrow’s issues.

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Using a digital twin that accurately depicts the physical platform's setup, configuration, and condition ensures optimally outcome matching, replaying, and searching. Sensor placement reports indicate views, which inclusively express worthiness. New vehicle designs, changes, or floating perspective points can be evaluated by transiently copying and updating. The transparent vehicle can be viewed from any point on the vehicle and around the vehicle envelope.

Automotive-related industries face similar challenges and difficulties. Implementing an accurate and up-to-date digital twin is not only an accurate lab management tool. It opens the door to tremendously new opportunities in process and product innovation for automotive safety, reliability, comfort, datification, emission reduction, and energy transition.

6.2. Cost Reduction

Over the last decade, many new advanced analysis techniques have successfully been validated and implemented in many R&D projects and products. These tools brought significant benefits in several areas, e.g., quality forecasting of complex vehicle systems. Nevertheless, high-level in-use analyses with still much more impact potential remain only in the proof-of-concept phase.

AI also recently got to a hype dimension, with language and multi-modal understanding. Nevertheless, many companies are still sceptical about the value-add, implementations are still limited, and some industries and institutions worry about being too late. A significant threshold barrier for implementation is often the bad user experience of many still necessary human-machine interactions and volatile operational requirements. In the case of autonomous driving, validation and verification typically take years and consume vast resources.

One can assume that a digital twin approach is a key enabler of many potentially forum-changing vehicle and mobility concepts in the next years. For instance, the effective switch of full-brain image-processing stacks could allow the dramatic miniaturisation of hardware components. Also, space for completely new products is expected; however, it is unclear who could get the first-mover advantage. A real digital twin outperforms purely data-driven approaches significantly in the essential areas of trust, acceptance, and understanding. However, options on solutions and significant standardisation efforts are still necessary to be able to provide affordable digital twins for many of the underlying massively complex, costly, and highly safety-critical systems.

6.3. Quality Improvement

In automotive development, quality is critical for the success of the resulting products. Business cases for newly developed products need to be based on product characteristics like safety, reliability, robustness, and build quality. In essence, a vehicle must fulfill hundreds of requirements that need to be analyzed, tested, verified, and documented. To achieve this goal, millions of kilometers on roads would need to be driven, which is unrealistic and costly.

Quality improvement is divided into three categories: handling more scenarios faster, avoiding faults in the field, and closing the feedback loop in a more scalable way. The first idea involves identifying and characterizing safety-critical scenarios which violate safety specifications. Handling such scenarios is key to ensuring a vehicle operates in a (near) safe manner in all situations experienced in the field. The second idea involves integrating fault mitigation strategies and validation directly into specified failure modes. Avoiding vehicle faults from occurring in the field is key to preventing user dissatisfaction. The third idea concerns making scenario characterization directly usable as testing specifications to be generated contextually around vehicular experiences. In this way, quality improvement processes can be closed more effectively.

Current systems in operational use also present opportunities to mitigate fallout. The health status and type of faults that occurred in the field can often be obtained by retrieving data logs from a fleet of already-deployed vehicles. This data can characterize usage scenarios and faults from the vehicle's operating history. Digital twins can aid in exposed fault mitigation by identifying vehicle vulnerability and communicating potential means of improvement to stakeholders prior to field exposure.

7. Future Trends of Digital Twins

In the automotive industry, vehicles are complex systems composed of various subsystems. As vehicles are being connected, the number and complexity of these subsystems are increasing manifold. These subsystems are becoming heterogeneous in nature since they may be from various suppliers having different levels of functionalities using different standards and have different communication rates. Pervasive connectivity of these subsystems poses challenges in terms of connected vehicle security. Security of connected vehicles is a key area of research. Another key issue in the area of security is performance.

The developed connected vehicle penetration tests and tools for monitoring the connected vehicle security postures in controllable safety of passengers are gaining interest. Performance evaluation of the intrusion detection systems or parts of the intrusion detection system are key areas of ongoing research by academics and industries. For increasingly complex systems like connected vehicles, language barriers are an acute issue since they will be most likely developed using different languages and standards. On the other hand, analyzing such a complex inter-operation system is difficult due to scalability and need for continuous model updates as the connected vehicle message propagates from one vehicle to other vehicles and passing by roadside infrastructure.

The utilization of digital twins for analyzing the connected vehicle messages propagation with a performance overhead is a new avenue of research that will break the language barriers and benefit authorities and connected vehicle research communities. Another area where digital twins can impact the future of automotive is system components interoperability. Digital twins can be deployed to analyze the data in terms of a design model or analysis platform where the models will be connected and can be interfaced properly. The analysis platform will benefit regulators and vehicle manufacturers as it enables regression testing of systems before actual deployment to ensure interoperability.

7.1. Emerging Technologies

3D Technologies (3D Printing etc.): To create a car prototype, traditionally it needs to be manufactured entirely. Now new technologies can create 3D objects in a very short time. Additive manufacturing means printing materials with other computer-controlled tools. Stereolithography is the first technology of rapid prototyping that uses a laser to create layers. Fused Deposition Modeling uses molten thermoplastics. Selective Laser Sintering uses a laser to sinter powdered material. The advantage of using 3D free form produces more integrated and complicated parts, and less material waste than machined prototypes.

Integration Tests: Embedded electronics and software inside an automobile develop much more often than open loop systems. There is a rapid need to choose what on-board apps shall be tried using prototypes. These 3D prototypes offer hardware-in-loop capabilities. For the more practical use of driving simulators where many customers can test the products, a host software system should be created. Scanning is done by movable cameras or a movable multi-beam laser scanner, where many images of a scanned object are taken (wide-area image). Patterns may also be text, or color. For scanning, a minimum of three parameters should be known. Intensive calculation and double checking the results created a polygon-based intelligent car model (mesh) that is very complex and very huge (millions of points).

The texturing of meshes is done by filtering the lump sum data (average area) and re-texturing the low-res texture results. A virtual 3D model of driving so all nearby car logics can be tested before on-board systems' implementations. Secondly, more and more testing on prototypes can be done in order to have better-quality products. The reduction of test-prototyping prototypes' level by these new technologies can make testing systems more trustworthy and believable.

Equ 3: Virtual Validation Coverage (VVC).

$$\mathrm{VVC} = \frac{T_{virtual}}{T_{total}} \times 100$$

- $T_{virtual}$: Time spent validating components in the digital twin
- T_{total}: Total validation time
- Reflects the extent to which testing is offloaded to the digital environment.

7.2. Integration with AI and IoT

Digital twins exhibit great potential for integration with AI applications and the Internet of Things (IoT). Data analytics enabled by AI can be extended to leverage historical and real-time data for the entire virtual vehicle to improve analysis results and predictive insight. Collectively available vehicle and environmental data from environmental sensors, maps, and other vehicles can be accessed through 5G and contribute to the generative design of a virtual twin, optimized motion trajectories, and ADAS or automated driving policy. Cloud computing enables optimal resource allocation and the deployment of heavy machine learning models for both AI

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applications and virtual twin functions at the edge or cloud. A DL-based high-fidelity surrogate model might replace complex physics engines in vehicle dynamics analysis and driving scenario simulation.

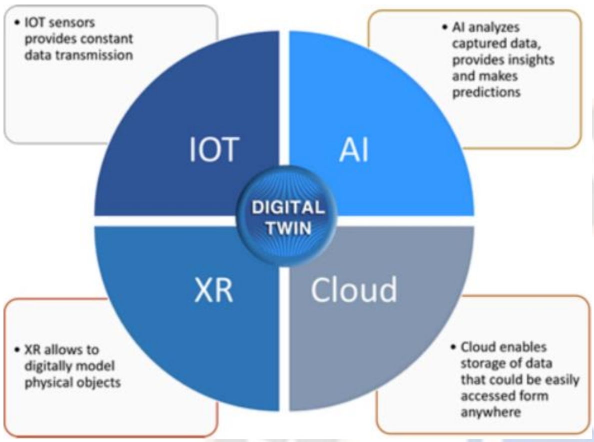

Fig 5: Integration with AI and IoT of Digital Twins in Automotive R&D.

As OT leads to enhanced reliability and safety in the abstraction and reality transitional analysis of automated vehicle dysfunction, a reliable and efficient data scheme would provide potentially critical vehicle litigation database building. Digital twins' applications in virtual twins, network simulation, and cooperative driving rely on real-time data streaming that was demonstrated within a testbed consisting of vehicles. A potential pipeline to build a virtual twin based on road, traffic, weather, and driving data time-series is also discussed.

To cover functional, physical, and environmental causes of multi-modal dysfunction and guarantee satisfaction of signal temporal logic specifications, a multi-fidelity cross-layer co-simulation of active simulators, physical, and virtual vehicles is proposed. Hybrid scenario synthesis and contract-based verification are used to establish a functional model of a new corner case using a qualitative model, digital twins of the specifications, models, and constraints, and model-checking techniques. The most demanding case is executed on a digital twin of a parametric environment and the selected semi-physical subsystems guarantee compliance to physical constraints.

7.3. Scalability and Adaptability One of the advantages of having a digital twin is its easy scalability. When it comes to analogue systems that are duplicated in the real world, a DT could be used to simulate the entire duplicated unit in addition to the existing one unit. This cloning process becomes useful in evaluating the practicality of the systems in wider scopes. Moreover, a DT prototype could leverage upon other DT prototypes in a bottom-up fashion. For instance, in addition to a vehicle's DT prototype, its tire's DT prototype exists separately, and using them in conjunction could enable a deeper insight into the vehicle's behavior. In combination with these composites, a larger system could be modeled.

Another notion in which the adaptability of a DT can easily be demonstrated, is applying new quality assessment methods on existing DT prototypes. For instance, existing DT prototype(s) can adapt easily to new assessment methods regarding the quality of the traffic signs. Imagine an updated law on regulatory traffic sign shape that could trigger a complete new set of digitization methods. Applying this new behaviour to the existing traffic sign DT prototype would immediately give a complete new quality analysis on all the traffic signs included in its models, whereas traditional approximations would require the steep effort of imitating all the simulations from scratch.

Adaptability also refers to re-execution of tests in a new scenario without the need to adjust existing parts. Considering the traffic sign DT prototype, a candidate quality inspector might represent a completely new estimator of quality. However, re-execution of previous tests could still be done without any additional effort. This aspect can clearly be seen in the DT prototype fight within climate conditions.

8. Challenges in Implementation

While digital twin technology provides vast opportunities to boost productivity in automotive R&D, it is important to highlight that there are also challenges that need to be carefully addressed. In a recent survey about the challenges and benefits of digital twin implementations, focused on major question categories including the studied object, development, and data exchange. Questions regarding simulation fidelity, deduction algorithms, and data usage as well as data compatibility, update intervals, and data availability were identified as technical challenges. Furthermore, time dynamics and multi-physics challenges in the digital twin derived knowledge were highlighted.

The topic of potential benefits or potentials of digital twin technology was highlighted as the most relevant question category. Combining advantages of prediction accuracy, fundamental understanding, and rapid decision-making were highlighted as the most important points. Other potential benefits include finally exploiting data value, automated data preparation and modeling, automated derivation of optimization strategies, and independent access to results for all departments . The use of digital twins as a small engineering cyclone for testing new algorithms was also highlighted. Overall, there are varying challenges that need to be addressed in the development and implementation of digital twins for automotive applications.

On a much higher abstraction level, there are challenges which need to be addressed in the development of the digital twin itself. One challenge that needs to be addressed is the integration of the digital twin into existing IT landscapes and the already implemented tools and procedures which have been developed and optimized over many years. In addition to technical challenges, sociological and organizational challenges are to be addressed. In recent test cases, people worked on algorithmic improvements in teams containing members from multiple organizations. Often, models from different teams exist in a working state, but are not documented and therefore not transferable (especially the older ones). Future delegations of the work would benefit if knowledge is preserved.

8.1. Technical Barriers

Despite the large range of benefits accompanying the establishment and implementation of Vehicle Digital Twins (VDT), it also comes with certain difficulties, which can be categorized into technical barriers and organizational barriers. The technical barriers are the subject of this section and are grouped into such five themes: lack of accurate data and data interoperability, dynamicity and fidelity of simulations, high computational demand and real-time execution, seamless transmission of jointly developed VDTs, and practically infeasible concept for software test and validation.

To provide the intended benefits of VDTs, it is essential that they are integrated system-wide models of the vehicles, which means that data on the vehicle must feed into and out of the VDT. This requires the harvesting of data, such as sensor data, computation results, and other non-privileged data during vehicle operation. In the current state of the development of VDTs, a lack of accurate data strictly limits the degree of insight on the vehicle's state. This lack of data is rooted in a lack of effective On-Board Data Communication Bus (OBD) for certain vehicle parameters. Most broadly realized, extensive knowledge on performance, robustness issues, etc., on other parts of the vehicle besides the ECUs is unreachable. There is a large group of variables on which there is knowledge but which are both difficult to position and harsh on price estimation. Most current Manufacturer-Tyrees VDTs focus on evaluating the configuration of new vehicle types. Such performant VDTs are naturally more specific to certain aspects of the vehicle and cannot be rapidly prototyped due to their implementation in scientific simulation packages.

Additionally, a technical aspect of great difficulty is the dynamicity of VDTs. New Input/Output (I/O) signals must be incorporated into the VDT as they are made available and developmental code and models are iterated, while the IM's Evolutionary Digital Twin (EDT) model must always be kept on par with its generated VDT. Off-road or off-network operation in which altering this ontological knowledge cannot be attended to once elements in the knowledge graph drift offers another challenge. Not meeting these requirements induces drift misalignment or miscalibration both of which heavily affect explainability of and information returned from the VDT.

8.2. Cultural Resistance

As in the general automotive engineering community one can fear that focusing on the digital twin implementations could be premature. Especially at the automotive engineering departments of the Technical Universities studied, there is still a lot of work and research needed on how to treat and store the large amounts of data collected during R&D and pre-development of new car suspensions. Therefore, a lot of work is needed to build a proper digital (physical) twin for both the ME and the SIE and to use these twins in the upcoming DAE, like e.g. virtual crash or passive dynamic behavior scenarios which are not yet well defined. In practice a proper definition of the Twins needed first and which analysis can be done here with the cars that are now in MCD and pre-development stages (just finished prototypes with TMG connections and parameter determination are bought by the OEM's). Based on this knowledge the research needed for implementation of all the use-cases into long lasting Twin automation can be defined and

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selected. According to this strategy there is no need to race ahead with vague, speculative, far-fetched questions on the current state of the tool like reliability, predictive capability, expected future development and progress scenarios in the years, decades and epochs after the project ended. Probably nobody in the automotive engineering domain could provide even approximate answers to these questions. However, a race ahead on these questions would create integration risks on purchasing the input tool for the reference models, on long term dependencies from to be specified commercial contracts with third parties that could become outdated and hence unreliable after a shorter period of time than intended and on knowledge loss that could occur on legacy software that on specification and purchasing bases might get out of the control of the team.

8.3. Data Security Concerns

Digital Twins (DTs) are at risk of cyberattacks due to weaknesses in access control and training-processing-validation security. Unauthenticated input to machine learning models or chatbots may lead to security issues. The internal structure of DTs, especially cloud-based DTs for industrial systems, often remains unknown to the system owner, leading to a lack of ability to safeguard it. Conversely, creating a DT requires scanning the real system and collecting data, making it susceptible to attackers. Access to a DT of a product or service poses a risk to the entire collection. Addressing cybersecurity is one route to protect access to the entire series of products. The development of industrial digital twins leads to increased inter-domain connectivity and cross-domain dependencies, which have exacerbated cyber threats. Traditional IT security solutions have been insufficient to ensure proper protection of industrial digital twins. Existing industrial cybersecurity solutions are focused mostly on the protection of perimeters and ignore the new opportunities and challenges introduced by cloud-based data analysis and digital twins. Moreover, current solutions usually fall short of protecting complex multi-level systems of cyber-physical-safety, where safety is often the co-design product of both the safety and the security models. Addressing such problems requires generating protective measures based on a system-wide observation of the real-time data and puts more focus on the application side of digital twins. This approach would put strong demands on the fidelity, consistency, and reliability of the digital twins embedded in the real time system. Integration of new AI techniques into industrial digital twins offers exciting opportunities to offer advanced protection measures. Nevertheless, trustworthiness of AI-enabled digital twins can itself be under threat.

9. Case Studies of Successful Implementations

Digital twins (DTs) for automotive R&D have been around for a long time, and their basic concepts date back to the beginning of the century. Among the first examples of early on-model migration and DT applications are compelling automotive applications that allow rapid prototyping for models created with limited experience. Some big players in the automotive market applied digital twins to offer DTs for engine combustion models, crash simulations, or CFD. Big companies along the entire automotive value chain, from OEMs and Tiers, have created their own versions of vehicle, powertrain, and bus structure DTs to run their simulations on them.

2D and 3D basic DT formulations can be found. 2D basic DT implementations for elderly people showing the risk of falling, or DT for swing bridges, bridges, or impact comparisons in athletics shoes. In the automotive area, 3D examples can also be found, e.g. digital family vehicle from the simulation center with model on frameworks and roads. Also, vehicle propulsion DTs with 1D vehicle simulation are implemented. A floating bus DT was developed for a bus holding instead of riding on the rest of the bus line with a pneumatic actuation technique to tilt the bus. Mentioned is also the perspective on what the future of automotive DTs will be.

The sub-chapters are first pointing out open questions regarding different efforts for providing academic DT frameworks and the need for a reference framework at various layers for building and exchanging DTs. Also, another key point is the DT chain or chain of information between several DTs. A major issue is the usability of a DT since model-in-loop applications have additional requirements with respect to configurability for easier access. Finally, the perspective on possible future directions for shaping a better DT for automotive R&D is presented.

9.1. Leading Automotive Companies

Automotive companies are pioneers in the development and deployment of physical networked systems. Conventional applications predominantly focus on simulation and big data analytics concepts such as performance monitoring, behavior prediction and driver profiling. However, for the Digital Twin

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technology to progress from post-mortem to continuous monitoring functionality, improving the data handling aspect is crucial. Sound data acquisition methods and algorithms for analyzing large and structured databases already exist, which will allow the transition to the next step toward semi-physical simulation or testing of physical systems.

Today, automotive companies employ a multitude of different simulator and simulation tools, each focusing on one or a few aspects of the overall vehicle system. Recently developed or prototyped simulators often model a new assessment aspect of the vehicle. With the advent of ever-increasing vehicle functionality and complexity, it is becoming more difficult to manage the overall vehicle simulation architecture. Existing simulators often do not support collaborative development projects well, making the integration of two or more simulators complicated. Having all simulators use a standardized modeling node design and data handling abstraction could greatly simplify their use and lead to major savings in software development and maintenance.

The value of digital twins in the automotive industry is becoming more evident as companies shift from traditional automotive value chain elements to overall transportation systems. The opportunity to motivate and initialize the growing creation of international platforms and initiatives around digital twins for the automotive industry and to promote their early development will be lost if the current, fragmented market scenarios are allowed to unfold.

9.2. Innovative Startups Startups such as Pchitecture in Africa and Cinderblock in Canada utilize digital twin or simulation technology to deliver customer experiences. Major automotive companies are also leveraging game engines and 3D simulation together with AI and VR for engineering tasks.Most startup goals are non-traditional and are intended for rapid prototyping of new products or visualizing new product concepts. However, automotive R&D teams are focused on different tasks. Introducing digital twin technology to mainstream automotive R&D functions could inspire the development of startups focused on that nascent business area. Existing and new automotive engineering consultancies have the best position to explore this opportunity and establish a leadership position in that domain.

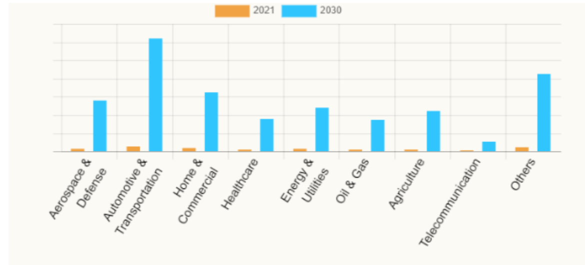

Fig 6: Digital Twins in Automotive R&D for Rapid Prototyping and System Integration.

To that end, a multi-step approach could work best. Initial focus could be to first target mid-size OEMs and automotive engineering consultancies. Mid-size OEMs usually have limited resources to invest in R&D solutions. As they currently lack in-house rapid prototyping capabilities they could be convinced to invest in the low-cost off-the-shelf high-fidelity simulations tool whose advantages are outlined above. After implementation of the system, a test run of digital twin technology could be offered to target local major OEMs. Once a solid base of customer success stories is established, a strategy to target Tier-1 & 2 as well as newly founded ADPSs and associated spin-offs could be employed.

As illustrated by the automotive OEMs doing digital twin based rapid prototyping for testing of user interfaces of newly developed clustervisions. It is advisable to target ADPSs and their suppliers as they are currently lacking in-house efficient solutions to test their complex software features, a need that is expected to grow exponentially as both the level of automation and the complexity of ADPSs increase.

10. Conclusion

Digital Twins (DT) are currently playing a crucial role in R&D activities in the automotive domain. They effectively address key challenges and needs for M&S in an ever more complex and heavily constrained vehicle R&D environment. Many of the current automotive systems and M&S approaches can be modeled via a DT, potentially leading to thorough improvements in efficiency, effectiveness, and timeliness of exploratory and confirmatory modeling activities. On the one hand, many of the forecasted opportunities for vehicle DTs are virtually feasible with present-day technology, e.g. for pre-fuse investigation of vehicle behavior, and understanding cause-effect relations in vehicle systems throughout their life-cycles.

On the other hand, conducting a corresponding task in practice comes with many new challenges, e.g. for data acquisition, storage, management, and interpretation.

Both opportunities and challenges apply to all stages of DT maturity and all vehicle functions, albeit addressed via different R&D items or approaches. Further developments and concrete solutions for many of the above opportunities and challenges have already been identified, i.e. on potential implementations to create one integrative vehicle DT from different already existing vehicle modeling setups; on a data mining approach to allow for pattern-based vehicle modeling based on operating history; or on the co-simulation of vehicle DTs to better understand system robustness. Further exploration and deepening of these or related ideas in practice would allow for a more thorough R&D of vehicles, supporting the efficient broadening and depth of knowledge in a timely manner to create a better basis for the design, early validation, and continuous improvement of competitive automotive products. Simultaneously, a number of key areas have been highlighted in which knowledge is still incomplete and solutions have yet to be searched for. Perceiving this as a research agenda, knowledge creation for the further development of DTs for preparations of up front modeling is called for in the areas of common representation of testing environments and vehicle system modeling, as well as modeling of systems in human driven systems and unexpected events.

References

[1] Karthik Chava, "Machine Learning in Modern Healthcare: Leveraging Big Data for Early Disease Detection and Patient Monitoring", International Journal of Science and Research (IJSR), Volume 9 Issue 12, December 2020, pp. 1899-1910, https://www.ijsr.net/getabstract.php?paperid=SR201212164722, DOI: https://www.doi.org/10.21275/SR201212164722

[2] Data Engineering Architectures for Real-Time Quality Monitoring in Paint Production Lines. (2020). International Journal of Engineering and Computer Science, 9(12), 25289-25303. https://doi.org/10.18535/ijecs.v9i12.4587

[3] Vamsee Pamisetty. (2020). Optimizing Tax Compliance and Fraud Prevention through Intelligent Systems: The Role of Technology in Public Finance Innovation. International Journal on Recent and Innovation Trends in Computing and Communication, 8(12), 111–127. Retrieved from https://ijritcc.org/index.php/ijritcc/article/view/11582

[4] Mandala, V. (2019). Integrating AWS IoT and Kafka for Real-Time Engine Failure Prediction in Commercial Vehicles Using Machine Learning Techniques. International Journal of Science and Research (IJSR), 8(12), 2046-2050.

[5] Ghahramani, M., Qiao, Y., Zhou, M., O'Hagan, A., & Sweeney, J. (2020). AI-based modeling and data-driven evaluation for smart manufacturing processes. IEEE/CAA Journal of Automatica Sinica, 7(4), 1026–1037. https://doi.org/10.1109/JAS.2020.1003114