



BEYOND THE RAILS: SIMULATION STRATEGIES THAT WORK

An analysis of critical rail freight issues and how aerodynamics and vehicle dynamics simulation capabilities can provide effective solutions.

WHAT SETS RAIL COMPANIES ON THE RIGHT TRACK

Top rail operators are not just keeping pace with industry demands; they're setting new standards in safety, sustainability and reliability. As global trade increasingly pivots to rail freight, these leaders understand that optimizing efficiency isn't just an option — it's a necessity.

With the rail freight market expected to grow by 200%, reaching 1,150 billion ton-km by 2050¹, the transition from road to rail is accelerating, bringing higher stakes. It is now more crucial than ever to close the gap between the high expectations for rail companies and the practical challenges of ensuring safe and reliable operations.

Rail freight operators need precision and complete visibility to manage complexities before they arise, formulating success from the very beginning. With the right digital strategies, companies are on the right track to capitalize on business opportunities that come their way.

This guide goes beyond the surface, delving into how advanced simulation strategies, driven by virtual twin technology, can deliver transformative benefits — providing the competitive edge needed to thrive in today's rail freight industry.

[1] "[Rail 2040: Scenarios and CEO Agenda](#)" by Arthur D. Little (August 2023)



1164

derailments took place in the United States in 2022², highlighting the daunting challenges faced by the rail industry in ensuring safe and reliable transportation

\$399 million

is the expected value of the rail freight transportation market by 2029, marking an impressive 28% growth, with freight traffic projected to grow at a CAGR of 3.6% from 2023 to 2029³

5%

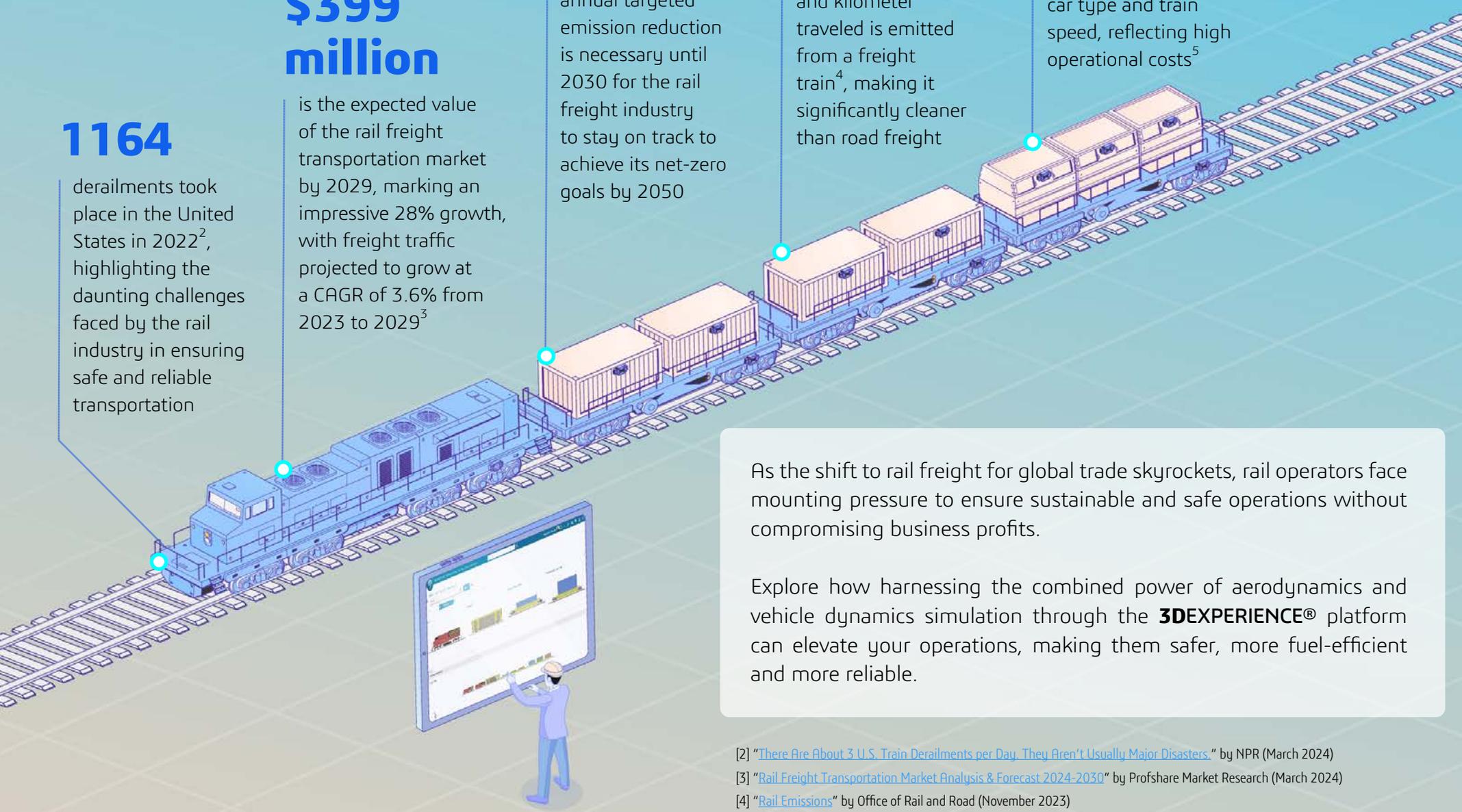
annual targeted emission reduction is necessary until 2030 for the rail freight industry to stay on track to achieve its net-zero goals by 2050

26g

of greenhouse gases per ton transported and kilometer traveled is emitted from a freight train⁴, making it significantly cleaner than road freight

60%

or more of a train's fuel consumption can be attributed to drag, depending on car type and train speed, reflecting high operational costs⁵



As the shift to rail freight for global trade skyrockets, rail operators face mounting pressure to ensure sustainable and safe operations without compromising business profits.

Explore how harnessing the combined power of aerodynamics and vehicle dynamics simulation through the **3DEXPERIENCE**® platform can elevate your operations, making them safer, more fuel-efficient and more reliable.

[2] "There Are About 3 U.S. Train Derailments per Day. They Aren't Usually Major Disasters." by NPR (March 2024)

[3] "Rail Freight Transportation Market Analysis & Forecast 2024-2030" by Profshare Market Research (March 2024)

[4] "Rail Emissions" by Office of Rail and Road (November 2023)

[5] "The Impact of Aerodynamics on Fuel Consumption in Railway Applications" by Ioan Sebesan and Bogdan Tarus (March 2012)

Unlock the Power of Proven Rail Simulation Strategies



Benefit

1

RAIL SAFETY

“

Much like peering into a crystal ball to glimpse the future, our virtual twin technology does just that. It enables rail operators to foresee and mitigate potential dangers, such as derailments, before they occur, ensuring that operations remain safe and uninterrupted.”

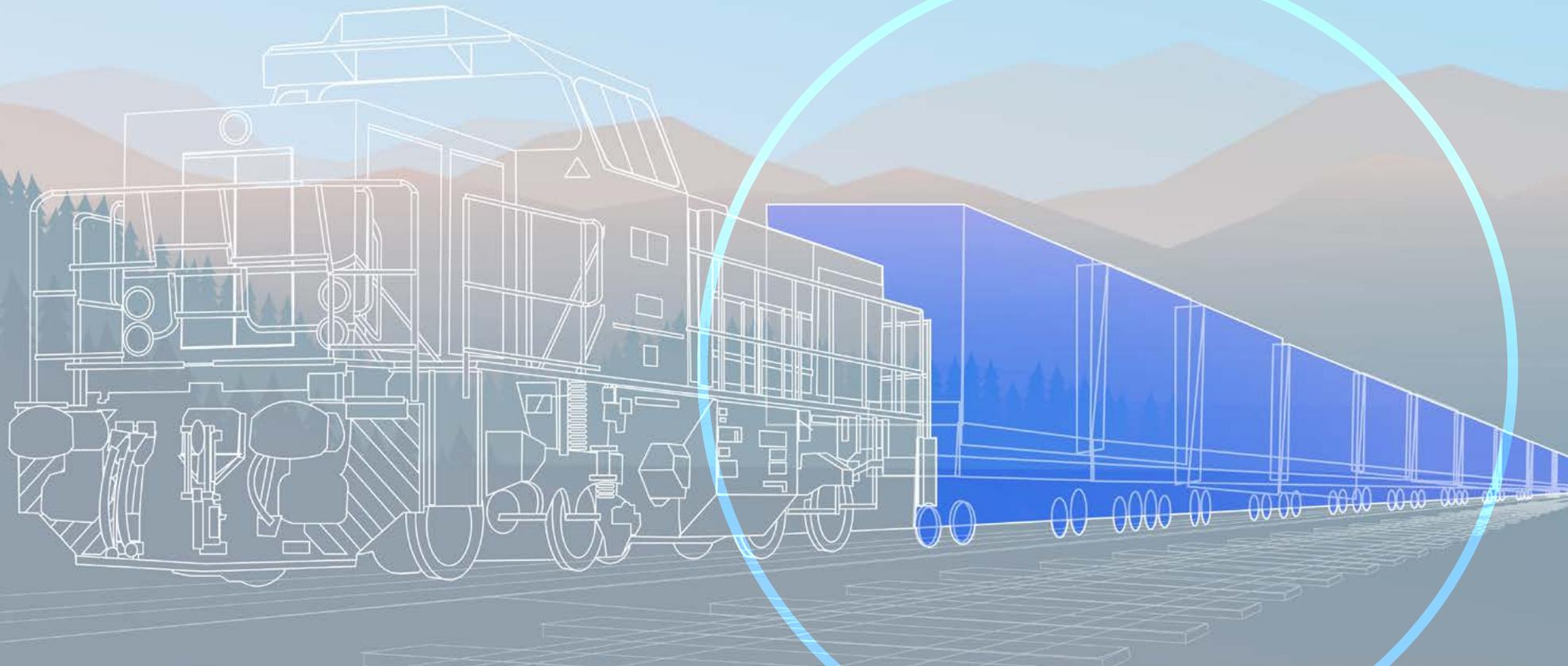
Paulo Barros

Value Consultant Senior Specialist,
Business Services Industry,
Dassault Systèmes

KEY CHALLENGES IN RAIL SAFETY

The safety of freight railway operations is a critical concern due to the complex dynamics involved in the movement of heavy rail vehicles over vast networks. With increasing freight volumes, longer trains and higher speeds, railway operators face multiple challenges that can compromise safety.

Given the recent increase in derailment incidents, every safety manager shares a common objective: To eliminate accidents, fatalities and injuries within all rail-related infrastructure and workplaces. The question is: What measures will effectively prevent such disasters? Take a look at each scenario on the next page and learn how vehicle dynamics simulation solutions address these critical issues.



Train derailment

Imagine having a heavy-loaded wagon weighing hundreds of tons suddenly derailing en route to its destination. The sheer weight and force can cause extensive damage, jeopardizing the safety of the crew, nearby residents and surrounding infrastructure or assets. While freight train derailments are generally less catastrophic than passenger train incidents, the potential risks shouldn't be miscalculated.

Extreme weather conditions

High waters from flash floods, river floods and persistent heavy rains have long posed significant weather-related challenges for the railroad industry and the nation at large. Such environmental factors often lead to obstruction-type incidents, where rail tracks are blocked by debris from rock slides, mudslides, fallen trees, slippery tracks and other hazards.

When rolling stock encounters these compromised or obstructed tracks, derailments become a real risk, especially if emergency braking systems are not operating at peak performance. This highlights the need for greater diligence in preventing accidents through the usage of advanced simulation technologies, which can help mitigate the damages caused by extreme scenarios, and potentially reduce the operational costs.





STRATEGY TO SUCCESS:

RAIL FREIGHT VEHICLE DYNAMICS SIMULATION

Effective rail safety management is imperative in managing accidents on the railways. Advanced simulation tools allow engineers to perform detailed analyses that ensure operational safety, improve performance and meet stringent regulatory standards. This is especially important in three vital simulation workflows – derailment analysis, emergency braking and critical speed analysis – which address key risks in freight rail dynamics.

These workflows also highlight the advantages of virtual homologation in the railway industry. Discover how rail freight vehicle dynamics simulation, driven by virtual twin technology on the **3DEXPERIENCE** platform, elevates emergency protocol through advanced analyses and predictive capabilities.



Unlock the full potential of **Rail Freight Vehicle Dynamics**

1 Derailment - Rollover analysis

Freight train derailments pose significant risks to both infrastructure and the environment, often leading to costly delays, repairs and hazardous material spills. One common cause of derailments is vehicle rollover, typically triggered by excessive lateral forces, unbalanced loading or improper track alignment.

Real-world examples show that uneven track conditions or sudden lateral impacts from curves or obstacles often result in cars tipping over, especially in freight cars with a high center of gravity, such as tankers.

Digital simulation solutions enable safety managers to run homologation tests in compliance with country-specific regulatory standards. For example, the European Standard EN 14363 covers derailment analysis for railway applications and outlines the requirements for evaluating the running behavior of rail vehicles.

With SIMULIA Simpack's simulation capabilities, engineers can assess these risks by modeling the rail vehicle dynamics under varying operational conditions — such as sharp turns or adverse weather — to study the derailment and rollover risks and mitigate potential incidents. Additionally, multi-body modeling facilitates the simulation of various train configurations across different track types, such as curved or S-shaped tracks.



These simulation capabilities offer valuable insights into how different train sequences behave under stress, helping identify factors that could contribute to rollovers. Understanding the train's dynamic behavior improves overall stability and guides design and maintenance enhancements.

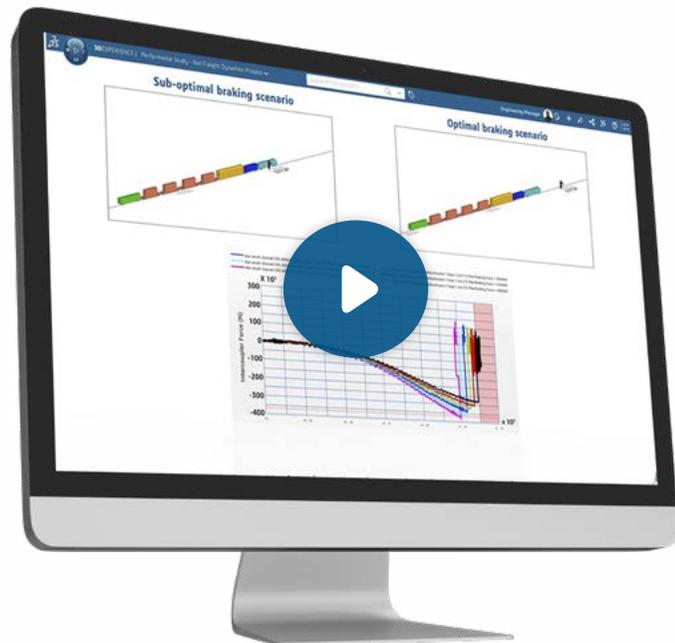


Discover the power
of **Rail Modules**

2 Emergency braking

Emergency braking is a critical safety measure for freight trains, deployed in response to unexpected obstacles or signal failures. Given the mass and momentum of long freight trains, the dynamics during emergency braking are complex, with risks of coupler failures and excessive longitudinal forces between cars.

Real-world incidents of train collisions or derailments after emergency braking illustrate the importance of optimizing braking systems and understanding the vehicle responses under such extreme conditions. The European Standard EN15839, which specifies the procedure for testing the running safety under longitudinal compressive forces, serves as a guideline for ensuring these systems meet safety requirements.



In light of these risks, SIMULIA Simpack allows engineers to simulate the entire braking process, factoring in wheel-rail interactions, brake force distribution and train composition to evaluate the effects of sudden deceleration. This analysis ensures that braking systems are designed for maximum safety and efficiency, preventing incidents like jackknifing or equipment failure.

Through realistic simulations of emergency braking under various conditions, such as adverse weather or track obstructions, operators can stay ahead of potential risks associated with these factors. This sophisticated simulation strategy enhances vehicle behavior predictions, thereby empowering engineers to anticipate and resolve potential issues before they escalate.

Beyond improving emergency protocols, this approach supports simulation-aided maintenance, accident investigations and warranty or misuse case analyses, offering effective and crucial insights into real-world safety challenges.



Explore the benefits
of **SIMULIA Simpack**

3 Critical speed analysis

Freight trains operating at or near their critical speed can experience dangerous phenomena like hunting oscillations, where excessive lateral motions destabilize the vehicle. These instabilities can lead to derailments, track damage or passenger discomfort in adjacent areas.

For instance, when trains exceed their safe operational speed on particular track sections or encounter resonance due to track irregularities, the risk of derailment increases significantly.

Rail freight vehicle dynamics simulation, such as SIMULIA Simpack, enables engineers to perform critical speed analyses for intermodal cars, whether empty or fully loaded. This simulation determines the safe maximum speeds of freight trains based on their configurations, loads and track conditions, revealing how various speeds affect lateral oscillations. It helps operators prevent accidents caused by exceeding critical speeds, ensuring smooth and stable operations under various operating scenarios.



> Elevate safety with **SIMULIA Simpack**

Virtual homologation and its benefits in rail safety

Traditionally, railway vehicles undergo extensive physical testing to meet homologation requirements, which certifies that the vehicles are safe for operation. Virtual homologation, facilitated by advanced simulation tools like SIMULIA Simpack, allows for a significant portion of this testing to be performed virtually. By accurately modeling real-world conditions, virtual homologation reduces the need for costly, time-consuming physical trials while accelerating the certification process.

This approach also enables engineers to identify and address potential issues earlier in the design phase, improving safety and performance, and reducing the risk of operational failures. Virtual homologation also ensures compliance with standards like EN 14363 (testing running behavior) and EN 15839 supporting a more streamlined and cost-effective certification process.

In essence, these robust simulation workflows are essential for rail freight operators to proactively address derailment risks, optimize emergency braking systems and ensure safe speed limits. Combined with virtual homologation, these simulations become critical tools in the ongoing effort to enhance the safety, reliability and efficiency of rail freight operations while adhering to key EN standards.

By simulating vibrations from different loading conditions and movements, operators can determine safe speeds for curved tracks and evaluate the effectiveness of existing emergency protocols, making necessary adjustments to speed and responses to prevent such safety issues.



Benefit

2

SUSTAINABILITY

“

Aerodynamic drag directly affects a freight train's fuel consumption. Rail operators can use virtual twin driven simulation tools to explore different train configurations and arrive at the most fuel-efficient design modifications. This helps in finding an optimal balance between performance and fuel costs, ultimately improving sustainability KPIs.”

Muthu Sivanantham

Solution Experience Senior Manager,
Business Services Industry,
Dassault Systèmes

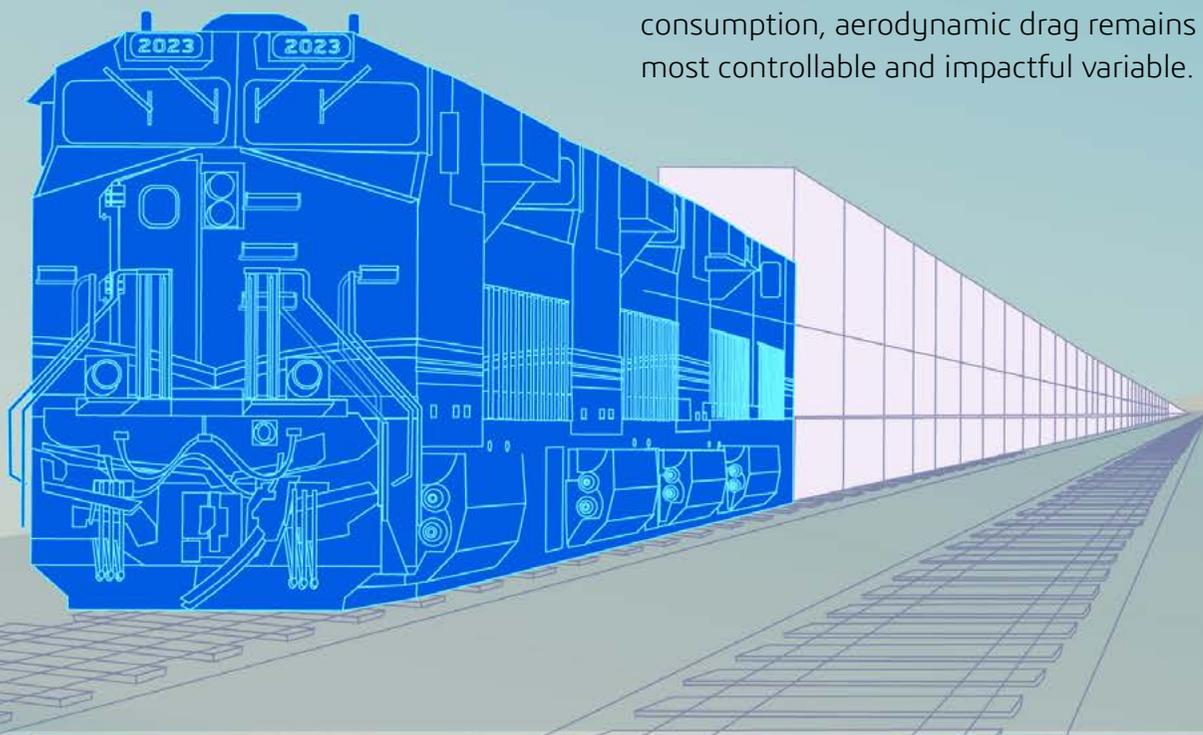
KEY CHALLENGES IN FUEL EFFICIENCY

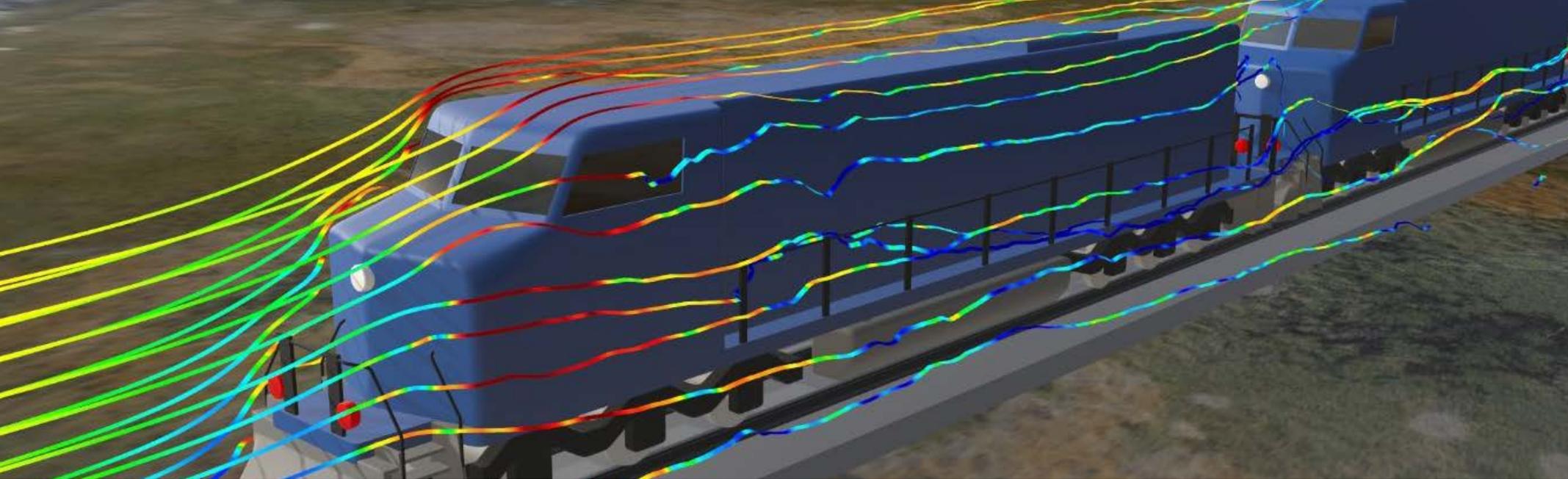
With the growing shift from road to rail, the pressure on rail operators to reduce costs and enhance efficiency is intensifying. Operational costs, particularly fuel expenses, represent a significant portion of a rail company's budget. To accommodate the increasing freight volumes and meet sustainability targets, rail companies must find ways to lower these costs effectively.

Fuel efficiency is not just a financial concern; it's also a crucial element of environmental management. Higher aerodynamic drag increases fuel consumption because more energy is required to overcome air resistance. While factors such as gradients, crosswinds and rolling resistance do affect fuel consumption, aerodynamic drag remains the most controllable and impactful variable.

To address this challenge, rail companies must explore various configurations of locomotives and wagons. They need to understand how different arrangements – such as placing more locomotives at the front or in the middle – affect the forces acting on the train. This includes studying how pulling and pushing forces vary, particularly when forces become negative (i.e. pushing instead of pulling).

Consider a scenario where you have 100 railcars running kilometer after kilometer. Effectively studying this entire train configuration, including its impact on aerodynamic drag, requires robust simulation solutions. Such software must manage diverse configurations and provide insights into how different arrangements influence drag and overall performance. The complexity of these scenarios demands a best-in-class, scalable solution. However, many rail operators are currently unable to fully leverage these benefits due to the absence of such solutions.





STRATEGY TO SUCCESS:

RAIL FREIGHT AERODYNAMICS SIMULATION

1 Simulate unlimited rail configurations

Using rail freight aerodynamics simulation capability, operators can simulate the aerodynamic forces acting on the freight train, which helps in understanding how these forces affect the train's stability. By analyzing these forces, it is possible to design trains that are less susceptible to vibrations and disturbances caused by aerodynamic forces.

The combination of PowerFLOW application, together with other physics analyst and testing applications on the **3DEXPERIENCE** platform, empowers rail operators to easily configure scenarios and perform unlimited what-if analyses using the pre-configured feature.

The user-friendly interface and intuitive functions make it simple to build different train compositions and simulate their behavior across various conditions. Best of all, unlike physical testing, operators can quickly obtain drag coefficients for each configuration, enabling them to swiftly determine the most optimal way to run a train.



Unleash the potential of
Rail Freight Aerodynamics

2 Cost-effective aerodynamics testing

The rail freight aerodynamics solution, which includes PowerFLOW as one of its core components, allows operators to test unlimited rail configurations in a cost-effective manner. With advanced capabilities for aerodynamics testing, it provides highly realistic 3D visualizations of how wind affects the train from the front to the sides of the cars. By analyzing different train configurations, operators can visualize the effects of wind and identify the most efficient setup.

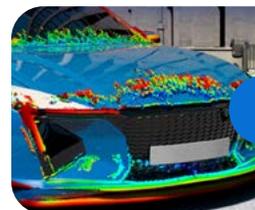


In this example, Configuration 3 shows the lowest drag coefficient, leading to an 8% reduction in fuel consumption compared to Configuration 2.

In PowerFLOW, rail operators can conduct design of experiments (DOE), enabling them to change variables like locomotive placement and see real-time effects on drag and fuel consumption. This powerful digital solution provides insight into how different configurations, such as an open hopper versus a double-stacked car, respond to wind and other aerodynamic factors, helping operators make data-driven decisions.

This computational fluid dynamics (CFD) based software emerged as a highly cost-effective and accurate alternative to traditional wind tunnel testing, as demonstrated in a collaborative study between Dassault Systèmes, an academic institution, and a North American rail operator, achieving exceptional accuracy at a significantly lower cost.

Effectively managing drag through these aerodynamic simulation capabilities can significantly reduce fuel costs — representing 20% of overall energy costs — by minimizing aerodynamic drag and optimizing the entire rolling stock. This not only results in substantial cost savings but also contributes to a lower carbon footprint, making it an essential factor in improving rail freight efficiency and sustainability.



Maximize efficiency
with **PowerFLOW**

Benefit

3

RELIABLE FREIGHT OPERATIONS

“

Rail operators, whether they have internal engineering teams or rely on external support, can benefit from advanced simulation solutions. Virtual twin technology can boost their engineering capabilities, improve safety and operational performance, and pave the way for greater self-sufficiency and enhanced reliability.”

Muthu Sivanantham

Solution Experience Senior Manager,
Business Services Industry,
Dassault Systèmes



KEY CHALLENGES IN RAIL RELIABILITY

Rail operations can experience significant delays and disruptions due to mechanical failures and disruptions within the rail network. Such issues may stem from unforeseen mechanical component malfunctions or external factors affecting the network's integrity.

For example, high winds can lead to derailments or rollovers, particularly affecting lightly loaded or empty hopper cars. High winds can also exacerbate the effects of aerodynamic drag, amplifying the forces acting on the train and disrupting the stability of freight trains. This weather-induced accident underscores the need for a reliable system to predict and mitigate such risks.

On top of that, the current physical testing and validation methods are often labor-intensive and costly. For instance, simulating the limits that cause derailments typically involves derailing a train, an obviously unfeasible and risky approach. Manual mathematical computations, while helpful, are constrained in their effectiveness and often lack the precision needed for complex simulations. Rail operators may also rely on in-house tools created by engineering teams, which might not match the sophistication of specialized industrial simulation software.

Due to these complexities, decision making by the stakeholders takes longer as they're dependent on operational data, which is procured in a non-practical, time-consuming method.





STRATEGY TO SUCCESS:

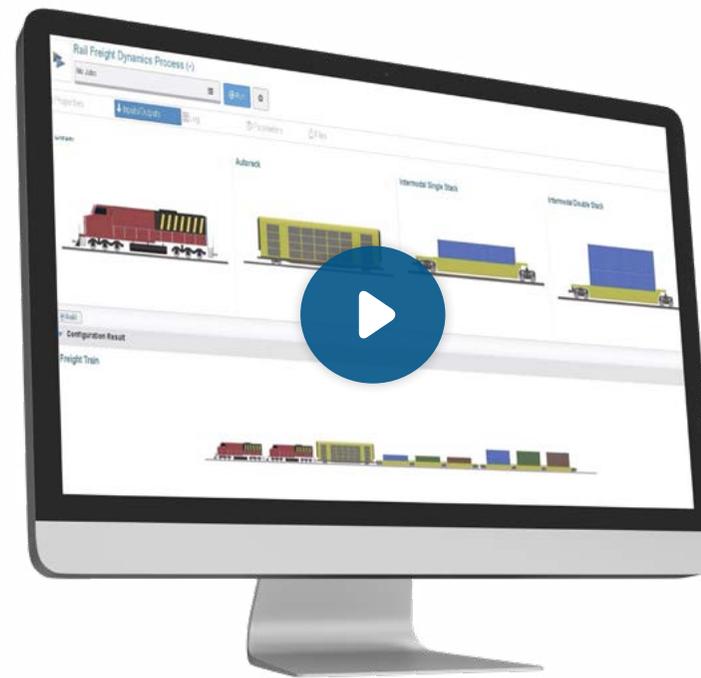
RAIL FREIGHT AERODYNAMICS SIMULATION

1 High-precision virtual testing and validation

Rail simulation is vital for preventing major incidents such as the 2023 East Palestine derailment by facilitating predictive maintenance. By integrating real-time data with multi-physics and multi-scale analyses, the rail freight vehicle dynamics simulation solution can pinpoint potential failures before they arise.

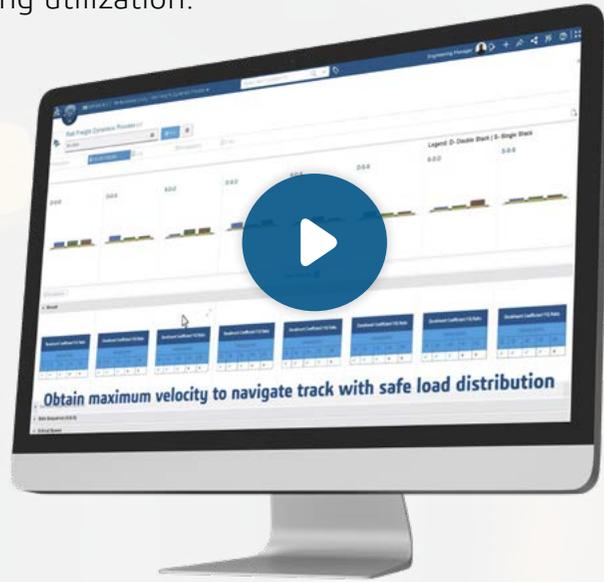
This proactive approach allows rail operators to address issues early, rather than responding reactively. Such comprehensive analysis enables more informed decision-making and significantly lowers the risk of similar incidents in the future.

With the combination of rail vehicle dynamics simulation and aerodynamics simulation solutions like Simpack, Rail Modules and PowerFLOW, limitations in simulating parameters and testing limits are addressed through digital 3D mockups, virtual demos and unlimited simulation scenarios.

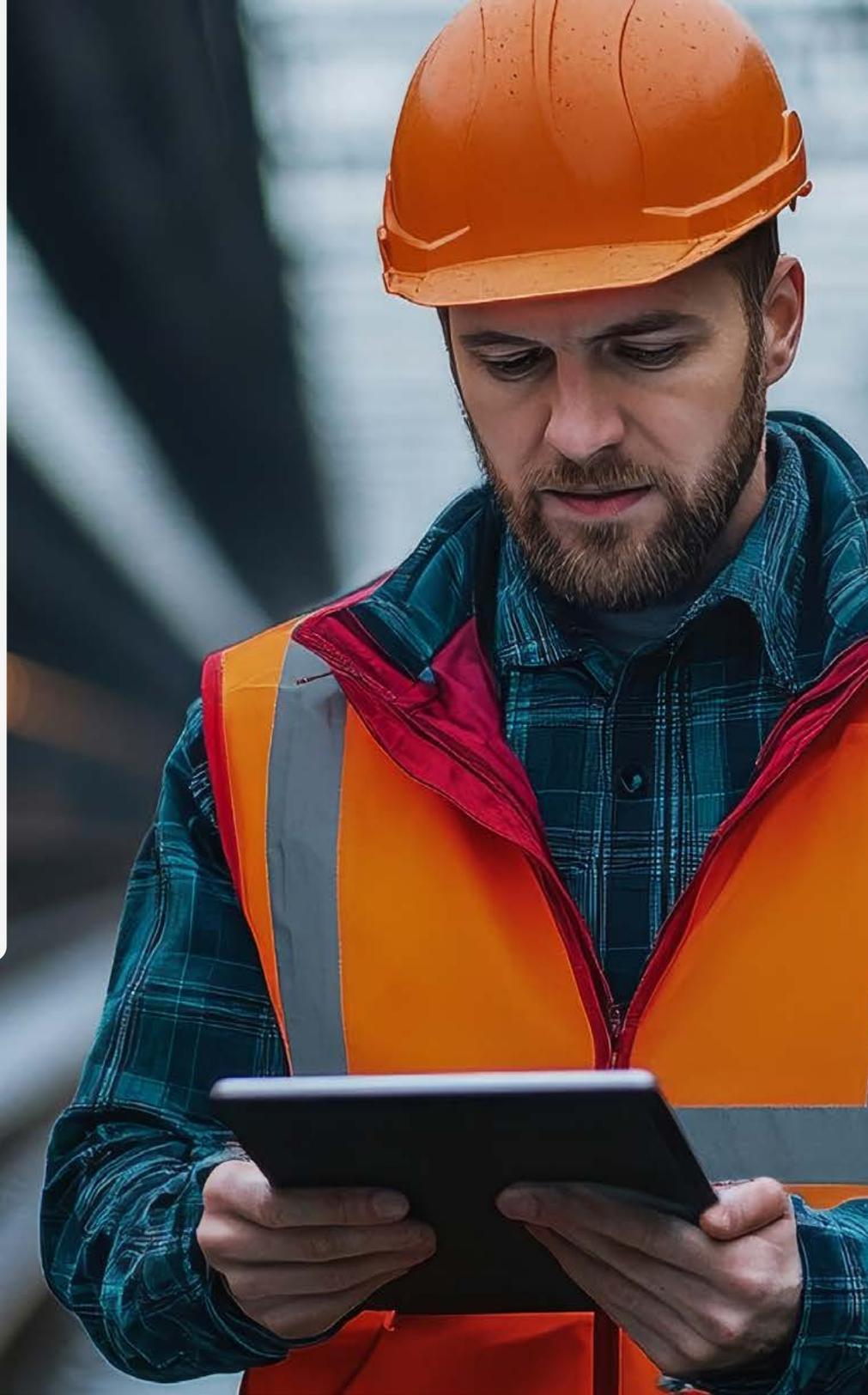


> Discover the power of **Simpack**

The end-to-end capabilities of these solutions that encompass the entire product lifecycle of rail components — from design and simulation to operations and maintenance — help operators monitor and maintain their assets effectively, minimizing downtime and maximizing utilization.



Here, operators can obtain maximum speed to navigate tracks with safe load distribution to reduce disruptions.

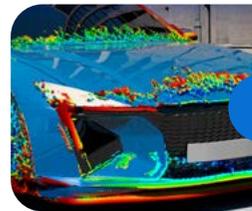
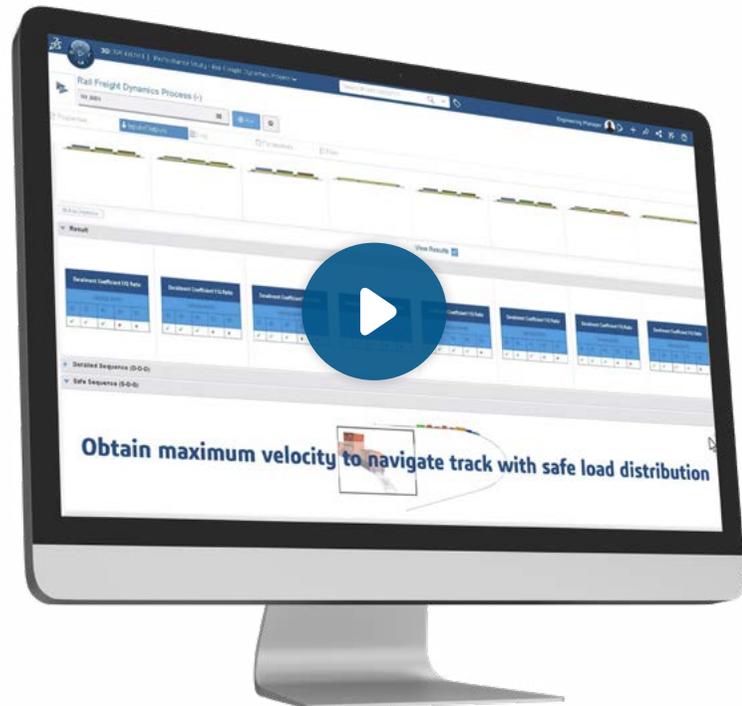


2 Two powerful simulation capabilities, one platform

The real advantage of these simulation solutions lies in integrating two powerful simulation capabilities within a single platform. By seamlessly combining inputs and minimizing data friction through a unified architecture and common data model, the **3DEXPERIENCE** platform exemplifies how integration can enhance efficiency and streamline processes. For instance, aerodynamic inputs can be integrated into vehicle dynamics simulations to assess intercoupling forces and derailment risks. This holistic approach is unmatched in the market, offering a unique capability to enhance rail reliability.

In addition to making previously impossible tasks — such as simulating real-world scenarios — possible through virtual twins, these solutions offer transformative capabilities that allow rail companies to achieve more while reducing costs.

These solutions foster closer collaboration and seamless integration of digital technologies; they enhance cross-departmental cooperation, enabling operations managers to communicate efficiently with safety, engineering and fleet managers simultaneously, which in turn ensures uninterrupted and reliable operations.



Explore the benefits of **Rail Modules** and **PowerFLOW**

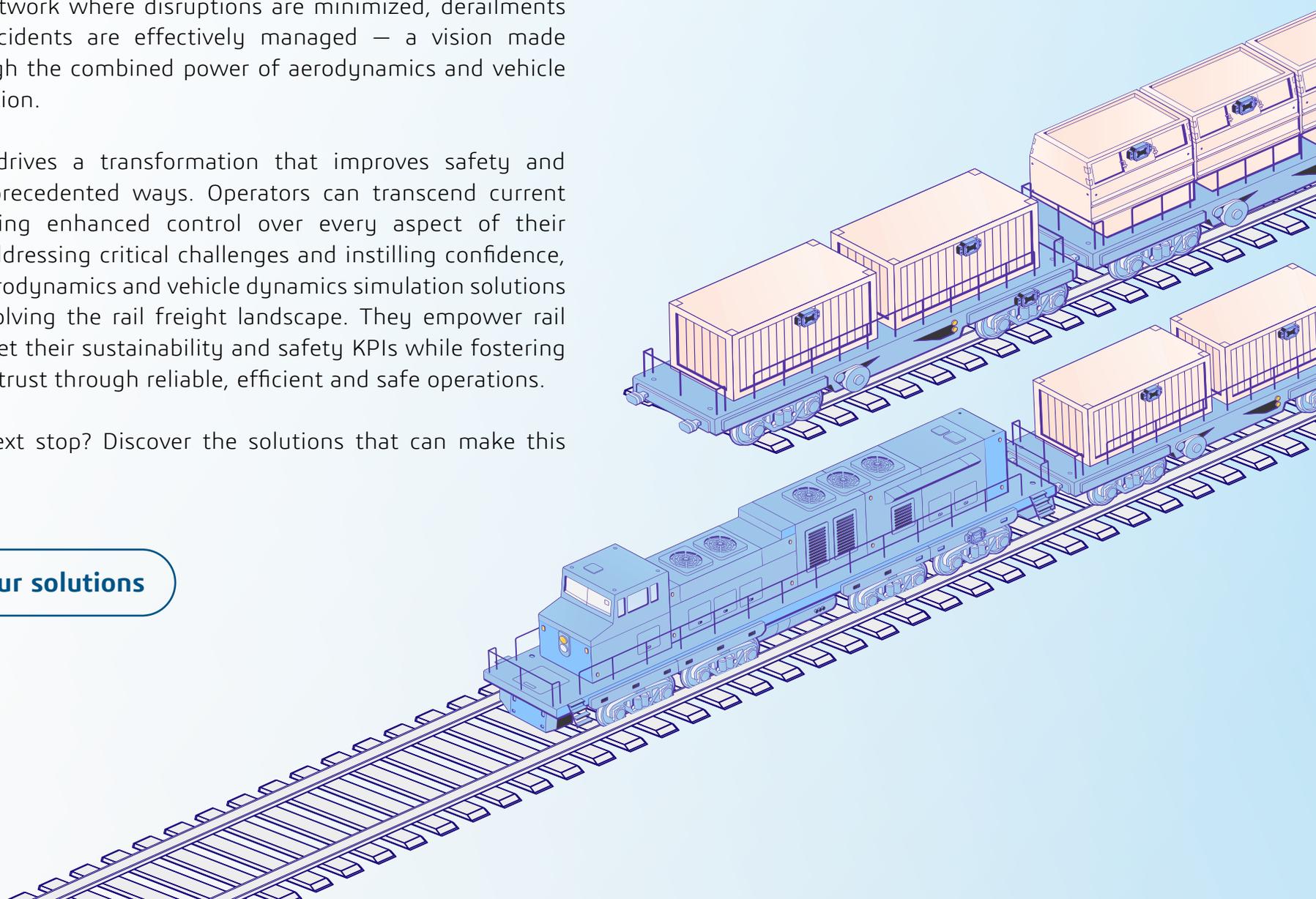
SIMULATION THAT TRANSFORMS THE TRACKS

Imagine a rail network where disruptions are minimized, derailments are rare, and incidents are effectively managed — a vision made achievable through the combined power of aerodynamics and vehicle dynamics simulation.

Rail simulation drives a transformation that improves safety and efficiency in unprecedented ways. Operators can transcend current limitations, gaining enhanced control over every aspect of their operations. By addressing critical challenges and instilling confidence, the rail freight aerodynamics and vehicle dynamics simulation solutions are pivotal in evolving the rail freight landscape. They empower rail companies to meet their sustainability and safety KPIs while fostering lasting customer trust through reliable, efficient and safe operations.

Ready for the next stop? Discover the solutions that can make this vision a reality.

[+ Discover our solutions](#)



MEET OUR EXPERT



Muthu Sivanantham

Solution Experience Senior Manager,
Business Services Industry,
Dassault Systèmes

Muthu is responsible for providing game-changing industry solutions to Dassault Systemes' logistics and rail industry customers and promoting digital twin solutions in the industry. Muthu is a passionate technology leader focused on sustainability and carbon-free energy, with a strong acumen in digital manufacturing. He has around 30 years of industry experience serving customers in the automotive, aerospace, energy and now the logistics and supply chain industries. He holds a master's degree in computer science with a master's certificate in business management and has served on The American Society of Mechanical Engineers' (ASME) digital twins task groups.



Paulo Barros

Value Consultant Senior Specialist,
Business Services Industry,
Dassault Systèmes

With 18 years of experience in the logistics and transportation sector, having filled multiple roles in companies that operate logistics across various modes of transportation, Paulo Barros drives digital transformation programs and leads client relationships. He supports the global logistics team in the Dassault Systèmes' consultative selling process (value engagement) to facilitate client business transformation. Paulo is also responsible for identifying market trends and spearheading the development of cutting-edge solutions to meet the evolving needs of the logistics and transportation industry.

Our 3DEXPERIENCE® platform powers our brand applications, serving 12 industries, and provides a rich portfolio of industry solution experiences.

Dassault Systèmes is a catalyst for human progress. We provide business and people with collaborative virtual environments to imagine sustainable innovations. By creating virtual twin experiences of the real world with our 3DEXPERIENCE platform and applications, our customers can redefine the creation, production and life-cycle-management processes of their offer and thus have a meaningful impact to make the world more sustainable. The beauty of the Experience Economy is that it is a human-centered economy for the benefit of all – consumers, patients and citizens.

Dassault Systèmes brings value to more than 300,000 customers of all sizes, in all industries, in more than 150 countries. For more information, visit www.3ds.com.



3DEXPERIENCE®



Europe/Middle East/Africa
Dassault Systèmes
10, rue Marcel Dassault
CS 40501
78946 Vélizy-Villacoublay Cedex
France

Asia-Pacific
Dassault Systèmes
17F, Foxconn Building,
No. 1366, Lujiazui Ring Road
Pilot Free Trade Zone, Shanghai 200120
China

Americas
Dassault Systèmes
175 Wyman Street
Waltham, Massachusetts
02451-1223
USA

©2024 Dassault Systèmes. All rights reserved. 3DEXPERIENCE, the 3DS logo, the Compass icon, IPME, 3DEXCITE, 3DVIA, BIOVIA, CATIA, CENTRIC, PDM, DELMIA, ENOVIA, GEOWIA, MEDIBO, NETVIBES, OUTSCALE, SIMULIA and SOLIDWORKS are commercial trademarks or registered trademarks of Dassault Systèmes, a European company (Societas Europaea) incorporated under French law, and registered with the Versailles trade and companies registry under number 522 306 440, or its subsidiaries in the United States and/or other countries.