SIEMENS DIGITAL INDUSTRIES SOFTWARE

Enhancing **autonomous heavy-vehicle design**

Leveraging simulation software to cope with the growing complexity in today's vehicles

Executive summary
This white paper considers the benefits of simulation solutions for designers and engineers in the heavy-duty vehicle industry, from conceptualization to realization. It discusses the latest progress in the areas of virtual vehicle development and testing, simulated sensor development, creating virtual working environments, and presents how the effective and fluid integration of these simulation technologies has been achieved in Simcenter™ software, which is part of the Xcelerator™ portfolio, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software.

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Abstract

With the onward march of technology, off-highway machinery is becoming more and more sophisticated. As the complexity of machinery increases, so does safety concerns and the likelihood of human error in operation. Further, technological progress does not come cheap. Companies that invest in advanced machinery want optimum results, while safety and optimization of production are also key considerations. With all this in mind, developers and engineers in the off-highway vehicle industry are focusing increasingly on highly sophisticated partially or fully autonomous options for their products. Automation is considered to be a panacea for achieving optimal safety and functioning.

However, autonomous vehicles are a huge design challenge. There is – and always will be – a requirement for physical prototyping, but the introduction of vehicle autonomy creates the need to test enormous numbers of variables. Simulation during the design process – of the machine, the natural environment and the sensors – is the solution to this. Using simulation, design engineers can rapidly test enormous numbers of variables. The result is reduced time-to-market, reduced research and development (R&D) costs and a far better understanding of the capabilities of a machine than could ever realistically be possible with physical prototyping alone. Using the latest simulation technology, off-highway vehicle developers have the chance to be at the forefront of a digital design revolution.

Simulation: a cost benefit and safety solution

Heavy duty, off-road vehicles – for example, the machinery we find in mines, on farms or in the construction industry – are prime candidates for automation, and it's happening now for a range of reasons. Advanced driver assistance systems (ADAS) are already fitted to many large vehicles, with the aim of improving operator safety. These include remote-control driving/actuation and fully autonomous driving. Automated machinery in mines is already well established[1] since it removes much of the risk to humans working in hostile conditions and/or confined spaces. Now the possibility of partially or fully automating heavy machinery across the board is being seriously investigated.

Automation is not only seen as the way to optimize safety – there are also clear cost benefits in maximizing efficiency and performance. For example, an automated vehicle on a farm could run 24 hours a day if necessary. The concept of autonomous off-highway machinery has one specific advantage over that much talked-about phenomenon, the driverless car, and it's a significant reason for the technological development in the sector. Although the environments in which they operate can still be challenging and fluid, off-road machines operate in more predictable settings than the open road, meaning there is less need for such artificial intelligence (AI) and machine-learning (ML) capabilities.[2] There are other drivers for automation too. For example, companies using off-road machinery strive for efficiency, and skilled operators of this complex machinery can be extremely expensive and difficult to find. Full automation is one potential answer to these issues.

Knocking on the doors of perception: replicating human sensory abilities

Designers of autonomous off-highway machinery face a specific challenge: how to endow their machines with a digital brain and sensory abilities that exceed those of a human operator. It's possible for an autonomous vehicle to surpass the sensory perceptions of a human operator because the system incorporates sensors that see things a human never can, such as in blind spots behind the machine. But it's a tough challenge because it's more than just a question of a brain and senses. Human operators have hindsight and experience that also inform their ability to interact with the environment their vehicle is traveling through or working in. With these factors in mind, it is clear that creating an autonomous vehicle involves the challenge of getting a prototype to respond appropriately to an almost infinite number of variables arising from the nature of the environment a vehicle moves in and the reactions to that environment of its mechatronics.

When we talk about the environment, we mean, for example, terrain, dirt, weather, unexpected obstacles, other traffic and people. It's impractical to build a physical prototype of an autonomous vehicle and test its reactions to all the possible scenarios it might realistically encounter; this would be a lengthy process and impossibly expensive. The answer for autonomous off-highway machinery designers is simulation. Incorporating simulation as far as possible into the research and development process will afford significant advantages in terms of time saved, optimization of design and cost.

Simulation technology: **what can it do?**

The machine

Let's start with the machine. For years vehicle manufacturers have used model-based systems engineering. It is an approach perfectly aligned to the development of autonomous vehicles in the form of the digital twin. Creating a comprehensive digital twin involves the digitalization of all the phases of a machine's development process, from design to realization to utilization. It comprises software that captures real-world data about the physics of a machine, and the performance of its systems and components, and produces an exact live digital facsimile of that machine. This enables developers to observe the behavior of the machine as a whole, including the interactions between the thousands of parts within it. It also enables the testing of its performance requirements in its operating ecosystem throughout its lifecycle.

All this is done in a safe and cost-efficient environment. The data generated is used to modify the design. It refines and accelerates the entire design process, replacing laborious and costly physical prototype testing with virtual engineering. Digital twin technology isn't only confined to machinery. The concept is used to model many physical objects, including buildings, terrains, natural environments and vehicle sensors – which will be discussed later in the white paper. In Singapore, city planners have even created a replica of their entire city.[3]

Machine simulation is not only about the digital twin. When it comes to heavy equipment vehicle modeling, the key for R&D teams is to introduce all of the possible variables so everything can be tested. Advanced simulation software can include a huge variety of potential dynamics as part of the simulation. This can range from the type of soil the vehicle is running on to the make of tire being used. The more dynamics the simulation uses, the more accurate it will be, and the real-world results of such simulations are far reaching. Full autonomy, or partial autonomy via operator assistance, results in improved machine controllability in difficult environments. Safety is also improved; for example, by automating the process of keeping the machine within the load safety zone. Additionally, autonomous vehicles deliver improved energy efficiency with better energy distribution, as well as improved powertrain durability. Comprehensive simulation also allows for accurate gradeability (calculation of the steepest gradient a machine will be able to climb) and stability assessments prior to physical prototyping

Simcenter Amesim™ software is an integrated, scalable vehicle system simulation platform. Its capabilities enable engineers to rapidly create and penetrate deep inside the functioning mechatronic systems of a vehicle – for example, mechanical, hydraulic, electrical, pneumatic – so they can evaluate and optimize their performance. It's an open and flexible software environment that can easily be fused with computer-aided engineering (CAE) and computer-aided design (CAD) software packages. Simcenter Amesim further offers a broad range of useful features to suit the development requirements of every possible type of off-highway vehicle. For example, there is a track generator feature that enables engineers to measure the impact of terrain on vehicle dynamics, tractions and powertrains when developing tracked vehicles. Simcenter Amesim has the capability to simulate all types of heavy equipment, including construction,

agricultural, mining and materials-handling vehicles, and can model all relevant dynamics (both vehicle and powertrain) for each. This is a lot of simulations. Simcenter Amesim is well suited as a system simulation tool because it is fast, reliable and easy-to-use. Validating machine design in this manner radically reduces the rounds of physical prototypes that must be created, saving huge amounts of time – sometimes weeks of the time for R&D engineers

Simcenter Amesim can even connect to the natural environment model, which is covered in the paragraph below and also in the next section – *Automating and accelerating the verification workflow.*

The natural environment

The key question for the end user of an autonomous vehicle is how can he or she be confident the machine will respond as required in any conditions? The living environment is continually changing.

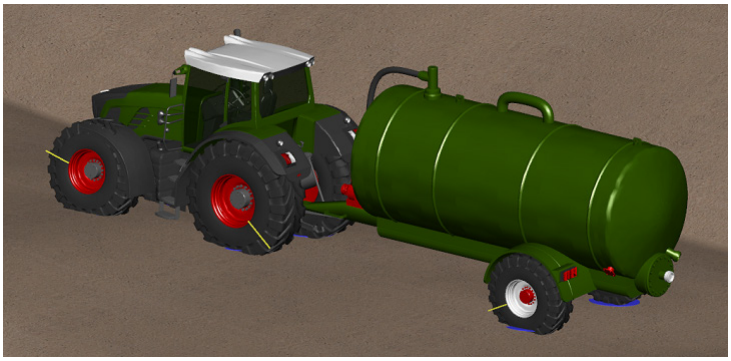

Figure 1. Tractor with trailer on uneven soft soil, powertrain and vehicle dynamic

Simulation of the environment in which heavy-duty equipment operates has to consider the multiple complexities of the rough terrain and the unexpected surprises an off-road vehicle might encounter. Dips and inclines, dust, obstacles such as rocks, ditches, trees and moving objects such as pedestrians and other mobile and immobile machinery all have to be factored into the digital representation. Then there are the weather conditions we encounter in the natural world – rain, wind, snow, extreme cold or heat, fog and bright sunlight. All these factors have a bearing on an autonomous machine's behavior,[4] as does the time of day since a primary benefit of autonomous vehicles is their 24-hour availability.

Simcenter Prescan™ software, which is an environment-modeling tool, delivers the capacity to create a complete simulation of the natural environment – offering a vivid representation of a vehicle's sensors. It does this by factoring into its simulation the nature of the sensor picking up the information, whether it is a camera, lidar or radar. It is also flexible enough to allow the import of a digitalized model of any kind of off-highway vehicle, including construction, agricultural, mining and materials-handling vehicles. The next section of the white paper, which examines sensor simulation, will also elaborate more completely on the capabilities of the Simcenter Prescan solution.

Figure 2. Examples of environments, both including natural obstacles, crossing pedestrians and moving machines.

The sensors

The sensors on a vehicle interpret the natural environment and transmit data to the machine's digital brain, which then governs the response of the vehicle. Though sensors are physically a part of the vehicle, they are usually manufactured by a company other than the vehicle original equipment manufacturer (OEM), and sensor simulation software capabilities likewise tend to be separate and well defined. Sensor simulation is a highly complex area. If a human operator's senses are replaced by cameras, radar and lidar, how do we know what the vehicle will sense, or, possibly with serious consequences, will fail to sense?

With sensors we are probably at the core of the advantages of simulation. They range from basic ground-truth sensors that identify objects that appear within the vehicle's path, to probabilistic sensors that detect possible obstacles and dangers in the vicinity and feed in their coordinates and motion data. Finally there are physics-based sensors installed in the form of camera, radar and lidar that digitalize the entire 3D scenery in which the machine is operating, mapping all geometric detail.

Combining sensory data from these three sources – sensor fusion – enables optimal path planning and object detection. Whether a vehicle uses ADAS or is fully automated, ensuring sensors are set up for optimized functionality involves many millions of testing miles in a wide range of driving conditions. It also involves creating simulations of the sensors themselves – such as how they behave in adverse conditions where they may be coated in dirt or rain – so their design can be improved to guarantee reliability and safety. All this is only possible if the majority of the validation work is done via simulation technologies. In addition to Simcenter Prescan, Siemens offers a variety of other simulation solutions that can help with different elements of these tasks, such as Simcenter 3D high frequency simulation software and Simcenter STAR-CCM+™ software. Simcenter 3D high definition simulation software provides detailed simulation to assess how a radar sensor behaves, for instance, when integrated behind a bumper on a vehicle to verify an antenna layout. Simcenter STAR-CCM+ software can support thermal analysis and sensor soiling analysis (dirt, rain, etc.).

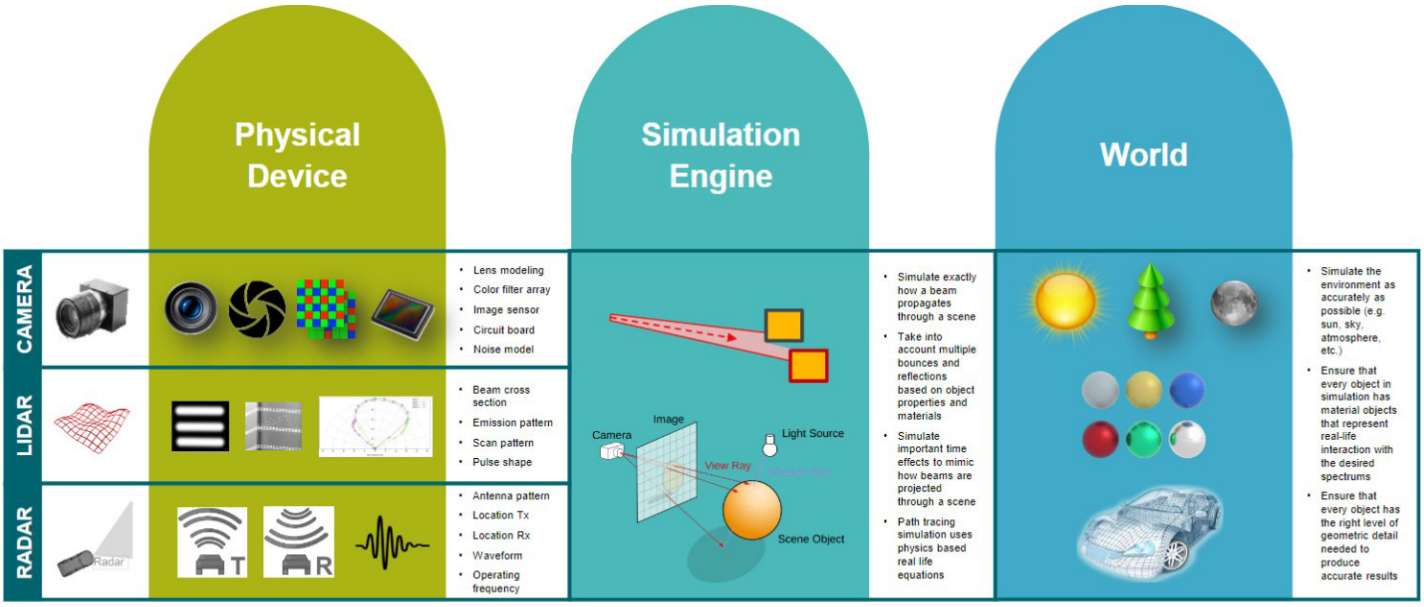

Figure 3. Summary of sensor modeling capabilities and principles.

Simcenter Prescan simulation software offers an optimized human/computer interface platform enabling validation in five stages:

1. It allows the recreation of realistic working environment scenarios for off-highway vehicles within minutes
2. A range of sensor models can then be added
3. The design and verification of algorithms for data processing, sensor fusion, decision-making and control can now be accomplished
4. Engineers can run experiments on a range of operating systems and hardware platforms
5. They can change the scope of their experiments by altering features in the physical landscape and other parameters, such as sensor setup and algorithms

Simcenter Prescan has the added flexibility of being able to be used to simulate sensor technology at different levels of fidelity. It permits engineers to create simplified models, enabling the running of a large number of test cases, or it can allow a more in-depth, complex simulation of a sensor, to give a granular assessment of the technology.

Automating and accelerating the **verification workflow**

Making life easier for designers

The task for designers and engineers is to produce a fully functional autonomous machine capable of operating at levels of safety and efficiency above and beyond those of manned machinery. The challenge for digital scientists is how to process the millions of pieces of data generated during the simulation development process. This is where the assessment procedure itself becomes automated, and a key cost-saver in the development of autonomous off-road vehicle simulation is the automation of the verification and validation workflow.

HEEDS™ software is an example of software that can be used to evaluate the thousands of scenarios created by different simulations, streamlining the engineering process and eliminating the need for large numbers of engineers to spend their valuable time working on hundreds of simulations. One example is automating the assessment of how a simulated autonomous vehicle was performing in a range of lighting conditions. For example, using HEEDS, not only can you system model the vehicle, sensor and the natural environment so you can test it in all possible lighting conditions, but it also automates the process of evaluating performance in all possible lighting conditions. The most advanced verification workflow software solutions are open, meaning they can work equally well with third-party or in-house simulation tools.

This final stage of automating the verification workflow is absolutely crucial to the successful simulation of autonomous vehicles. The point of the simulation process is to be able to efficiently generate a massive amount of relevant simulation scenarios. By definition, therefore, if the verification of all outcomes had to be done manually no matter how sophisticated the individual simulations were, it would be an unmanageable system for humans to operate.

Aligning with industry needs

Simulation will be used more and more in the conceptualization, design and realization of heavy duty vehicles. The challenge for manufacturers is to get up to speed swiftly with the technology. The Simcenter suite is easy to set up and use, and it fuses with a wide range of software and hardware applications. It aligns with the needs of the heavy equipment industry as a whole but is domain oriented. And it embraces all the elements required for smooth and effective vehicle design. This includes the architecture of the vehicle, its individual mechatronic components and how they bear on each other, sensor design and how sensors react to and digitally represent the environment, as well as the environment and how it is designed to best represent reality in digital form.

Simulation software is not designed to do away with the process of building and testing physical prototypes. This has always been necessary, and always will be. The thing that has changed – and the thing that has created the need for simulation solutions in the vehicle development process – is the ever-increasing complexity of modern technology, which creates enormous numbers of variables. This is true even in modern, nonautonomous automobiles. But it is doubly true of autonomous vehicles where the manufacturers are not only trying to manufacture a vehicle, but also manufacture the capabilities of a human driver.

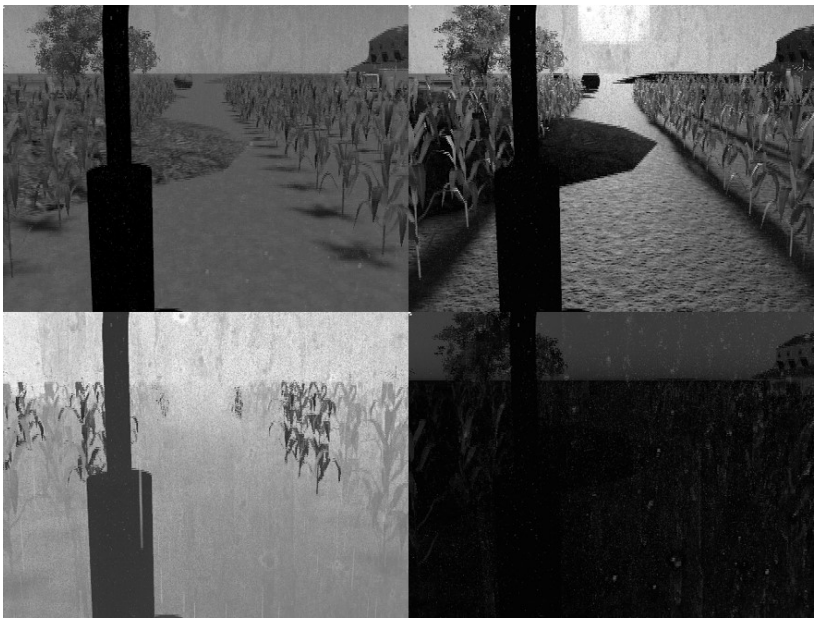

Figure 4. Camera detection of pedestrian in cornfield, natural conditions sensitivity study. Top left: nominal conditions. Top right: sunset reflection. Bottom left: dirt on camera. Bottom right: night conditions.

Conclusion

Heavy duty off-highway vehicles are a rapidly growing market that is poised to recover fast after COVID,[5] and there will be strong pressure on R&D teams to deliver many new autonomous solutions in the coming years. As such, simulation software packages are key for today's off-highway vehicle designers.

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