INTERNATIONAL HEAVY HAUL ASSOCIATION

Heavy Haul Vision 2030

Railways of the future

Facilitated and project managed by Special Advisors to IHHA: Michael Roney and the late Pierre Lombard
Initiated & spearheaded by Brian Monakali, Chairman of the Strategy Committee, IHHA

Launched at IHHA Conference 2023, Rio de Janeiro, Brazil

Foreword

BRIAN MONAKALI

Chairman, IHHA Strategy Committee and Vice Chairman, IHHA

Throughout the past four decades, the heavy haul railway industry has been exceptional in pioneering developments and implementation of cutting-edge technologies and innovations that improved railway safety, operational efficiency and customer experience.

Some of the successes include hauling heavy commodities using longer and heavier trains with distributed power; strict maintenance and operating practices; advanced safety management systems such as rail stress management; ECP braking; train authorisation methods; and management of wheel-rail interaction. The International Heavy Haul Association, with its 10 member countries, has been instrumental in providing a collaboration platform that enabled the achievement of these breakthrough accomplishments.

In modern times, the railway is facing a pivotal moment of reappraisal with the opportunity to build a better, safer, greener and more customer-focused service fit for the digital age. There is also a need for a skilled, diverse workforce to deliver the Railway of the Future. Considering this rapid transformation of the railway industry, the Heavy Haul Vision 2030 (HHV2030) formulates a strategy and a roadmap to navigate the transition into the transformed Railway of the Future, focusing on seven primary areas: customer experience; safety; operations; rolling stock and infrastructure maintenance; energy and environment; information; and skills.

The HHV2030 unpacks the main global challenges; the latest trends in the industry; areas of improvements; what a good future looks like; the specific outcomes to be achieved; objectives to be delivered; tools and techniques that are required to achieve the strategy; and an implementation plan phased into two-year, five-year and 10-year horizons.

The strategy provides a clear steer for our future direction, intended to be particularly valuable for suppliers to the railway, research institutions, customers of the railway, railway professionals and various industry associations, presenting an industry view of the direction of technical developments over the coming decades.

Endorsement by

ANTONIO MERHEB

Chairman, IHHA

It gives me great pleasure to mark the Heavy Haul Vision 2030 launch at the 12th International Heavy Haul Association Conference, held in Rio de Janeiro, Brazil.

This is indeed a significant milestone for IHHA and the global heavy haul community. This came at a perfect time, when our freight transportation industry is facing several challenges that impact the efficiency and sustainability of the operations. IHHA and the global Heavy Haul community are delighted by this gesture and milestone as it will pave a way towards seeking solutions and innovations that shape our future.

On behalf of the IHHA board of directors, I would like to thank the Strategy Workgroup from the IHHA member countries for their contributions in the development of the Heavy Haul Vision 2023. We thank all the experts from the heavy haul railway community around the globe for their valuable contributions and for providing constructive inputs to the Vision document. I would also like to thank Scott Lovelace, who has given us the opportunity to work on this project and for leading IHHA initiatives in his long journey in this industry.

Mike Roney, your support, and meaningful contributions towards the IHHA vision of promoting excellence in heavy haul operations are recognised – thank you for facilitating and being a project manager for the vision development. I would also like to thank the late Pierre Lombard, who was a co-facilitator and project manager in the development of the Vision document. May his soul rest in peace.

A special thank you to Brian Monakali, who was IHHA Chairman at the time, for initiating and spearheading the Heavy Haul 2023 vision development. You were instrumental in gathering a global team of experts to work on the development of the vision. Your passion for promoting global best practice in heavy haul is appreciated and recognised.

I hope this Vision document will in a small way help you to continue the advancement of technology to achieve a more efficient and safe railway.

Executive
SUMMARY

The IHHA engages in a continual process of adaptation to ensure it satisfies the demands of state-of-the-art technical information that is relevant in a changing and developing industry.

In a 2017 benchmark survey, respondents saw further advances in the length and weight of trains and continued advancements in computer-aided train driving, as well as increased automated track and rolling stock inspections.

The 2017 IHHA conference in Cape Town brought awareness of the approaching Fourth Industrial Revolution characterised by cloud computing, 3D printing, big data and the Internet of Things (IoT). It was illustrated that we are increasingly moving towards the concept of a digital railway. The 2018 IHHA conference in Narvik, Norway, probed even more deeply into the implications of Rail 4.0.

As a lead up to the 2019 Narvik conference, the IHHA held a strategy workshop in 2018, in Luleå, Sweden, to outline the vision for heavy haul railways in 2030. The representatives saw heavy haul railways dealing with higher tonnages in the future by unlocking capacity through the use of true virtual moving blocks, aided by communications-based train control. They saw trains running autonomously with tighter headways, dispatched and guided by computers analysing vast amounts of data in real-time. Track and rolling stock inspections would be performed by onboard and wayside sensors feeding artificial intelligence algorithms capable of trending conditions that would lead to predictive condition-based maintenance.

The heavy haul strategy workgroup probed the enablers of the Heavy Haul vision 2030. Among these are the challenges of transforming the skill sets of the rail workforce to align to the new digital rail platform, and raising the capabilities to process big data.

The Fourth Industrial Revolution (4IR) describes the exponential changes to the way we live, work and relate to one another due to the adoption of cyber-physical systems, the Internet of Things and the Internet of Systems. Workplaces and organisations are becoming “smarter” and more efficient as machines and humans start to work together via technologies of big data analytics, digitisation, Internet of Things (IoT), Artificial Intelligence, machine learning and video analytics, as we use connected devices to enhance our supply chains, etc.

The competitive pressures of 4IR will mandate changes in the way freight railways operate – changes that will be elusive to achieve without transformational technological changes.

It is foreseen that by 2030, the technologies associated with 4IR will have reached stages enabling Train Management Control Systems (TMCS) to operate automated trains on flexible-length virtual moving blocks without any on-track or track-side equipment. Sensor systems will measure and detect on-train and track-side parameters and report results in real-time to controllers where it can be stored and/or processed for immediate or later use. A key impact of all of this will be the ability to tighten train headways and gain increased tonnage throughput on existing infrastructure, reducing longer-term capital requirements as tonnages increase.

The heavy haul Railway of the Future is seen as a digitally driven lean production line that is fully integrated with the commodity supply chain and its needs. Trains are launched on demand in pre-planned train slots with trip plans. Trains will be equipped with self-diagnosis of maintenance needs and would be able to obtain unprecedented levels of availability and mean time between repairs.

Operations Safety in the Digital Culture: It is anticipated that the rail industry will need to move away from soft administrative controls like procedures and rules and to invest more in the R&D necessary to engineer, automate, and eliminate exposure to risk. There should be a systems approach in the design for safety. This will require collaboration between rail operators and research institutions, vendors and regulators.

Heavy haul railways have seen a steady decline in year-to-year total number of train derailments in spite of increased tonnages carried. Over the past decade, there has been some plateauing in human-factor derailment rates. While

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the digital railway invites new technologies, the regulatory framework may be challenged to change in accordance with the opportunities to modernise safety management.

The Customer Experience: In most railways, customer-experience enablers are not built into its strategies. The enablers' priorities and measurements have more to do with processes and procedures than the customer's happiness. Recognising the importance of providing an emotionally positive experience to customers will become increasingly important. A major step forward will be needed to provide a real-time digital customer experience.

Operations Command and Control: In the digital Railway of the Future, communications and data analysis need to be "network-centric". Rather than tracking an individual train movement, or viewing traffic flows on a single corridor, this information would be integrated with real-time tracing of all other parts of the network. Predictive algorithms would anticipate when and where traffic flows will converge.

Connected and Secure IT: Computer systems are evolving as a key to improving operational efficiency. Railway operations have become increasingly reliant on computer interfaces, and network outages can have important influences on rail service reliability. The potential for cyber attacks has become an issue. It can cause blockage of traffic, degraded operations and even safety risks. The challenge is to add cybersecurity awareness and cyber defense measures to the rail industry culture.

Communications-Based Train Control and Throughput: Heavy haul railways have concentrated their research on maintaining productivity through running longer, heavier and more reliably. In this way, heavy freight railroads have common characteristics of high axle load, high reliability of the assets, and long trains, but with low commercial speed.

Investments in communication and automation systems resulting in truly mobile signalling blocks as well as in tracks of high strength and reliability for axle loads of over 50 tons, will enable trains to be bigger, heavier and safer with increased tonnage throughput. Distributed traction will continue to be popular, but with increased distance between locomotives, as computers will manage train automation, longitudinal train shocks and forces on the rail.

Is Bigger Still Better? The demise of the air industry's own 'bigger is better' trend (Airbus A380) is included as a possible caution for heavy haul railroads. One of the driving forces behind past increases in axle load, bigger wagons, longer trains, stronger locomotives, distributed power, improved braking systems, etc., has been the need to optimally utilise the opportunities provided by a finite number of available slots. This contributed to the resultant economics of bigger is better. In future, the number of slots per time period will no longer be a finite number. It will become variable and with substantial scalability on unidirectional lines especially. Under a new regime of autonomous trains and flexible virtual moving block, it will become possible to achieve higher capacity with shorter and lighter trains or convoys of trains. The current trend towards higher axle loads and longer trains could be disrupted.

Energy and the Environment: While heavy haul railways are recognised as the lowest energy mode for land-based transportation of bulk commodities, the future will see more pressure to optimise fuel consumption and to convert to more environmentally sustainable means of propulsion. Various helpful technical developments are foreseen with 4IR specifically contributing via more intensive use of DAS and ATO systems together with the installation of energy storages on the traction rolling stock to reduce the total energy consumption on the locomotive.

New Rolling Stock: Maintenance costs will have to be lower and more predictable whilst maintaining high levels of freight car availability. New freight cars should contain "smart sensors" that can transmit condition data continuously. New materials and 3D printing manufacture will optimise the car structure of rolling stock. The payload of wagons will be higher relative to tare weight. Improvements in car body design is foreseen that will facilitate automated detection and performance monitoring of components.

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High-Availability Rolling Stock: Performance-based maintenance is the preferred strategy because it can offer improvements related to safety, reliability, and efficiency. Historically, this maintenance strategy has relied on manual visual inspections. As wayside detection and onboard monitoring improve, these automated systems will become the primary source of rolling stock health monitoring, leading a transition from manual to automated inspections. Data analytics will be the pathway to predicting and optimising when and where maintenance on rolling stock is conducted.

Integrated Track Construction Systems: The future anticipates a major breakthrough of technologies and equipment for the intelligent construction of infrastructure. New assembly-type structural systems, intelligent digital manufacturing technologies and automated installation technologies are foreseen. Precision measurement and structural safety dynamic monitoring sensors integrated into information management technologies will enable post-construction performance monitoring.

Proactive Infrastructure Maintenance: Whereas many track maintenance activities are corrective rather than proactive and preventive, the heavy haul railway of 2030 should see increased dynamic track maintenance planning based on real-time objective condition data. Maintenance advisory systems would predict failures before they happen, giving the advance time needed to integrate maintenance plans with train schedule plans. Sensors and automated inspection systems should increase and be interconnected to create a smart infrastructure, using smart systems to analyse data in real-time and schedule predictive maintenance.

Human Resources in the Digital Age: AI and automation will progressively take the “work” out of many jobs as computers do more and more of the menial work as well as work requiring real-time quick and automatable decisions and/or reactions. People will be set free to do the creative things that will remain beyond the ability of AI for a long time to come. A major cultural shift lies ahead for man, worker, management and unions.

IHHA believes that no one rail authority will have the skills and foresight to do this all, and encourages their member railways to share their experiences with any one of the above streams where they may be progressing either bi-laterally or through group benchmarking. Taken as a whole, IHHA member railways will do better with an open agenda of sharing pitfalls and successes. They can only move to Rail 4.0 with the great support of their suppliers and university affiliates, and individually with their supply chain partners and customers. These partners will move more in lockstep if the vision is clearer and more commonly spoken between railways. The IHHA technical conferences help in this endeavour.

This Heavy Haul Vision 2030 document seeks to accelerate the process by bringing together the heavy haul railways of the world in collectively defining what our railways want to be in 2030 and beyond.

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Background and
SCOPE

The International Heavy Haul Association (IHHA) is dedicated to the pursuit of excellence in heavy haul railway operations, engineering, maintenance, and technology.

It strives to accomplish this mission through the acquisition of knowledge relevant to this goal by sponsoring and organising international and regional conferences, specialist technical sessions and specialist seminars, by commissioning guideline manuals, by writing best practice books, by preparing and distributing conference proceedings and technical documentation, and by related activities as recommended by the Board of Directors.

Historically, the IHHA has shared technical information that helps its member railways and national railway authorities to overcome the challenges of running heavier and longer trains. Now, the IHHA engages in a continual process of adaptation to ensure it satisfies the demands of state-of-the-art technical information that is relevant in a changing and developing industry. A further activity of IHHA is benchmarking, where railways and rail authorities share more holistic information on their respective pathways to success. The premise is that all can learn from the experiences of others, and that common elements in direction will drive down the costs of all heavy haul railways and improve their safety.

As the wellspring for the current visioning, IHHA conducted a benchmark survey in 2017 focused upon the key technologies that heavy haul railways see as important to their past success and their future. The survey was answered by a broad and diverse representation of rail authorities around the globe, and can be considered as being well representative of the directions of the rail bulk haul industry worldwide. There was considerable commonality in their visions of key innovations and their visions of what is needed to be competitive and sustainable in the future.

Many responses included improvements in rail freight scheduling and line throughput that has built capacity. This has included improved network communications (e.g. GSM-R), data radios, network planning and scheduling systems, track authority control, integrated mine to port planning, and automated loading and unloading technology.

Looking ahead, respondents saw further advances in the length and weight of trains and continued advancements in computer-aided train driving. They saw accelerated conversion to technology-based train inspections that lead to full condition-based wagon maintenance, and continued advancement of automated track inspection technologies.

Computer-aided train planning and dispatching was reportedly under advancement, with sophisticated algorithms under development to identify clear pathways for launching trains. A key to improved throughput and line capacity was seen to be the move to communications-based train control.

The Railway of the Future was not seen as an abstract concept as many railways and suppliers are already actively on this trajectory. The consensus was that heavy haul railways will need to have trains running autonomously and unmanned, supported by computerised dispatching and overseen by people. Network-centric cybernetics will be sought to take a broader and more proactive view of optimal network flows to drive operations strategies and tactics.

Survey respondents also saw that all repairs and maintenance activities will need to become predictive, planned and proactive, leading to a future with close-to-zero service disruptions or safety incidents. This would require that multiple wayside and onboard sensors report data to expanding databases with structures that will support “big data” analytics that will mine data for cross-correlations and project trends. In this way, all track, trains and rolling stock maintenance will be driven by algorithms with rule engines, eliminating the need for standing train inspections or point-to-point over-the-road track inspections. The outcome would be a large shift to planned maintenance that will not interfere with planned train schedules or cycle times.

The next key event leading to this visioning exercise was the choice of the theme of the 2017 IHHA conference in Cape Town. The opening session of the conference introduced the theme of Advancing Heavy Haul Technologies in a Changing World by defining that we are already on the pathway to a changing world set by the Fourth Industrial Revolution, characterised by cloud computing, 3D printing, big data and the Internet of Things. It compared technology within the greater societal change to the digital world, and then illustrated that, all around the world, we are increasingly and collectively relying on computers to:

- Eliminate boring repetitive tasks
- Automate maintenance facilities
- Start tackling “Big Data” analytics
- Provide higher levels of assistance to train drivers
- Remotely detect track and wagon issues

The 2017 IHHA conference in Cape Town segued to the 2019 IHHA conference in Narvik, where the theme is “Heavy Haul 4.0 – Achieving Breakthrough Performance Levels”. This conference probed even more deeply into the opportunities of the digital railway, and will host a full strategy session on the implications of Rail 4.0.

As a lead up to this conference, the IHHA held a strategy workshop in 2018 to outline the vision for heavy haul railways in 2030. The strategy workshop took place in Luleå, Sweden on September 15 and 16, and was attended by representatives from Australia, Europe, India, Russia, South Africa and North America, with submissions as well from China Railways and Vale, Brazil. The workshop reviewed presentations on a suite of themes around at a common vision of Heavy Haul 4.0.

The representatives saw heavy haul railways dealing with higher tonnages in the future by unlocking capacity through the use of true virtual moving blocks, aided by communications-based train control. They saw trains running autonomously with tighter headways, dispatched and guided by computers analysing vast amounts of data in real-time. Track and rolling stock inspections would be performed by onboard and wayside sensors feeding artificial intelligence algorithms capable of trending conditions and proactively assigning maintenance work orders. Technology was determined to be a key lever in achieving safer, more productive and more reliable railways and the lowest possible risk environment for employees. In the future, railway assets would be closely managed with the help of extensive data analytics capable of assessing remaining asset life, but prompting actions that would economically extend asset life.

The heavy haul strategy group probed the enablers of the Heavy Haul 4.0 vision. Among these are the challenges of transforming the skill sets of the rail workforce to align to the new digital rail platform, and raising the capabilities to process big data. The Digital Railway 4.0 was defined as requiring much greater communications capabilities and bandwidth to handle real-time monitoring of train and track status and condition. Cybersecurity was seen to need to evolve in relation with this growth of IT command and control of heavy haul rail operations.

The details of the strategy workshop were next to be presented to an invited group of decision-makers in a parallel session held in conjunction with IHHA 2019 in Narvik, Norway. The feedback from this strategy workshop, along with the defining presentations of the various Theme Champions from all of the IHHA member nations, form the basis for the current visioning document for Heavy Haul 4.0. This white paper envisages the impact of the Fourth Industrial Revolution (4IR) on the heavy haul rail industry by the year 2030.

The International Heavy Haul Association is looking to this Vision 2030 document as a framework to dialogue further with suppliers, researchers, educators and regulators to help move heavy haul railroading forward. The objective of this visioning exercise has been to develop a common perspective to focus these discussions.

What is the role of a vision document in the Heavy Haul industry, and why is it important to have one?

"The role of a vision document is to provide an overview of the future of Heavy Haul railways and focus industry efforts on achieving a clearly defined end goal. Despite the numerous challenges the industry faces today, a vision document highlights how innovation and targeted strategic investments in technology can lead to significant improvements in safety, efficiency and sustainability in the years to come."

Nkululeko Gobhozi (Pr. Eng) | Chief Engineer | Technology Management Transnet Freight Rail | South Africa

"The vision document is the foundation for building the future of heavy haul operations. From inspiring innovation to driving change, the vision provides the direction to face the challenges encountered today and tomorrow. It also encourages industry thought leaders to expand their thinking to encompass the needs of generations of railroaders to come."

Kari Gonzales | President & CEO | MxV Rail | USA

"The vision document reflects opinions and needs of the heavy haul railways in the world and serves as a compass both for the industry, to develop the next generations of technological solutions, and for the participating railways themselves, which end up having access to this compilation that includes other railroads and help build their technological roadmaps for the coming years."

Edilson Jun Kina | Railroad Engineering | Vale | Brazil

"Such a document defines and clarifies the IHHA mission, and is a driver of IHHA. It helps to direct decisions within IHHA, laying the foundation for everything that we do. It also establishes realistic goals and objectives for IHHA. With the inbuilt diversity of the members specific infrastructure and its operation configuration, such document builds and increases IHHA team spirit as an organisation."

Per-Olof Larsson-Kraik (PHD) | Senior Advisor | Trafikverket (Swedish Transport Administration) | Sweden

"Heavy Haul Railways, by nature, have a history of innovative solutions to safely move high volumes of commodities for global supply chains. The Vision Document describes what the future environment could be for our people, technology and industry. Building on this, a Vision Document is important to inspire and guide our future leaders to keep Heavy Haul Railways cost competitive in the global supply chains that we compete in."

Jason Livingston | Head of Network Asset Management | Aurizon | Australia

Workgroup

TEAM MEMBERS

Workgroup Members at IHHA Strategy Session, Luleå, Sweden, 2018

Looking from left to right, the workgroup team members are:

- Ravi Jain, Dedicated Rail Freight Corridor of India
- Nikita Gorshkov, Head of International Cooperation, JSC Railway Research Institute, Moscow, Russian Federation
- Lisa Stabler, President, Transportation Technology Center Inc., Pueblo, CO, USA
- Michael Roney, Iron Moustache Consulting, Canada
- Uday Kumar, Director, Luleå Railway Research Center, Luleå, Sweden
- Bernard Schmitt, Freight Advisor, Union Internationale des Chemins de Fer, Paris, France
- The Late Pierre Lombard, Special Advisor to IHHA, Pretoria, Republic of South Africa
- Caesar Mtetwa, General Manager, Rail Network, Transnet, South Africa
- Peter Maraucher, Train Systems and Reliability Leader, Aurizon Rail, Brisbane, Australia
- Anshuman Sharma, Dedicated Rail Freight Corridor of India
- Shaun Robertson, Principal Advisor – Rail, Rio Tinto, Australia
- Chris Prebble, Consultant, Aurizon Rail, Brisbane, Australia
- Brian Monakali, General Manager, Capital Planning, Transnet, Republic of South Africa
- Ramin Karim, Professor, Luleå University of Technology, Luleå, Sweden
- Teodor Gradinariu, Senior Technical Advisor, UIC, Paris, France
- Per-Olof Larsson-Kraik, Senior Advisor, Trafikverket, Luleå, Sweden

Missing from the photo are the following Workgroup members and Theme Champions:

- Edilson Jun Kina, Railroad Engineering, Vale, Brazil
- Mark Kirpatrick, General Manager Network Operations, Aurizon, Brisbane, Australia
- Shuang Kang, China Academy of Railway Sciences, Beijing, People’s Republic of China
- Zhang Bo, China Academy of Railway Sciences, Beijing, People’s Republic of China
- Zhang Geming, China Academy of Railway Sciences, Beijing, People’s Republic of China
- Scott Cummings, Scientist, Transportation Technology Center, Inc., Pueblo, CO, USA
- Ndeleni Mkhonta, Chief Engineer, Rail Network, Transnet, South Africa

What is the Digital

REVOLUTION 4.0?

The Fourth Industrial Revolution (4IR) describes the exponential changes to the way we live, work and relate to one another due to the adoption of cyber-physical systems, the Internet of Things and the Internet of Systems.

Workplaces and organisations are becoming "smarter" and more efficient, as machines and humans start to work together via technologies of big data analytics, digitisation, "Internet of Things" (IoT), Artificial Intelligence, machine learning and video analytics as we use connected devices to enhance our supply chains, etc.

It is expected in this era that computers will be able to take on many tasks previously being performed by humans. Whereas in the past, computer programs have relied on human inputs of data, they are now being connected to multiple sensors that provide direct inputs of real-time situational data. Some of these inputs are in the form of digitised visual images that advanced algorithms scan to recognise patterns, similar to the way that humans recognise objects and recognise people. Another branch of artificial intelligence is the use of neural networks. With neural network logic, computers are trained to develop their own algorithms defining success based upon continuous associations of outcomes with complex inputs. In effect, computers are becoming self-learning, in the same way that humans develop preconceived notions from processing life experiences.

In the digital world, most observations can be quantified by sensors, digitised and analysed as useful information that can be processed through machine learning as proposed actions. Or the processed data can be directed to collaborative robotics to execute the actions, including 3D manufacturing from digital printing and powder metallurgy.

It has been likened to the stages of the Industrial Revolution, as it has similar wide-ranging implications for change as the Agrarian Revolution, the onset of steam power, internal combustion engines and assembly-line production, as well as the more recent use of computers as industrial enablers.

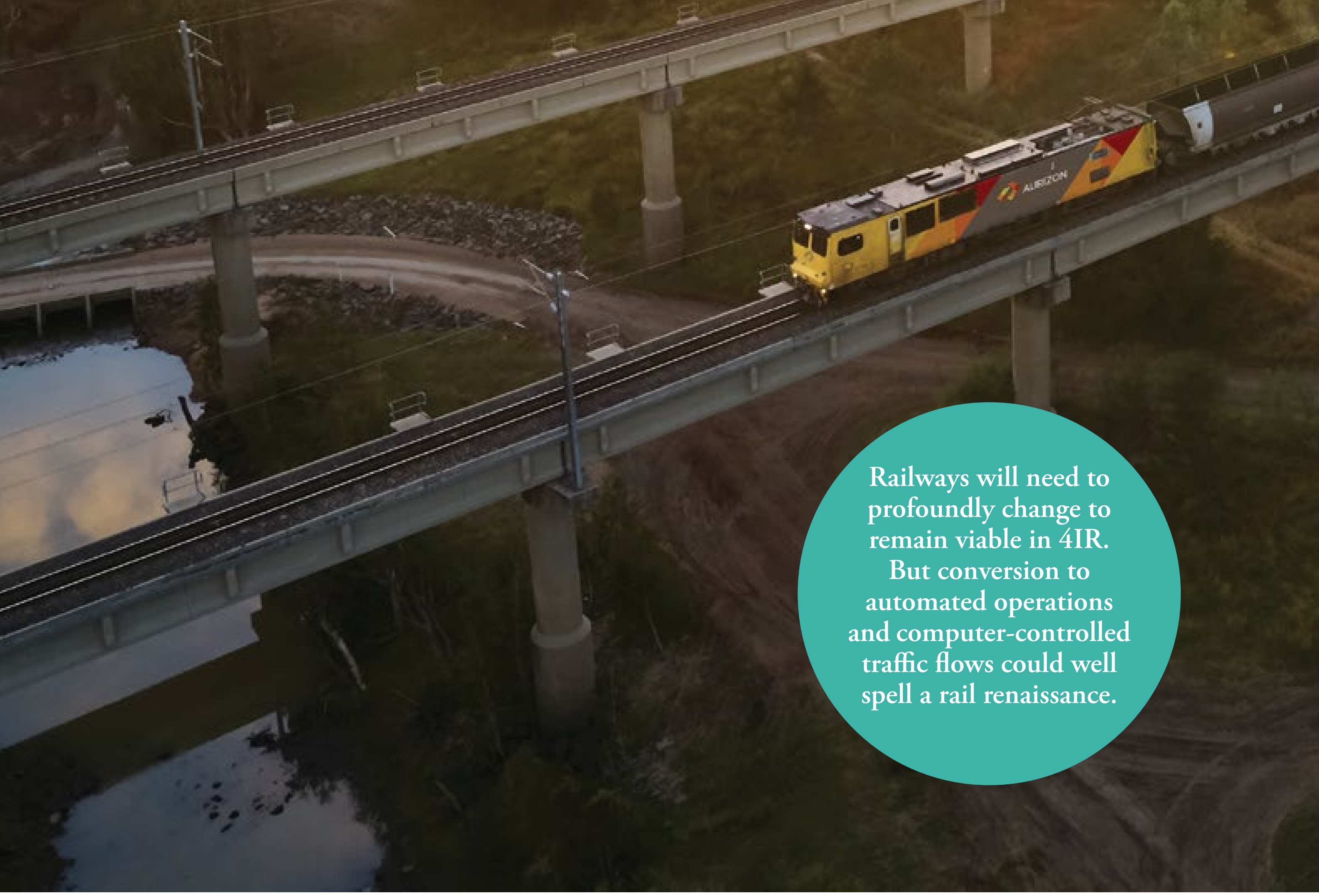
Why Railways Need to Adapt and

BECOME RAIL 4.0

Looking backwards, and using the parallel of a previous transition of the Industrial Revolution, one might ask whether the rail mode would be viable today if still propelled by steam locomotives?

Looking forward, can freight rail be sustained amidst the inevitable move of trucking to fleeting of autonomous, self-driving trucks?

The competitive pressures of the Fourth Industrial Revolution will mandate a change in the way freight railways operate. The competition will put added pressure on cycle times, asset ultilisation and operating costs to hit targets that cannot be met without transformational technological change. Technology and innovation is not a goal in itself. It is a means to a goal. That change will have the headwinds of a capital-intensive industry with long asset service lives and ageing workforce demographics. On the other hand, by virtue of the fewer degrees of freedom of the rail mode, conversion to automated operations and computer-controlled traffic flows could well spell a rail renaissance.



Railways will need to profoundly change to remain viable in 4IR. But conversion to automated operations and computer-controlled traffic flows could well spell a rail renaissance.

Key Impacts, Disruptions and

OPPORTUNITIES

The Fourth Industrial Revolution will be very disruptive for the rail asset mix and its supporting infrastructure, as we move to digitally driven railroading.

It will also be disruptive to many traditional railway jobs. But it will be an exciting time for the future of heavy haul railroading. The challenge will be to manage the digital railway at its speed of change.

It is foreseen that the technologies associated with 4IR such as big data analytics, digitisation, Internet of Things (IoT), Artificial Intelligence (AI), machine learning and video analytics will have reached stages enabling:

- Train Management Control Systems (TMCS) to operate without any on-track or track-side equipment
- Trains being located on flexible-length virtual moving blocks instead of traditional fixed blocks
- These flexible moving blocks to be defined by the variable demands and needs of the TCMS
- Automation of Train Movement Control (TMC) whereby all the functions required to accelerate, decelerate, cruise and/or stop a train can be handled on-train and/or remotely taking into consideration track geometry, train composition, braking models, in-train forces, real-time feedback from onboard and track-side sensors as well as operational requirements as represented by the position and speed of other trains, etc.
- Sensor systems using acoustics, vibrations, accelerations, optics, radar, laser, ultrasound, strains, etc., to measure and detect on-train and track-side parameters and report results via digital communication means in real-time to controllers where it can be stored and/or processed for immediate or later use
- Analytics capable of extracting patterns and trends, and make predictions, etc., from big data
- Strong interconnected and network-centric communication capabilities

A key impact will be the ability to tighten train headways and gain increased tonnage throughput on existing infrastructure. This will reduce longer-term capital requirements as tonnages increase. This will put strong constraints on available track time for inspections and regular maintenance. On the other hand, autonomous track measurement vehicles, a network of in-track sensors and digital imaging of track and structures features will mean that point-to-point visual patrols by track inspectors will be eliminated. In addition, the continuous and real-time analysis of track and infrastructure data will identify and trend conditions so that repairs can be anticipated in advance and planned for track windows that are either identified by train scheduling algorithms or created by changing traffic patterns.

Trains will run autonomously under the control of centralised computers with pacing according to traffic patterns. Any unforeseen circumstances will be detected by crossing monitors, rockfall detectors and onboard LiDAR sweeps of the right-of-way. Optimal train driving will improve line capacity utilisation while reducing fuel consumption. Train starts and time lost to make crew changes will be eliminated. Optimal driving algorithms will be backed up by longitudinal train action sensors, better controlling longitudinal train dynamics and lateral curving forces.

> Trains will run autonomously under the control of centralised computers with pacing according to traffic patterns. A key impact will be the ability to tighten train headways and gain increased tonnage throughput on existing infrastructure.

Motive power and rolling stock will be frequently monitored by a combination of onboard and wayside detectors that gauge vehicle health and feed proactive advisories on planned repairs, including machine vision systems with artificial intelligence. Onboard detectors will need powering, either through ECP braking circuits or onboard energy harvesting. The processing of health monitoring data through “rules engine” algorithms will make it unnecessary to do manual visual standing inspections of trains, as repair personnel will be directed to specified locations in the train. These proactive planning algorithms, plus increased use of robotics, will enable many more repairs to be performed on tracks, as opposed to having rolling stock cut out to be staged in repair shops.

New train control systems will no longer require track circuits or wayside signalling. Almost all rail joints will be eliminated from track. On the other hand, the digital railway will require large investments in communications architecture and infrastructure. Vast amounts of new data will need to be transmitted in real-time to central processors. In particular, the requirement to send digital images, for example when required to take over driving a crippled train remotely, may require 4G communication networks along the right-of-way. Locomotives will require multiple antennae to transmit various data feeds, and will require a careful synergistic design of transmission capabilities. Additional power drops will likely be required along the right-of-way to power many new wayside detectors.

The digital world will transform many of today’s “finders” into “fixers”. Personnel who once worked in a locomotive cab or rode a hi-rail vehicle would find themselves in an office in front of a computer screen reviewing possible false positives from machine-based inspections and overseeing how the automation is performing. Many new opportunities will require computer programmers, data analysts, data miners, signal pattern analysts, electronics technicians, process engineers, reliability engineers, instrumentation technicians and robotics technicians and maintainers, communications engineers and technicians.

The nature of humans managing train service may need to be rethought. The vision would have computers tactically managing the initiation of train starts and their trip plan, overseen by humans. As data flows will be intended to be more consolidated, there is less need for management of railway activities as a series of silos. Supervision of trains will likely require small corridor management groups working with cross-functional information, and focused on handling variances. Higher level network managers will deal with computer-based strategic advisories on network flows, impending disruptions and recovery strategies.

The digital railway will turn many of today’s problem “finders” into “fixers”.

Global Heavy Haul Railway's

VISION 4.0 FOR 2030

Global Heavy Haul Vision 2030: A Safe, Competitive, Responsible, Reliable, Integrated and Intelligent Heavy Haul System Powered by Rail 4.0

Looking down at the heavy haul Railway of the Future from a high level, the IHHA Strategy Workgroup sees the railway as a digitally driven lean production line that is fully integrated with the commodity supply chain and its needs. Trains are launched on demand in pre-planned train slots with trip plans that "direct hit" at the port without unloading delays. Trains are dispatched according to algorithms that balance and optimise train flows. As all train movements and emerging conditions of equipment, infrastructure and weather disruptions are monitored continuously, as are the readiness status of loading and unloading facilities, instructions to autonomous trains are dynamically altered to maintain network fluidity and reduce energy use.

Trains are equipped with self-diagnosis of maintenance needs and are able to obtain unprecedented levels of availability and mean time between repairs. Both equipment and infrastructure are monitored with trending algorithms that reduce unplanned maintenance events to rare events.

This high-level view sees continuous improvements in rail safety, driven by improved diagnostics of track and rolling stock health and optimal autonomous train driving strategies. Human-factor elements are reduced due to reduced human interventions. In addition, computer-based train monitoring, automated track inspections, and UAV drone-based inspections with digital imaging have vastly reduced the need for people to occupy track.

During the next 10 years, railways will progressively integrate man-machine interfaces, such that, by 2030, fully autonomous heavy haul railways will be common. In the autonomous railway, humans will be tasked with overseeing operations guided by artificial intelligence, and will be focused on dealing with variances.

The basic building blocks for the autonomous railway are as depicted in Figure 1.

For an autonomous railway to work safely and effectively, it must be built on a firm foundation of communications that are linked to train control and condition monitoring. New traffic management systems must follow this firm foundation to guide network-centric traffic flows. All computing systems need to be integrated to operate seamlessly to guide supply chain shipment flows.

The following sections break down the strategic vision of the Digital Railway of 2030 and provide further granularity by functional categories under the headings of:

- Fashioning a Digital Customer Experience
- Network-Centric Computer-Assisted Planning and Control
- Information Technology and Cybersecurity in the Connected World
- From Driver Assist to Autonomous Trains: Is Bigger Still Better?
- Creating New Capacity with Minimum Capital
- Operations Safety in the Digital Culture
- Gaining Traction Sustainably
- Revolutionising Rolling Stock Design and Manufacture
- Maintaining High Reliability in Rolling Stock
- Integrated Track Construction Technologies
- Maintaining High Guideway Integrity and Availability
- Human Capital and Skills for Man-Machine Interface

For each of these headings, theme champions from the IHHA Strategy Workgroup have addressed a vision that addresses:

There will be continuous improvements in rail safety, driven by improved diagnostics of track and rolling stock health and optimal autonomous train driving strategies.

- Current Status and Challenges
- What Will the Future Look Like? Vision, Strategy and Objectives
- Enablers that Must Be in Place
- Sequencing of Desired Outcomes and Implementation Plan
- Possible Common Research Needs

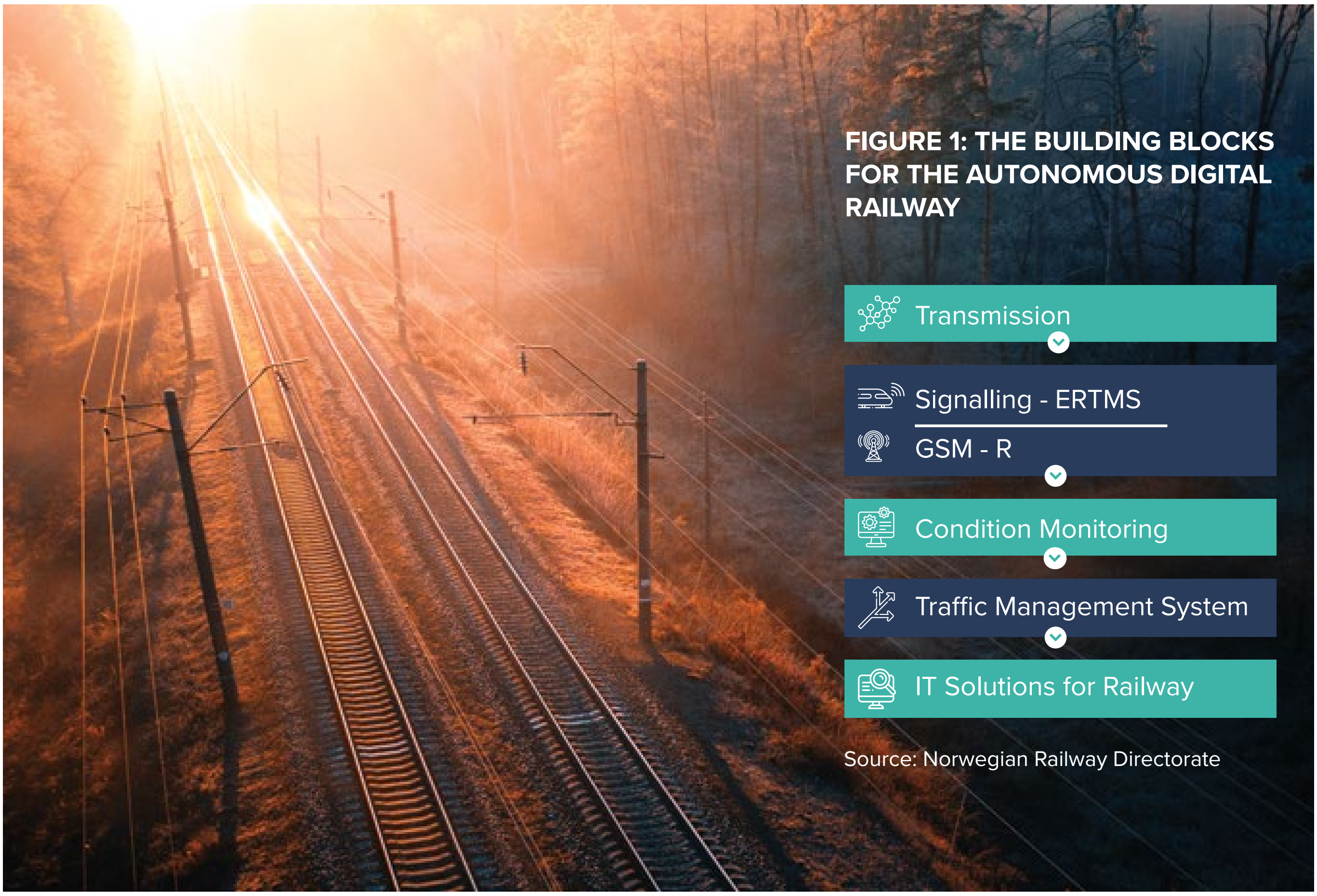


FIGURE 1: THE BUILDING BLOCKS FOR THE AUTONOMOUS DIGITAL RAILWAY

Source: Norwegian Railway Directorate

Operations Safety in the DIGITAL CULTURE

7.1 Current Status

Heavy haul railways have seen steady decline year to year in total number of train derailments in spite of increased tonnages carried. This statistic has been driven in part by significant improvements in rolling stock and track condition monitoring, which can be attributed to improved automated inspection technologies and their interfaces to work practices. In addition, there have been notable improvements in safe working technologies, track circuitry, safe separation, inter-workforce communication systems and top-down safety messaging. While human factors and fatigue are also much better understood, safety gains have been slower, but similarly following a positive trajectory. Over the past decade, there has been some plateauing in human factor derailment rates.

Rail maintains a good position relative to other means of land transport, but a future safety strategy is needed to maintain this position, while driving to the goal of zero derailments and a risk-free workplace.

7.2 Challenges

Railways are ultimately responsible to the public, who may see single incidents such as derailments as highly visible, in spite of reducing relative rates of occurrences. Railway managers are seen to have a clear “duty to ensure safety so far as is reasonably practical” (ONSR regulations 2016).

We need to ask whether additional safety technologies are simplifying and replacing safety controls, or adding new additional layers of confusion?

Increasing digital technology and automation are increasing the amount of available data and analysis and increasing the complexity and cognitive workload. The digital railway may require changing skill sets to be operated and maintained at the same time that the workforce demographics may be ageing. It may be asked whether additional safety technologies are simplifying and replacing safety controls, or adding new additional layers of confusion?

Increasing rail tonnages, axle loads and net tonne kilometres may shorten the time interval required for interventions and responses as wear rates increase and maintenance availability is constrained.

While the digital railway invites new technologies, the regulatory framework may be challenged to change in accordance with the opportunities to modernise safety management. The regulatory concept on rail operators to “ensure safety so far as is reasonably practical” creates a duty to change as technology improves, and with the rapid rate of digital technology evolution, the benchmark for what is “reasonably practical” in safety-related technology is continually advancing.

The rail industry needs to move away from soft administrative controls and invest in the R&D necessary to engineer, automate, and eliminate exposure to risk.

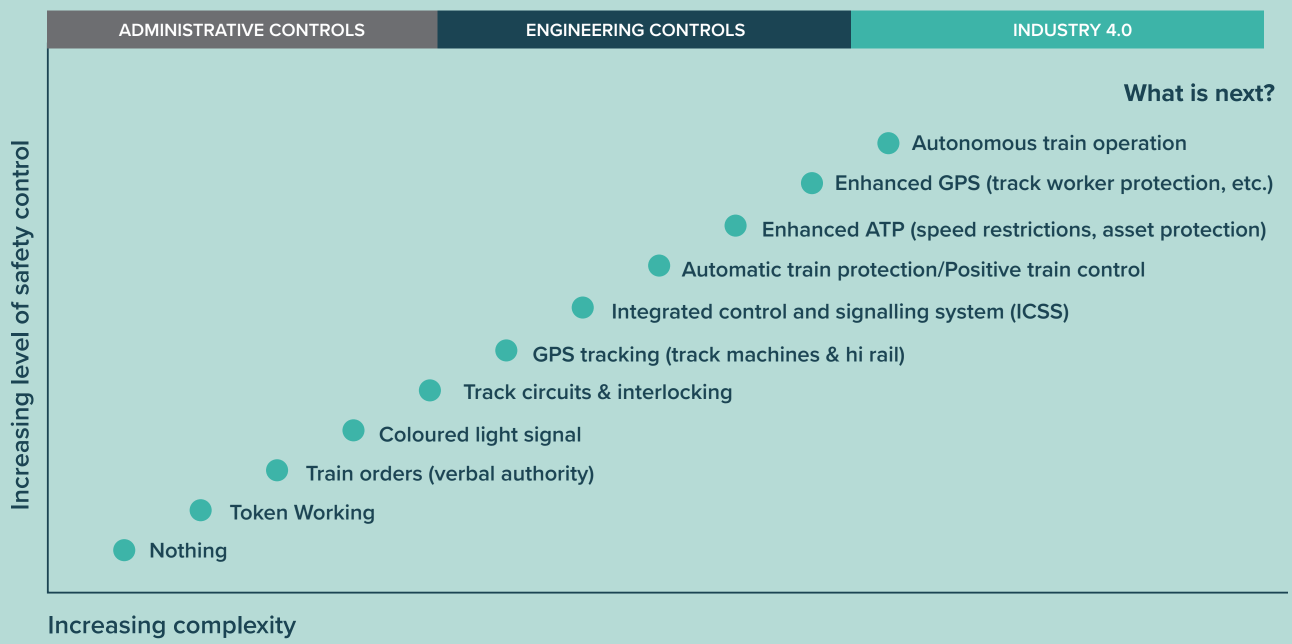
7.3 What We Need to Do

The rail industry needs to move away from soft administrative controls like procedures and rules and to invest in the R&D necessary to engineer, automate, and eliminate exposure to risk, designing for safety from a systems approach. Functional safety and complex control systems engineering will be critical to everyday operation (SIL ratings, CENELEC, systems engineering, etc.). This will require a willingness to change and improve and will require collaboration between rail operators and research institutions, vendors and regulators.

Many significant advances in safety are now demonstrated technology, so the challenge now is increasing the rate of upgrade and technology adoption across the heavy haul rail industry globally. Full automation of train driving to remove drivers from harm’s way and use SIL-rated safety controls to manage current human decision-making over

signals and train movements is now demonstrated technology that could be adopted across industry. Automation of track maintenance activity with high-volume machines removes track workers from the line of fire as does track inspection by drones or train-mounted machine vision and detection systems. Significant advances have been made in automation of rolling stock maintenance facilities to remove workshop staff from the line of fire and error-proof maintenance tasks with automation and digital quality control. The capability of big data analysis, machine learning and mathematical optimisation is now widespread and enabling significant advancement in processing speeds and integration of disparate data streams to deduce asset condition and safety-related risks that were previously undetectable. It could be argued that many of these new technologies and automation systems are now "reasonably practical" with price reducing as industry uptake increases, and railroaders have a duty of care to evolve and implement where tangible safety improvement is possible.

EVOLUTION OF SAFEWORKING SYSTEMS



Operations Safety in the

DIGITAL CULTURE

7.4 Pathway to the Future

Short Term (2 years) – Enablers and R&D

- Implementation of LTE / 4G / 5G technology for increased bandwidth enabling communications-based technologies and increased data streaming
- Investment into improved track network health and remediation
- Rationalisation of rolling stock fleets and retiring of aged equipment
- R&D in machine learning, signal processing and response for enhanced condition monitoring systems from onboard, wayside and vision technology
- R&D into mobile solutions for staff in the field for work tasking, real-time info, automated track access and electronic protection
- R&D into driving strategy automation for error proofing and efficiency
- Upskilling of the rail workforce for new digital technologies

Medium Term (5 Years) – Trial and Implantation of Next-Gen Solutions

- Communications-based train control leads to closer spacing and higher-density traffic
- Wayside machine vision systems replace manual rolling stock inspection
- Enhanced track and infrastructure condition monitoring in place (phased array, LiDAR, etc.)
- Enhanced onboard monitoring systems in place with real-time streaming for condition monitoring and predictive failure analysis
- Broken rail detection moves to onboard
- Move fault detection and response to real-time
- Drones in widespread use for inspections and incident response
- Integration and advanced analytics of condition monitoring data enabling predictive maintenance and reduced faults
- Improved safety functionality of infrastructure and rolling stock (positive train control, comms-based signalling, electronic brakes, spring park brake, etc.)

Long Term (10+ Years) – Moving to Automation and Rail 4.0

- Zero dark territory – full positive control
- Elimination of passive level crossings
- Fit-for-purpose rolling stock and infrastructure – upgraded for higher axle loads and traffic density
- Automated train operation to remove drivers and human error
- Automated worksite protection
- Automated parking brakes
- Automated track maintenance machines
- Automated rolling stock maintenance
- Automated switching and shunting
- Manual inspection of trains eliminated by wayside machine vision systems and onboard instrumentation
- Safe, reliable networks with people removed from line of fire and human error eliminated

Fashioning a Digital Customer EXPERIENCE

8.1 Current Status

The last decade has seen rapid advances in connectivity, mobility, analytics, scalability and data. With the help of the Industrial Internet of Things (IoT), manufacturers have digitised operations, transforming efficiency, supply-chain performance and innovation. This revolution creates entirely new business models for freight transportation and railways.

Seeing what has already happened in other sectors (retail industry, services, insurance, etc.), a heavy haul railway should achieve its highest customer centricity maturity through some recognition of the importance of providing an emotionally positive experience to customers.

Major trends resulting from big data analytics, IoT and AI, are clients demanding railways service them via smartphone messenger services (such as WhatsApp).

A major step forward is needed to provide real-time information all the time via a range of different mobile touchpoints. The introduction of the digital customer experience (CX) means a huge improvement and upgrade of IT networks to get all customer touchpoints assessed, and connected through the right interface. In order to achieve this, the organisation and structure of the railway may be impacted.

8.2 Challenges

The challenge begins with considering the customer, not the organisation, at the centre of the exercise. This requires a vision of customer experience mobilising, organising and committing all employees on a top-down basis to customer needs.

There will also be the need to shape customer interactions into different sequences by digitising processes and getting different channels to interact with one another. This is especially true for large, established organisations that have not broken down operational silos across sales, maintenance, and operations.

IT and communication networks need to be reliable, highly secure and able to support the increase in this kind of customer service mobile traffic.

8.3 Enablers That Must Be in Place

The enablers to be in place for the future are:

- Customer Relation Management (CRM)
- Predictive analytics
- Cloud computing
- Location-based applications
- IoT connected devices
- Interactive voice responses
- Intelligent assistant / Chatbots
- Speech voice analytics
- Mixed reality

In most railways, customer experience enablers are not built into the customer experience strategy. The enablers' priorities and measurements have more to do with processes and procedures than the customer's happiness.

Recognising the importance of providing an emotionally positive experience to customers will be important.

At the heart of the challenge is the siloed nature of service delivery and the insular cultures, behaviors, processes, and policies that flourish inside the functional groups that railways rely on to design and deliver their services.

Fashioning a Digital Customer

EXPERIENCE

Customers will demand real-time information on shipment status and rates all the time, and via a range of different mobile touchpoints.

8.4 Key Performance Indicators for Customer eService

It is important to establish the right metrics to capture customer feedback. For heavy haul, the following may be used:

- Measure customer satisfaction
- Customer effort required to use your self-service systems
- Customer retention rates

8.5 Sequencing of Desired Outcomes and Implementation

In the short term, the underlying data infrastructure needs to be modernised. The three key areas to make it more robust and agile are:

- Data volume and variety
- The ability to accommodate massive volumes as well as many different types of data
- Data, analytics and AI strategy

There needs to be a clearly defined strategy connecting each of these three aspects. Only when data and analytics are working in lockstep with one another, will it be possible to accelerate and scale analytics and AI across the organisation.

Over the mid and longer term, it is important to note that the whole process to achieve customer experience (CX), needs time and a strong top-down commitment.

8.6 Areas of Common Research Interest

Major actors in the supply chain need to extend and deepen a holistic approach that includes the customer in the fields of predictive analysis, standardisation, design value and lean management.

Network-Centric Computer-Assisted Planning and
CONTROL

9.1 Current Status

Today, shipment planners interface with customers and with train service designers who devise train schedules or launch train starts. Corridor managers oversee train flows in given network segments, and train dispatchers decide on meets and overtakes and direct the traffic, while permitting track occupancies for maintenance and inspections. Processes have been integrated with the use of various software packages and consolidation of dispatching, as well as operations and commercial functions in network management centres. But the various levels of human input do not necessarily lead to the optimal outcomes. Traffic flows can be overtly affected by the needs of one customer, the decision to handle an over-length or underpowered train, or the overlaying of trains with variable schedule performance on trains with tight trip plans. In addition, current train management tends to be two-dimensional, in that it may focus on the best plan for a given rail corridor. In reality, most railways, including heavy haul, are influenced by the convergence of trains from multiple segments onto a spine network. The trip performance for these trains on other parts of the network ultimately has a large impact on when they will need to be given clearance to enter a given corridor. And even for a mine to port operation, queueing delays at loading and unloading facilities can back up traffic in both directions.

When we add to that the effects of weather, unplanned track outages, temporary speed restrictions, and train mission failures, there becomes a large variance in train trip times and arrivals. Railway companies sometimes boast of having a great day, or a great week where freight volumes were way ahead of plan, as everything cooperated. But they will also admit that there are not many great days, and the good days may cause senior management to raise the bar on traffic throughput targets to unrealistic levels.

9.2 Challenges

Today's challenges are capacity constraints that continue to develop. Even as rail expands at the rate of current gross domestic product growth, there will be capacity constraints on existing infrastructure. Railways must balance track possession optimisation (given the need to balance maintenance vs operations), customer expectations of high-service reliability (like parcel delivery services), and efficient asset utilisation, all while being safe and socially responsible.

New construction by itself is unlikely to hit the kinds of levels of growth needed to support a conceivable doubling of freight tonnage. Operators will need to leverage efficiency levers more than usual: construction/civil/engineering. Optimisation and density will be the key, achieved through a combination of linear density, axle loads, speed and network stability improvements.

What we used to be able to get away with in terms of "service" is changing. In a world where we all expect to get that Amazon package two days before Christmas without fail for $5, when will our multi-million-dollar customer accounts start to expect the same thing?

Likewise, the world's tolerance for fatalities and major injuries in the workplace are falling – increasingly criminal charges for transgressions are becoming heavier.

Road vehicle automation will challenge shorter rail hauls and will need to be outperformed, or new markets sought. And natural disasters are expected to be more frequent and severe, while at the same time there will be a requirement for better and faster recovery capability.

Network-Centric Computer-Assisted Planning and

CONTROL

9.3 Vision for Network Operations

The challenges will require delivering a different looking railway in 2030 that manages and operates autonomous technologies. To be effective and efficient, operations command and control processes need to anticipate and predict events and adjust activities. Execution needs to be continually informed by the real-time context of the railway to optimise throughput and pace trains. Intelligent train operations will see dynamic virtual blocks with optimal buffering between trains. Buffering between trains will take into account the collected data on train positioning, braking curves, dynamic data collection and on-time response using train-to-train communications. The new state of the art is moving from the best "master plan" to managing real-time live-run variations in operations and doing rapid re-optimisation.

It will involve encompassing more rigid asset management, supported by big data. Asset management is defined as systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles, for the purpose of achieving its organisational strategic plan.

In the digital Railway of the Future, communications and data analysis will be "network-centric". Rather than tracking an individual train movement, or viewing traffic flows on a single corridor, this information would be integrated with real-time tracing of all other parts of the network. The data flows from IoT devices would seek an optimal treatment of the collected data. Predictive algorithms would anticipate when and where traffic flows will converge, when connecting railways will arrive with shipments, and the development of bottlenecks, including loading and unloading. Think about what a Five-Star General needs to know to understand battle situations on multiple fronts of the war theatre, and the status of their supporting logistics chains and directing strategies and tactics. Similarly, there must be quick feedback on their successes or failure to respond nimbly.

Intelligent train operations will see dynamic virtual blocks with optimal buffering between trains.

The success of the heavy haul railway of 2030 will be measured by how well it can manage and operate autonomous technologies.

The future will see automatic train driving using computer-based train planning, including all additional parameters (capacity optimisation, predictive maintenance influence, trains preparation including train loading and rolling stock maintenance, and braking parameters).

Intelligent train operations will see optimal buffering between trains, taking into account the collected data on train positioning, braking curves, dynamic data collection and on-time trip plans using train-to-train communications.

Track possession optimisation methodologies will maximise the productivity of track possessions, optimising the value balance between the length of the possession and the disruption to customers.

The new state of the art is moving from the best "master plan" to managing real-time live-run variations in operations and doing rapid re-optimisation.

9.4 Enablers Will Need to Go Beyond Technology

Employees will need to be led through a generational change with directed change management. New skills and experiences will be needed. Analytics and practical knowledge will need to merge, and the human/machine interfaces will need to be understood by employees transformed to new skills, or hiring will need to bring on staff with the right new skills.

Managers and supervisors will need to morph from “doing work” to “managing exceptions” and “managing assets”, overseeing decision support systems and predictive modelling. They will have to on occasion intervene in automated processes as required to manage exceptions, and then undertake a recovery that restores automated processes. The supply chain will be integrated and people will be expected to work as teams overseeing cross-functional information.

Managers and supervisors will need to morph from “doing work” to “managing exceptions” and “managing assets”.

In support of managing and operating autonomous technologies, information systems will need to be robust and fail-safe. They will need to progressively integrate legacy applications and new technology with a holistic computing architecture and data warehousing. Cybersecurity will need to be built in to all critical-applications-affected network operations.

One enabler would be an industry-wide approach to develop robust autonomous systems and recovery strategies, facilitated by stronger institutions driving collaboration, standardisation and productivity improvements across the rail industry.

Senior leaders will need to manage the transition to the autonomous railway, deciding the priorities and sequencing along with the technologies, systems, regulatory support and human resources that will make it work.

Network-Centric Computer-Assisted Planning and

CONTROL

9.5 Sequencing of Desired Outcomes

An approach then is to prioritise, and to this end, heavy haul must focus on the key assets – resource optimisation and asset management. Operators will need to focus on collective methods of operation changes over the next 10–20 years. For example:

1. Senior leaders will need to manage the transition to the autonomous railway, deciding which areas of operations to target, develop and deploy the necessary roadmaps, and perhaps most critical, seek to obtain the key, and likely new staff and resources we will need to make this journey.
2. Not all of the winners in technology will be immediately obvious. The key will be to get to a state of "ongoing development and direction". This is more like running a software company constantly evolving a product vs a big civil construction project for a client.
3. Pay attention to data – who owns it, who controls it, and how it comes together. Managers must also think about protocols and processes for when it all goes wrong.
4. Pay attention to disruption technologies or practices. It may not be possible for the railway of today to win in all of the usual areas in the future. The key will be picking the right ones, and moving towards them.

Within the first two years, railways would concentrate on modernising their core systems to improve resource and asset scheduling. This would involve standardisation and modularisation and integration with supply chain partners. It would mean a more rigid structuring of asset management and an emphasis on capturing the relevant granular data to support preventive maintenance and optimal planning of track-block requirements while managing traffic throughputs.

Two to five years out, train handling would be incrementally automated to improve efficiency and reduce cost. Automation would be paced to align with organisational and technology maturity, including communications capabilities and the development of an IoT network. Predictive preventive maintenance algorithms would be further developed.

Five to 10 years into the conversion to operating the digital railway, digitised network control would be integrated with signalling to leverage algorithms that optimise performance and throughput capacity. This would be further developed 10 years into the future through artificial intelligence learnings on traffic-flow optimisation.

This will require research on distributed cognitive computing-endowing machines with the ability to be aware of and understand their surroundings – and to learn. Robotics research will also yield endowing machines with the ability to perform goal-oriented tasks autonomously.

> Within 5–10 years, digitised network control should be integrated with train control systems to leverage algorithms that optimise train fluidity and throughput.

Information Technology and Cybersecurity in the

CONNECTED WORLD

10.1 Current Status

Computer systems are evolving as a key to improving operations efficiency. These systems consist of:

- Transportation or trip planning systems
- Computer-aided dispatching support systems
- Blocking and yard management systems
- Resource management and maintenance systems (crews, locomotives, cars, track, maintenance of way and shops)
- Traffic monitoring and asset tracking systems
- Train control systems

Railways have many legacy and complex IT systems that make cross-functional sharing of information a challenge. This may limit the efficiency of resources and reliability that may be needed to meet global market growth. Railway operations have become increasingly reliant on computer interfaces, and network outages can have important influences on rail service reliability. The potential for cyber attacks has become an issue. For rail, it can cause blockage of traffic, degraded operations and even safety risks. These potential losses have been anticipated, but are not yet evaluated.

On the other hand, the move to communication-based train control such as PTC has forced railways to take a fresh look at data management architecture. The features of the rail network have needed to be precisely located and identified, and all train data has had to be lined up consistently across cross-functional databases. This has helped to break down some data silos.

10.2 Challenges

There are challenges introduced by the vast amounts of data that is being collected from multiple new sensors, technology-to-technology interfaces and the early status of big data analytics and cloud-based computing. Human-machine interfaces will require further development.

The characteristics of railway infrastructure make them targets for cyber attacks due to the following:

- The increased connectivity of the digital railway
- High degree of integration between IT and Operational Technology (OT)
- Distributed architecture
- Long lifecycles for equipment and certification processes. Once a component of the system is certified, it might be obsolete from a cybersecurity perspective in particular, considering the quickly evolving threat landscape
- Diversity of supply chain and technology
- Traditionally, the rail business has been very safety-orientated and there is a difficulty integrating both worlds, cybersecurity and safety

The challenge today is to add cybersecurity awareness and cyber defence measures to the rail industry culture in the same manner that safety has been added to the culture of manufacturing and transportation.

10.3 Vision for the Future of IT

The Railway of the Future will require data that is intelligent and interconnected, enabling a shift to management by situational awareness, prediction and proactive planning. Data must be communicated right across the railway enterprise, being shared as needed by all stakeholders. Systems and objects will need to “speak” to one another, allowing relationships to be analysed and decision-making to be continuous and near real-time.

Information Technology and Cybersecurity in the

CONNECTED WORLD

The elements that will need to be in place to provide the information and communications platform to support the Railway of the Future will be:

- A high-capacity, broad-spectrum communications capability, e.g. a 4G/5G remote data transmission network
- Central processing units on locomotives that can process and transmit data relayed from motes on freight cars
- Instrumentation suitable to helping the railway collect new information to monitor operations more closely and act more proactively
- Consistent communications protocols for wayside sensors
- Hand-held devices so local forces can arrange track time; record work and rolling stock placement; and process inventory
- Structured hub and spoke databases that can align data from multiple sources to the correct GPS location, shipment, car, train, time stamp and asset identification, which are expandable and can be queried for analysis by users
- Databases supported by auto-correlation and trending algorithms
- Cloud computing that can distil "big data" into logical pattern recognition
- Rules engines operating in the background that can automatically apply logic to convert a trend or correlation, or a threshold reached into a logical recommended course of action

Integrated data streams will bring together information on railway traffic and shipment flows with similar information on the performance of supply chain interfaces at mines and customer facilities, at ports and unloading facilities, customer demands and spotting of loaded and unloaded equipment at customer facilities. Integrated data will need to ensure that yard and line movement plans are operating in sync, and that connecting railways are on track for shipment hand-offs.

Key elements to achieve cybersecurity are:

- Security by design or integrated security for products and systems
- Continuous exchanges of best practices in order to manage the risks
- Cybersecurity standards (e.g. NIST), certifications and guidelines for rail transportation as a whole
- Effective response to cybersecurity incidents
- Specific certification for:
  - Human resources to perform risk analysis, and to advise and implement cybersecurity solutions
  - Products and systems to resist particular threats or combination of threats, and to provide levels of assurance for dedicated cybersecurity functions
  - Awareness at different levels: Management; Operations; Suppliers

> As visioned by the IoT, systems and objects in the railway world will need to "speak" to one another, allowing relationships to be analysed and decisions to be guided in real-time.

Creating New Capacity with
MINIMUM CAPITAL

11.1 Current Global Trends

Cybersecurity is the new safety mantra for the digital railway.

Tonnage increases are expected for the world's railways, as rail transportation continues to track trends for growth in the world's economies. For example, the US DOT forecasts that total US freight movements will rise from around 18.1 billion tons in 2015 to around 25.5 billion tons in 2040, a 41% increase. It is exceedingly difficult to contemplate new railways in developed areas of the world, and even double and triple tracking can be very expensive.

Heavy haul railways have concentrated their research and their indicators to maintain productivity and increase capacity through running longer, heavier and more reliably. In this way, heavy freight railroads have common characteristics of high axle load, high reliability of the assets, long trains, but with low commercial speed.

However, unlike other modes that already apply technologies and search for solutions, the freight railroad weighs the variables of commercial speed and train length, which require more advances and more technology to leverage these KPIs. Although some railroads throughout the world are achieving evolution, improving the rolling stock and developing better communication systems, this is not a reality for all, since these investments are expensive and of long-term return.

Research in speed and distance between trains is very common in passenger rail and light freight, where they achieve fairly small train distances and reliable operational systems, but this is facilitated by the operating characteristic, in which it focuses on short trains and routes generally duplicated throughout its length.

Demand for freight transportation will rise

Billions of tons transported in U.S.

p - Projected

Source: FHWA Office of Freight Management and Operations. Freight Analysis Framework version 4.4

The U.S. DOT forecasts that total U.S. freight movements will rise from around 18.1 billion tons in 2015 to around 25.5 billion tons in 2040, a 41% increase.

Creating New Capacity with MINIMUM CAPITAL

11.2 Areas That Require Improvement

Of all the points listed as a great opportunity for improvement, two are improved with research on materials and physical issues: improvement of brake efficiency and improvement of draft gear systems. Four are impacted by the evolution of the Industrial Revolution 4.0: improvement of systems communication, elimination of unscheduled stops, decrease of distance between trains and increase of commercial speed.

Of the items that present great potential of evolution, the one “improvement of the brake efficiency” will guarantee better and more efficient brakes, allowing faster and bigger trains. The improvement of brake systems of heavy haul railroads at levels, at least equal to those of express trains, is important. Currently, the most common brake systems in heavy haul trains are pneumatic and non-regenerative power.

In addition to brakes, “improved draft gear systems” will allow bigger trains.

Railway braking systems are a current constraint and a future opportunity for much bigger and faster trains.

In addition to these items mentioned above, items linked to data evolution and derived from the “improvement of communication systems”, will allow trains with increasingly distributed traction. This will also increase the collection and exchange of information between the trains themselves, ensuring safety and less distance between the trains, since the data can be interpreted and optimised to ensure optimal circulation.

With more efficient communication systems to allow global traffic optimisation and increased track reliability, fewer trains stop and more trains can be tracked, increasing overall system capacity.

Derived from the evolution of everything mentioned above, it will be possible to optimise the mesh and, consequently, the distance between the trains. This will be possible as long as data is collected continuously, optimisation systems manage circulation, and communication systems allow the exchange of information between assets, ensuring reliability and redundancy in the verification of everything that is happening.

The increase in speed is a consequence of the improvement of the other items mentioned. As the stops decrease, the average speed will increase progressively, leading to more freed tracks and increasing capacity.

11.3 Enablers

In order for cargo railways to evolve, a large volume of data must be collected, allowing computers to learn patterns and predict situations.

Due to the high cost of technology, the self-sufficiency of energy required and the large number of railroads concessioned by the world, local governments should encourage incentives, avoid bureaucracies and provide credits, if necessary, for the implementation of the necessary investments.

Research into high-capacity data transfer technology over long distances and large storage capacity will be necessary, ensuring real-time information to be processed and retransmitted. In addition, high-strength materials should also be surveyed to allow trains with higher axle load and length, increasing unit capacity of rolling stock.

As it increases capacity on all fronts, railways have become more efficient, less polluting and technologically smarter. In this way, all metrics already known will have an increase, such as the number of trains per day served in the same route, the volume transported in the same stretch, the average commercial speed and the occupation of the route.

In order for the future expectation to be set, efficient data collectors, storage architecture, processing and established data communication must be set up and functioning in perfect condition.

In addition, the data will need to be of sufficient quality to deploy a system of optimisation, artificial intelligence, machine learning and deep learning to deliver consistent and secure results.

Government actions to encourage research, technology, asset investment and environmental licenses need to be guaranteed as well as investment in electric power generation infrastructure, providing a large volume at a low cost.

Loading, unloading, buffering and sorting yards need to be highly efficient and to follow a rhythm that is in sync with the supply chain.

Loading, unloading, buffering and sorting yards need to have a high efficiency to ensure that occupancy follows a rhythmic and consistent pattern and is then maximised in the track.

With all these activators, areas of architecture and data science, Internet of Things, big data, machine learning, deep learning and information systems should be inserted in the operations and start working in partnership with the companies.

Finally, for the trains to increase their size, the materials must have consistently high load capacity, strength and durability. This will require areas such as materials engineering, electrical engineering, civil engineering and mechanical engineering, guaranteeing the communication, transmission and increase of the load capacity of tracks and trains.

11.4 What is the Future Expectation?

For operations

It is hoped that in the future, operations will all be optimised on time, guaranteed by the blockchain model to ensure safety and not allowing trains to be released in circulation without all other trains knowing each other's status. The evolution of data and processing systems will allow trains to make decisions well in advance based on the entire ecosystem the train is inserted into, i.e. the train becomes a collection of wagon and locomotive agents inserted into a collection of the railway system.

Due to the large capacity for information exchange and processing, integrated operations centres will become increasingly common, even with situations in which trains will take much of the decisions based on artificial intelligence algorithms embedded in them (decentralised). This process will guarantee the homogeneous circulation of trains, without major operational variations and optimised decisions with more speed.

Due to the great intelligence that trains will have, track and train verification systems will be more common, such as locomotive instrumentation to ensure on-time information of the current status of the train and its composition.

For rolling stock

Wagons are expected to be larger, with better aerodynamic characteristics, lighter and with more efficient materials. This will ensure faster train speed, lower shocks and, consequently, bigger trains, leveraging the trains' carrying capacity.

The locomotives of the future will be mostly electric, and railroads not adopting electric locomotives will switch to AC electric diesel or LNG gas turbines, eliminating DC electric diesel locomotives from current long-distance travel. This will allow the compositions to overcome larger ramps (grades), longer lengths and have better energy efficiency.

It is important to note that bigger trains, with more traction capacity locomotives and lighter materials, lack better draft gears, as well as better brake communication systems. With these issues solved, trains will be formed mostly with distributed traction, but with increased distance between locomotives and computers managing communication and shocks within the train and forces on the rail.

Creating New Capacity with

MINIMUM CAPITAL

For the track and infrastructure

The instrumentation of locomotives and wagons with video and sound, as well as other sensors, will guarantee a large amount of unstructured data for later analysis and evaluation. With video analysis techniques, as an example, it can issue alerts for all other trains en route possible problems. Rail neutral temperature information, rails with high degree of wear, or other problems can be detected by unstructured data collection techniques and deep pattern analysis (example of sound collection produced by the routers). With the great advancement of circulation, profiles of more favorable lines will be needed. In addition, superstructure materials should allow faster maintenance and less intervention time on the tracks.

It will also be important that the rails, bed and sub-bed of the tracks have greater capacity and resistance, allowing trains with increasing axle load. In addition, most of the heavy haul railways should be doubled, with a truly efficient, optimised and secure mobile block signaling system, as previously mentioned.

All of these paradigm-shattering processes will allow the reduction of train stops, on-track interventions at inappropriate times and, consequently, increased operational time and operational capacity.

11.5 Expected Results Over the Years

In the next 2 (two) years

A large part of the evolution of railway capacity will go through the advancement of data acquisition, storage and understanding. In the next two years, data collection systems are expected to be installed along the tracks, in inspection cars and in general equipment (rolling stock, maintenance workshops, loading and unloading points, yards and equipment).

During the process of installing these devices to obtain data, a data architecture must be constituted, guaranteeing a robust information technology ecosystem for the development of advanced analyses.

In parallel, investments in track recovery, duplication and rolling stock acquisition will continue to occur as demand comes, but integrated operations centres have begun to be implemented to ensure that demand is met efficiently and with the least possible costs.

In the next 5 (five) years

As track investments are made and research investments lead to better materials and larger wagons, increases in axle loads will be possible.

In this way, the sorting, loading and unloading yards must be developed to guarantee speed in the processes and decrease in the operating cycles, since the volume loaded per wagon will increase and, if nothing is done differently, the time to load will also increase.

To ensure the evolution of train size, investments in communication and automation systems should be made. In this way, trains can be bigger, heavier and safer.

Centralised control centres will have great ability to interpret, analyse and optimise future data. In this way, operations will have their operating costs minimised and productivity maximised, as it will reduce unwanted stops and increase the train commercial speed.

In the next 10 (ten) years

It is expected that in the next ten years, with the advancement in data quality and interpretation of information, autonomous unmanned trains with artificial intelligence will be operating much of the railways. In this way, the mobile signalling blocks will become increasingly smaller and the increase in track occupancy will be maximised.

In addition, the tracks will have mostly electrified stretches or traction with AC technology, as well as composition with brake systems, better draft gear apparatus and almost total instrumentation of assets.

Large amounts of heavy haul tracks will be doubled, which will require a greater amount of maintenance interventions and more maintenance equipment. Thus, the evolution of track maintenance equipment will use a large part of the data collected to interpret and generate maintenance plans focused on the most likely risk points.

11.6 2030 Vision for Increased Heavy Haul Rail Capacity

Looking at the current status of research and railways, it is expected that in the future the railways will have distance between trains similar to light and passenger trains, ensuring specified minimum braking distance and operational safety.

It is hoped that in the future, all trains will be electric traction, less polluting and more efficient (as the automotive industry is preparing itself). In addition, train distance drops significantly as signalling, communication and operational reliability systems increase.

In this way, truly mobile signalling blocks can exist, since data can be collected, stored and processed at a very high speed and, consequently, the operation of the tracks will be optimised because of the artificial intelligence.

Communication systems within and between trains will be governed by extremely efficient systems such as mobile telephony communications, allowing tracing of on-time trains and computers managing and governing train performance. Thus, smarter trains, with a great capacity to understand the over-the-road environment that is inserted and anticipating situations of stops, will allow that decisions of the best circulation are taken well in advance, avoiding stops and better capacity of circulation.

To ensure the maximisation of road occupations, there will be more buffer yards, duplicated high-demand routes, and increased efficiency of loading, unloading and sorting systems. However, yard buffers will be less common on a single route, but more yards will be created on railroads that do not yet have them. These yards will be created in better geographic position to ensure maximum occupancy of the mesh and production systems, avoiding idle and unnecessary spending on assets with less use.

The use of blockchain to guarantee the origin of the data, liberation of the train's circulation and origin of the loads should be adopted, allowing deep security of the information, preferences of the correct trains for the clients and creation of data operational patterns to improve the asset utilisation with advanced analysis.

Finally, it will be ideal tracks with a high level of reliability, guaranteeing axle loads over 50 tons and increased tonnage throughput.

From Driver Assist to Autonomous Trains: Is Bigger

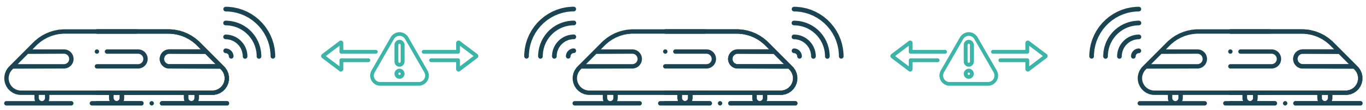
STILL BETTER?

12.1 Current Status and Challenges

This section is intended to be a thought-provoking one, flagging the possibility of 4IR disrupting current trends toward higher axle loads and longer trains.

With a true virtual moving block, train spacing can be set by braking distance algorithms.

Train Management Control Systems (TMCS) are traditionally based on fixed blocks demarcated by infrastructure elements such as track circuits, insulating block joints, axle counters, etc. Trains are regulated to be on one single fixed block at a time and can only enter the next block when it has been declared as vacant by the TMCS.



A train slot is a moving "window" in the Train Management Control System (TMCS). It usually consists of a number of fixed blocks and can accommodate a train moving through the system. Whilst a train is attempting to make smooth progress along the system, its "slot" progresses in a step-function manner as fixed blocks ahead of the train become available. Slots make provision for safety by keeping trains sufficiently far apart to allow for braking distances and additional safety margins. The slots are traditionally limited to a finite number being available per time period in terms of the hardware of a specific TMCS.

A train slot is an opportunity, and the capacity of a line is governed by the extent to which such opportunities are utilised.

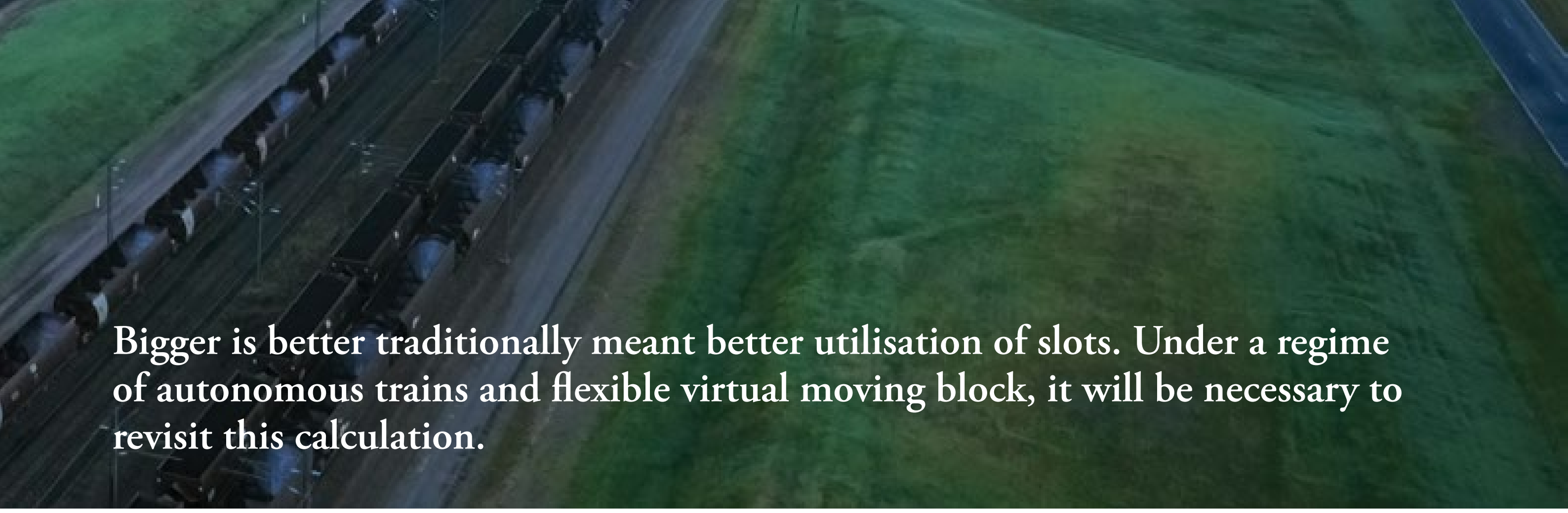
In practice, the theoretical number of available slots is reduced by factors such as maintenance activities, shut-downs, operational inefficiencies and mishaps as well as in-service failures of infrastructure and rolling stock. This loss of x% is an operational reality for both single and double lines.

Single lines suffer the added disadvantage of delays and inefficiencies caused by train crossings (meets). This loss of y% is a function of the number of crossings.

The throughput or capacity of a line can be described as the load per time period where:

$$\frac{\text{LOAD}}{\text{TIME}} = \frac{\text{LOAD}}{\text{SLOT}} \times \frac{\text{SLOTS}}{\text{TIME}}$$

In a given conventional system configuration, the number of slots available in practice per time period can be described as a finite number. This number can be optimised to a limited extent by addressing the inefficiencies x and y mentioned above.



Bigger is better traditionally meant better utilisation of slots. Under a regime of autonomous trains and flexible virtual moving block, it will be necessary to revisit this calculation.

On the other hand, the load per slot offers macro scope for enhancement by increasing the load per wagon (axle load and wagon size) and by increasing the size of the train (length together with distributed power).

This has been the driving force behind the increases in axle load; wagon volumetrics (and lighter wagon materials); longer trains; draft gear strength developments; stronger locomotives; distributed power and improved braking systems; and the resultant economics of bigger is better.

This product of the ± finite number of SLOTS/TIME with the attempts to maximise the payload per train in the variable LOAD/SLOT item, increased the LOAD/TIME throughput. There were higher costs of infrastructure, higher unit rolling stock costs and increased risks associated with higher derailment costs. The economics stayed ahead of the curve as engineers continued to find better materials and processes to reduce and/or limit operating and derailment costs.

Thus, the Bigger is Better trend became firmly established.

12.2 What Might the Future Look Like, Vision, Strategy and Objectives

As described in other sections, it is foreseen that the technologies associated with 4IR will enable TMCS to operate without any on-track or track-side equipment, with trains being located on flexible length virtual moving blocks defined by the variable demands and needs of the TMCS.

As Driver Assist Systems (DAS) develop, technology is likely to be taking more and more “work” out of the “job” of a train driver. Eventually, Autonomous Train Operating Systems (ATOS) are likely to take over with onboard drivers relocating to remote centres and becoming train controllers, with a mouse as the primary tool. Further upskilling and system development is likely to see one train controller taking charge of a whole convoy of trains whilst also adding higher-level skills to the process.

Sensor systems will be available to measure and detect on-train and track-side parameters and report results via digital communication means in real-time to controllers where it can be stored and processed for immediate use. Under-train optical sensors augmented with machine learning systems will serve as warning systems of broken rails whereby trains could be stopped in a timely fashion.

The number of slots per time period will no longer be a finite number. Both elements of the equation can now be utilised to increase capacity as densification of trains becomes the order of the day.

On single lines, train crossings will remain a determining factor, but convoys of shorter trains could be brought into existing sidings to cross an oncoming convoy.

On double lines, the virtually infinite number of available slots will now resemble a pipeline with capacity limited by other elements of the system.

The need to upgrade infrastructure for higher axle loads is likely to change. It will become possible to achieve higher capacity with shorter and possibly lighter trains. Only when capacity of several hundreds of Mt/a are required, does utilisation of slots again become a factor.

12.3 Enablers That Must Be in Place

Flexible virtual moving block TMCS and Autonomous Train Systems must be in place.

12.4 Sequencing of Desired Outcomes

The air industry is currently questioning its own “Bigger is Better” trend as the demise of the Airbus A380 seems to be in the cards. Are there any lessons in this for heavy haul railroads?

Gaining Traction

SUSTAINABLY

13.1 Current Status

While heavy haul railways are recognised as the lowest energy mode for land-based transportation of bulk commodities, the future will see more pressure to optimise fuel consumption and to convert to more environmentally sustainable means of propulsion.

13.2 Challenges

The age profile of existing locomotive fleets and the longevity of their expected years in service present a challenge to a fleet renewal strategy. There are similarly high costs for the implementation of new green technologies such as electrification powered sustainably by energy storage systems, and uncertainty about future energy cost differentials vs fossil fuels. Existing railways' specific infrastructure conditions, such as signalling and communications systems may slow the technical development of more efficient digitised train operations.

13.3 Vision for More Energy Efficient Heavy Haul Railways

In the future, motive power needs to be more powerful, while incorporating digital technologies to assist train driving and to be more fuel efficient and eco-friendly. All locomotives should be equipped with Automatic Engine Start/Stop (AESS) systems.

For electrified lines, more eco-friendly sources of power will be introduced. Research will be needed to develop improved methods of storing and recovering energy used in linehaul. Electric locomotives are expected to be more widely used, as well as clean energy locomotives and multi-energy hybrid locomotives. The application of new technology, new key components and devices will make locomotives more energy efficient as well as with lower noise and less electromagnetic radiation. The permanent magnet synchronous motor (PMSM) boasts such advantages as smaller size; higher power density and power factor; bigger output torque at low speed; higher efficiency and high reliability; and represents one of the development directions for future locomotive traction technology. At present, the power of PMSM has reached 1200kW, which can be used as locomotive traction motor.

Compared with traditional silicon substrate transistors, the new generation semiconductor devices represented by silicon carbide (SiC) and gallium nitride (GaN) have the advantages of high band gap; high saturation electron drift speed; high thermal conductivity; high critical breakdown electric field intensity; high melting point; and high resistance of voltage, frequency, temperature and large current. With their application, the energy loss and heat dissipation requirements of power modules can be relaxed; the volume and weight of cooling systems, main converters, traction transformers, reactors, capacitors and other devices decreased; the harmonic interference to power grids weakened; and system efficiency improved.

Traffic control management systems will anticipate connections and will link schedules at railroad junctions. Automatic train operation systems will be improved and replicated. Trains will be advised of energy optimal speed curves and train driving notch positions. Dispatchers and drivers will be connected to advice systems that direct pacing of trains to maintain schedules, while ensuring there is no wasteful over-speeding to an anticipated stop such as at a meet. These progressive digital changes will ultimately lead to automated train operations.

13.4 Sequencing of Desired Outcomes

Various helpful technical developments are foreseen with 4IR, specifically contributing via more intensive use of DAS and ATO systems, together with the installation of energy storages on the traction rolling stock to reduce the total energy consumption on the locomotive.

Digital and unmanned technologies will develop to provide energy efficient management of heavy trains and to reduce the environmental impact.

With the intelligent monitoring and health management of locomotive through sensing technology, and running state evaluation technology, the intelligent monitoring, fault prediction and life-cycle health management of locomotives will be realised.

Technologies of intelligent sensing and data transmission will enable real-time performance detection of locomotives. As a result, the health assessment of components, fault diagnosis and condition prediction will become increasingly viable.

Based on results of health assessment, it will be increasingly possible to prevent failures in operation, reduce accidents and to cut down on operating and maintenance costs. All this will continuously enhance the stability, safety and reliability of heavy haul trains.

The capabilities of big data technology will enable huge progress in the design, test and evaluation, manufacturing quality and product reliability of locomotives.

13.5 Common Research Needs

Digital and unmanned technologies need to be developed to provide energy-efficient management of heavy trains, reduce environmental impact and increase overall reliability.

Revolutionising Rolling Stock Design and

MANUFACTURE

14.1 Current Status

Heavy haul railways operate under specified limits of axle loads that may be set by the capacity of the freight car bearings; the volumetric capacity of the freight cars; rail and rail weld metallurgy and integrity; or by ballast depth or bridge condition. While it has often been feasible to increase axle loads when the infrastructure has the reserve capacity, axle load increases can require costly upgrades to freight cars or infrastructure.

Hence, railways and their freight car suppliers are very interested in the possibilities of substituting tare weight for increased product payloads within their current axle load limits. This has led to extensive use of aluminum car bodies for coal service and use of lighter weight designs for bogies.

Railways have also invested in means of lowering the stress state of freight cars through wayside detectors that identify freight-car health indicators. Wheel profiles have also evolved to shapes that reduce wheel/rail contact stresses and steer better through curves.

14.2 Areas Requiring Improvements

Further reductions are required in the dead weight of vehicles, which may require more use of composite non-metallic materials, whose high strength can reduce their size and weight.

Rolling stock safety has shown big improvements over the past years, but derailments are still very disruptive, and further work is required to improve ride quality.

Freight cars need to be easier to inspect with onboard of wayside automated systems to reduce idle time lost for routine inspections. Maintenance costs must be lower and more predictable, maintaining high levels of freight-car availability. New freight cars should contain "smart sensors" that can transmit condition data continuously.

Heavy haul loading and unloading facilities can have a large impact on freight-car asset velocity, and a trend to more automation and more rapid indexing of cars through loading and load-out can also increase stresses unless the wagons are engineered for more rapid indexing or continuous loading/unloading.

New high-strength, lighter materials and 3D printing will optimise the wagon structure for heavy haul rolling stock.

14.3 The Challenges

- Workforce demographics may mean an older workforce and a shortage of skilled workers
- New materials may be too costly to implement
- There may be great complexity in integrating intelligent sensing, big data analytics, machine learning and computer-assisted decision-making with legacy rolling stock technology
- New sensors transmitting health data may introduce too many "false positives"
- Communications infrastructure may curtail equipment health data transmission

14.4 The Vision for the Rolling Stock of the Future

The freight car of the future will contribute to a lower stress state by having coupling systems that better manage longitudinal force transients; wheels that better maintain conformal wheel/rail contact; and suspensions that have a low-spectrum dynamic stability within the full range of potential train speeds. New high-strength composite materials and 3D printing manufacture will optimise the car structure of rolling stock. The material strength and corrosion resistance will be enhanced, and the payload of wagons will be higher relative to tare weight. Big data analytics will allow close adherence of design to the load spectrum and can validate success in design and manufacturing quality to drive continuous improvements.

The time spent at loading and unloading facilities significantly impacts the train cycle times and asset velocity. The future will see more fluid and automated movement of cars through the first and last kilometre of their journeys.

Another area for improvement is the design of the car body and components with the goal of facilitating automated detection and performance monitoring in all weather conditions. Some components on a passing car are difficult to visually inspect from a wayside position due to obscured views that could potentially be redesigned without significantly impacting strength or functionality. The draft system in particular is difficult to visually inspect due to its placement within the car.

14.5 Enablers

The enablers for digital railway rolling stock will be:

- A 4G/5G communications network
- Low-cost onboard sensors for rolling stock
- Low-cost, long-life sensor batteries or onboard energy harvesting
- New composite materials technologies
- Improved ride quality and dynamic load dampening

Technological developments of locomotive and rolling stocks depend upon the integration of new technologies such as intelligent perception, data transmission, big data analysis, machine learning and intelligent decision-making with the technologies of locomotive and rolling stock, the availability and reliability of new technologies and materials, and the upgrading or construction of railway infrastructure in terms of the communication network and energy network.

14.6 Desired Outcomes for the Future

- High-strength, lightweight, corrosion-resistant new materials, new technology and new processes for wagons
- Optimise rolling stock body structure and reduce mass of yokes, couplers and bogies to improve payload weight to tare-weight ratios
- Develop onboard sensors and energy sources for continuous monitoring of freight-car health
- Digital identity of rolling stock componentry and real-time monitoring of vehicle load and health condition
- Establishment of rolling stock repair classification and maintenance advisory system adaptive to digitalisation, networking and intelligence
- The integration of new technologies such as intelligent perception, data transmission, big data analysis, machine learning and intelligent decision-making with the technologies of rolling stock

Maintaining High-Reliability

ROLLING STOCK

15.1 Current Global Trends

Identifying cars in need of maintenance has historically been performed using a combination of two methods: 1) time- or mileage-based maintenance or 2) performance-based maintenance. The specified time duration or mileage that a component is allowed to remain in service is generally targeted for a conservative value that is shorter than the full safe-service life of that component. Because of this, time- or mileage-based prescriptive methods are not the preferred method for optimising rolling stock maintenance.

Instead, performance-based maintenance is the preferred strategy because it can offer improvements related to safety, reliability, and efficiency. Historically, this maintenance strategy has relied on manual visual inspections. As access to more and better technology increases, more automated health monitoring systems are introduced that frequently or continuously monitor components to accurately predict and communicate when those components will reach some user-specified criteria. Currently, most automated systems are installed on the track wayside and can inspect cars that are pulled past the site. Automated systems that are installed on the rolling stock itself can provide continuous, rather than periodic, monitoring. Automated systems, whether located wayside or onboard, generate voluminous data that must be stored, communicated, and acted upon in order to improve efforts to correctly identify and prioritise rolling stock in need of maintenance.

In general, automated wayside systems are designed to evaluate the safety and performance of wheelsets, brakes, bogies, or other car body or draft system issues and are used to support performance-based maintenance strategies. They provide essential data for improving the identification of rolling stock in need of maintenance.

A variety of sensor and detector systems are in use looking at wheelsets, hot bearings, tread condition issues, wheel profiles and internal wheel health, etc. More recently, machine vision systems with various capabilities have also been deployed.

Storing, processing, and transmitting data from all of these detector types is a major challenge, but it opens opportunities to be much more effective in evaluating car health and therefore optimising maintenance.

Centralised databases store critical and detailed information from a variety of components including couplers, wheels, bearings, axles, wheelset assembly date and location, brake system components such as slack adjusters and brake control valves, and bogie components such as side frames and bolsters.

Combining detailed data about components and their total service mileage, enables analyses for both safety and business cases. Problems can be identified much more quickly and safety recalls can be targeted to specific cars known to contain the components in question.

This is another example of an increase in the amount of data that must be collected, transmitted, stored, and analysed. But it enables more intelligent decision-making and an improved maintenance situation for rolling stock.

15.2 Areas Requiring Improvements

Better methods for identifying conditions of interest from the images captured by wayside machine vision systems are a major growth area. Onboard monitoring offers the possibility of continuously assessing component health, but must overcome some hurdles if it is to replace or become an important supplement for wayside detection systems.

Another area for improvement is the composite use of component health data from multiple sources.

Optimising maintenance cycles for rolling stock holds potential to improve the efficiency of maintenance operations. This will likely mean fewer trips to the car shop, but more work to the car once it is in the shop. Balance must be struck between optimising the life of each individual component and reducing out-of-service time for the car.

15.3 The Rolling Stock Maintenance Vision

Looking ahead to 2030, the goals of improved rolling stock maintenance centre around safety, reliability, and efficiency. While it may be difficult to completely eliminate derailments due to rolling stock, this should be the goal.

The reliability of rolling stock can be enhanced with the improvements that automated technologies offer. Unscheduled train stops due to component failures reduce throughput capacity and will become less and less acceptable in the future of higher capacity demands.

As wayside detection and onboard monitoring improve, these automated systems will become the primary source of rolling stock health monitoring. This will increase efficiency as visual inspection by humans is used only to verify conditions requiring maintenance attention that have already been flagged by automated systems.

By trending the data captured by automated health monitoring systems, maintenance can be scheduled at times and locations that are convenient.

This illustrates that freight car safety appliance inspections can be performed by computer recognition of digital images. As wayside detection and onboard monitoring systems improve, these automated systems will become the primary source of rolling stock health monitoring.

15.4 Challenges

Power and communications for onboard systems will require some creative thinking. Onboard systems are envisioned to automatically form networks to transmit key bits of data to each other and eventually to a more powerful transmitter on a locomotive that could be several kilometres away.

Maintenance of wayside systems will increase in importance. Track maintenance equipment can create some complications by interfering with the devices and cables of the wayside system.

In interchange environments, issues related to data sharing and data formats from different technologies and different wayside vendors will need to be addressed.

Regulatory modernisation will be required to cope with the transition from manual to automated inspections.

15.5 Enablers

In order to move forward with the 2030 vision for rolling stock maintenance, certain enablers need to be in place. Chief among those is the ability to effectively analyse all of the collected data. Data analytics is the pathway to predicting and optimising when and where maintenance on rolling stock is conducted.

The ability to automatically recognise conditions in need of repair from an image collected by a machine vision system will need to improve. Vendors have gotten quite good at capturing high quality images of passing cars at high speeds. But some of the methods and algorithms used in other industries must be tapped into to fully realise the benefits these systems can provide.

Maintaining High-Reliability

ROLLING STOCK

15.6 Sequencing of Desired Outcomes

In the short term, algorithms for machine vision technologies need to be improved. Ideally, internal defects in wheels must be identified before they become visibly detectable, and so the deployment of additional ultrasonic wheel detection systems are required. Regulators will need to be convinced of the value of more automation from technology.

As the time horizon expands to about 5 years out, there may be additional technologies used in wayside detector systems and potential expansion for the use of machine vision technologies. Onboard systems may start to emerge as a viable supplement for wayside detection. And testing and data collection should be fully underway to support regulatory modernisation towards the use of automated systems for identifying rolling stock in need of maintenance.

A decade from now, as the 2030 vision is approached, onboard equipment will play a much larger role in continuously monitoring the health of rolling stock fleets. This, in combination with advances in wayside detection capabilities will drive improved safety results benefitting both regulators and railways alike.

Integrated Track Construction

TECHNOLOGIES

16.1 Current Global Trends

Construction is moving forward in building complete information platforms for engineering construction, integrating quality, safety, schedule control, inspection, pricing, etc. These platforms improve management efficiency and cost control. Automatic monitoring systems and information management systems for bridges, tunnels, subgrades and track-construction quality control are being developed and applied to improve the quality and efficiency of construction.

At the same time, large-parts assembly construction equipment is being developed to meet the design requirements and the needs of on-site mechanised assembly. The quality of assembly testing and assessment techniques is being studied, thereafter quality assessment standards are formulated, and an index system is established.

A regulatory environment is required that can recognise the improved safety outcomes from a performance-based rolling stock maintenance process driven by automated systems.

16.2 Areas Requiring Improvements

Building Information Modelling (BIM) is an integral part of the future of design, construction, and facilities management. Intelligent construction technology must integrate collaborative design, virtual reality, augmented reality, 4D project management, cloud computing, big data, Internet of Things, etc., to establish a complete railway construction management platform. BIM technology is used to perform pre-assembly simulation in advance. For example, the main structure of a new tunnel will be prefabricated assembly. An intelligent construction information management platform system based on BIM is built to realise intelligent construction of fully prefabricated tunnels. For intelligent track laying, a vehicle-mounted flash butt welding machine and a welding and heat-treatment integrated machine must be developed.

A new generation of intelligent construction robots is required that can perceive and understand the external environment through their own sensors, and make real-time decision-making according to their task requirements. The autonomous/semi-autonomous method can be used for human-robot collaboration and multi-robot cooperative high-precision operations. It can be used for the manufacture of key components of heavy-load railway infrastructure.

16.3 Goals and Outcomes to be Achieved

Artificial intelligence technology, featuring deep learning and self-upgrading should be applied to the manufacture of key components of infrastructure. At the same time, information technologies such as Internet of Things, sensors, big data, networks and wireless communications, and cloud computing should be integrated to automatically identify key components such as raw materials, processing technology, process parameters, product quality, and status, to improve production quality and efficiency.

Cloud computing, Internet of Things technology, intelligent sensing/ big data mining technology, and intelligent robots, will be effectively integrated and applied to the construction of railway infrastructure.

Integrated Track Construction

TECHNOLOGIES

Through BIM applications, engineering design, manufacturing, and construction, information would be displayed on the three-dimensional model and integrated management.

IntelliSense technology, the enormous computing power provided by cloud-computing technology, analytical tools provided by new technologies such as big data analysis, fault prediction and health management, will be used to develop automated monitoring systems and information management systems, which are used in the key links of infrastructure construction quality control, to improve construction quality and efficiency.

Standardised industrial production equipment and processes for infrastructure prefabrication will be formed, and large-scale erection equipment based on artificial intelligence technology developed.

Cloud computing, Internet of Things technology, intelligent sensing/big data mining technology, and intelligent robots, will be effectively integrated and applied to the construction of railway infrastructure.

Through deep penetration and integration of the technology chain and industrial chain, the construction of railway infrastructure will be intelligent, networked, and collaborative, achieving the goals of safety, efficiency, longevity, and environmental protection for heavy haul construction.

The future would anticipate a major breakthrough of technologies and equipment for intelligent construction such as new assembly-type structural systems and key structures, intelligent digital manufacturing technologies, automated installation technologies, precision measurement and control technologies, structural safety dynamic monitoring technologies, construction-wide information management technologies, and 3D printing/manufacturing technologies.

16.4 Enablers and R&D Needs

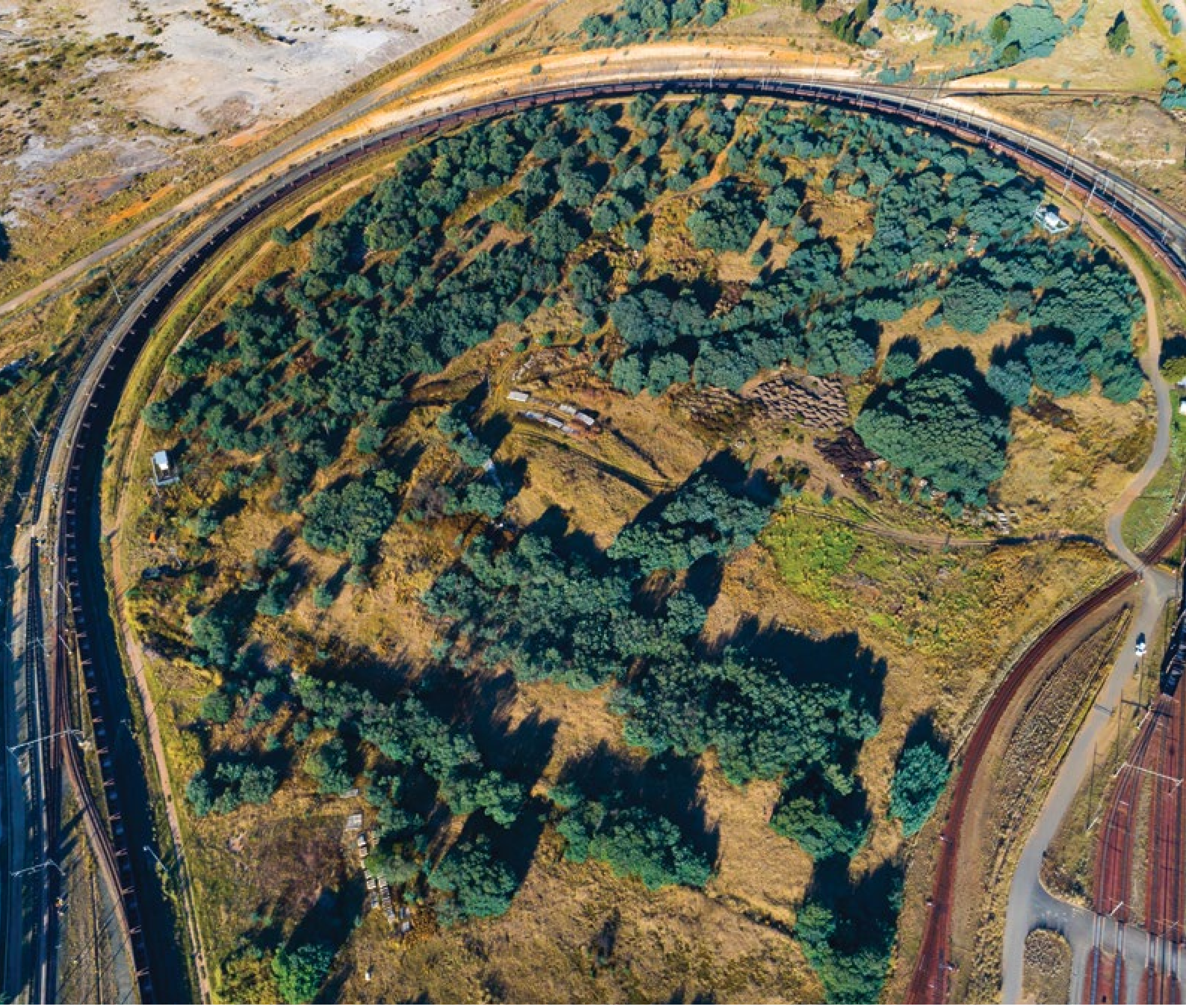
The enablers for digital railway construction technologies involve research and development in the following streams:

- Research on high-strength, high-performance, long-life, lightweight, and smart construction materials
- Study on industrialised production, mechanised assembly, and intelligent construction technologies
- Automatic monitoring system based on intelligent perception technology
- Structure construction and maintenance integration technology based on big data and BIM technology
- Development of construction equipment based on robotics and artificial intelligence technology

16.5 Sequencing of Desired Outcomes

Two Years Out

- Conduct research on Internet-based technologies and application technologies, next-generation communication technologies, and network construction and platform construction
- Based on BIM, cloud computing, big data, and Internet of Things, a railway engineering management platform will be established to implement image display and integrated management of engineering design, manufacturing, and construction information on a three-dimensional model
- Automated monitoring systems will be developed by adopting intelligent sensing technology, big data analysis, fault prediction and health management and other new technologies
- Research will be conducted on new materials, new structures, and assembly construction technology, standardised factory production equipment and processes for heavy-duty railway prefabrication



Five Years Out

- Build an integrated platform for construction and maintenance based on big data and BIM technology
- Build an automatic monitoring system based on new technologies such as IntelliSense technology, big data analysis, fault prediction and health management
- Gradually apply smart construction technology, form intelligent construction technology and standardise procedures
- Develop and gradually apply various construction equipment robots
- Start to apply high-strength, high-performance, long-life, lightweight, and smart materials

10 Years Out

- Realise intelligent production of key components of heavy haul railway infrastructure
- Realise remote control of construction automation
- Realise automatic monitoring and diagnosis of structural health status
- Implement intelligent construction technology based on BIM technology, and complete railway construction management platform (project management (PM) + Data Management (DM))
- Roll out automated construction equipment that integrates BIM and GIS

Maintaining High Guideway Integrity and AVAILABILITY

17.1 Current Status

The railway infrastructure varies in age, with most being decades old. Some heavy haul railway tracks show signs of being unable to handle the load. The increase in tonnage has put a strain on available track time for maintenance, resulting in unplanned outages that disrupt tonnage throughput. Most track maintenance activities are corrective instead of proactive and preventive.

Office-Based Track Inspector Accessing Digital Imaging and Onboard Sensors.

17.2 Challenges

IT & OT technologies, platforms and field connectivity are not integrated sufficiently to take advantage of digital e-maintenance opportunities. Infrastructure maintenance is still mainly driven by individuals inspecting at fixed intervals, and maintenance execution relies heavily on the skills of the inspectors. Many maintenance plans are still worked out on spreadsheets and are not easy to change as conditions evolve. Heavy haul infrastructure is often remote and may not have been upgraded in line with tonnage and axle load increases.

17.3 Infrastructure Maintenance Vision

By 2030, the heavy haul railway should have dynamic maintenance planning based on real-time objective condition data. Maintenance advisory systems should predict failures before they happen, giving advance notice to integrate maintenance plans with train schedules.

As a background, infrastructure of a digital railway will be self-aware, using real-time data to monitor and self-diagnose asset condition. This will involve a seamless integration of systems where the Internet of Things will talk to each other and learn appropriate actions. Work orders will be generated, overseen by supervisors, and assigned to digitally connected work crews. The digital guideway will maintain a high level of availability to meet customer needs under almost all conditions.

17.4 Enablers

The enablers are driven by business processes that are seamlessly integrated with digital solutions and “Fit for Purpose”. Sensors and automated inspection systems are selected and interconnected to create smart infrastructure. IT platforms and communications systems need to support big data and interconnectedness. The workforce will need to be agile and engaged in man-machine interfaces, with transformational capability driven by top-down change management.

17.5 Sequencing of Desired Outcomes

The goal is to optimise maintenance activities by using technology to collect and analyse data, predict potential issues, and inform decision-making processes. This will be achieved through a variety of steps, such as developing algorithms, consolidating data on a cloud platform, and deploying smart equipment and infrastructure. Ultimately, the aim is to create a more efficient and effective heavy haul rail infrastructure maintenance system.

0–3 years:

- Develop key infrastructure condition indices
- Determine and standardise threshold limits prompting maintenance action and renewals
- Audit Condition Assessment Systems (CAS) capabilities and processes to determine their suitability for the maintenance model prescribed
- Standardise maintenance user forms and input terminals
- Capture information into relational databases
- Catalogue asset information per asset

4–6 years

- Continuously audit and reiterate condition assessment systems' capabilities and processes
- Consolidate databases and data processing onto a cloud platform for near real-time post processing, analysis, dashboarding and distribution of information
- Evaluate and procure modelling software to predict known failure modes
- Develop rail network condition machine-learning algorithms
- Update heavy haul track maintenance manuals with latest directives

The heavy haul railway of 2030 should have maintenance advisory systems that predict failures or speed restrictions before they happen.

6–9 years

- Widescale deployment of high-speed, broadband connectivity for M2M telecommunications, such as LTE/5G
- Collect quality data by digitising maintenance data inputs from smart devices
- Integrate asset databases and asset registers in the cloud
- Develop decision-making parameters using existing data and systems
- Incorporate guide rail condition and maintenance data analysis algorithms into operational decision-making and asset life-cycle management
- Perform advanced analytics on data from existing systems

9–12 years and 2030

- Widescale deployment of smart equipment and infrastructure for real-time telemetry of the entire heavy haul value chain
- Optimise maintenance SOPs based on predictive maintenance models and insight
- S.L.I.C-enabled operations, where the Status, Location, Identity and Condition of each asset and resource is continuously monitored and the data informs the most optimal maintenance or operational decision for all stakeholders

Human Capital and Skills for Man-Machine

INTERFACE

People provide the expertise or ability to do something well. Various factors at the workplace, the organisation and in the environment affect this ability, lead to human error and affect health and safety. The addition of new 4IR layers of technology and better decision support systems will potentially reduce these human factors and errors where people interact with technology and the organisation.

The hidden risks of automation are that there are much greater consequences when the systems do not work. With the addition of each new layer of technology, humans may get taken "out of the loop" such that they do not understand what is happening and do not know how to intervene when there is a variance. Increased automation may result in some people getting lost, or becoming bored and fatigued in highly automated workplaces. With digitalisation, the correct person still needs the correct information at the correct time. It is incumbent upon the developers of new automated processes to determine the roles of individuals and their needed competency. The challenge will be to segregate what is best done by machines and where human strengths are best utilised, and maintained in an alert and engaged state, with improved decision support.

A future is foreseen where AI will be used to perform many decisions whilst increased automation and robotics will change supervisory work, reducing human error as well as accidents and injuries. Many new opportunities will require computer programmers, data analysts, data miners, systems engineers, signal pattern analysts, electronics technicians, process engineers, reliability engineers, instrumentation technicians and automation/robotics technicians and maintainers, communications engineers and technicians.

AI and automation will take the "work" out of many jobs, but introduces new challenges in keeping humans engaged in overseeing the inevitable variances and glitches in the seamless process of rail service delivery.

AI and automation will progressively take the "work" out of many jobs as computers do more and more of the menial work, as well as work requiring real-time quick and automatable decisions and/or reactions. People will be set free to do the creative things that will remain beyond the ability of AI for a long time to come. A major cultural shift lies ahead for man, worker, management and unions. There must be encouragement of an environment of lifelong learning and an expectation that employees will work in a number of different jobs.

Challenges of transforming the skill sets of the rail workforce to align to the new digital rail platform loom ahead. Employees will need to be led with directed change management. New skills and experiences will be needed.

The challenge of automation is to determine the balance between what is best done by machines and where the human role is best employed.

All Aboard for the FUTURE

It is clear from the vision portrayed by the IHHA theme champions that the various pieces of the digital heavy haul Railway of the Future are both defined and held together by the very elements of the Fourth Industrial Revolution. A synergistic railway is a connected railway that requires extensive network communications, alignment of all datasets, real-time sensing of status, location and condition, and continuous learning through information processing. It is a railway that will morph from humans reacting to situations, to humans assisted by machines for proactive advice, to machines operating much of the railway, overseen by humans. The way forward can be outlined by reviewing the following key elements for the digital railway that will need to be the top priorities for further development.

First and foremost, **safety will need to be engineered** into new technologies and systems to reduce the elements of human error. This must involve constant dialogues with regulators and a sharing of the information they need to know that the public is protected without the need of legacy regulations.

The digital railway transition process speaks to the importance of top-down driven **change management** that will see the various steps forward and will be guided by a rigorous **technology integration process** that can identify the most promising technologies and can drive them to work together in a **fail-safe** fashion. Change management will need to address the morphing of the man-machine interfaces and the culture shift to planned, proactive railway operations and maintenance, as well as leading new employee recruitment and existing employee **skills development.**

Legacy computer systems will be early barriers to moving forward. The vision needs all datasets to be able to talk to one another cross-functionally. This will require development of **hub and spoke enterprise computing** that is able to line up data-correlating shipment tracking with trip plans for yard, marshalling, loading and unloading status. It will mean that shipments can be tracked to the rolling stock, with train assignment, and that arrival times can be predicted and communicated to customers. Such computer systems will need to build in the best possible **cybersecurity.**

Asset Management Systems will need to be further developed early on. All assets, whether fixed or moving, will need to have defined maintenance, replacement protocol and deployment plans. Systems will need to be capable of tracking all rolling stock by their componentry, location, condition and their distribution and maintenance plan. It means that infrastructure will need to collect and line up all condition data by asset type, configuration, location, work done and planned work. It means that the right sensors need to be in place and powered to track location, status and condition in real-time. Only then can the algorithms be built to monitor trends of the asset's health.

Inspectors and workers charged with repairs will initially be provided with advice on where to look and work orders to validate. Then, they would increasingly **oversee machine-based inspections,** freeing them from routine manual inspections of infrastructure and rolling stock. Construction and repairs may increasingly be possible with the help of robots trained to weld, replace components and build things.

At an early stage, **communications networks** will need to be upgraded to LTE/4G/5G, to handle the greater communications bandwidth that networks of onboard and wayside sensors will require, and the need for quick turnaround of the information required in terms of defined actions.

Big Data Analytics will need to be developed to mine artificial intelligence from large amounts of data so rules engines can be developed to initially advise on actions, then initiate actions through computer logic, and finally to refine computer logic for artificial learning.

As railways move to **communications-based train control systems,** they will put more pressure on suppliers to improve train braking to take advantage of shorter virtual moving blocks. They will ask suppliers for more fuel-efficient, but nimble locomotives with more green power alternatives. Communications-based train control will open up further analysis of optimal train lengths, pacing and spacing to increase throughput on existing rights of way.

IHHA's role in the achievement of the

HEAVY HAUL VISION 2030

INTERNATIONAL HEAVY HAUL ASSOCIATION

IHHA's strategic intent is to strive for achievement of Excellence in Global Heavy Haul Rail Operations.

The role of IHHA is to:

- Share Heavy Haul Rail best practice
- Promote advancements in innovation, technology and engineering in Heavy Haul Rail
- Significantly contribute in the skills and development of Rail professionals
- Provide a platform for Heavy Haul railway professionals across the world

IHHA continues to achieve its role by:

- Hosting conferences, technical workshops and strategy seminars
- Writing and publishing Best Practice books
- Hosting networking sessions and gatherings for Heavy Haul Rail professionals
- Continually assessing market trends and developments to inform strategic direction of the industry
- Promoting active participation of all Heavy Haul industry associates including, researchers, suppliers, customers, regulators, rail operators, and professionals, in activities of IHHA
- Providing guidance on areas of further research and development
- Leading the way in fostering Heavy Haul railways to be responsible local and global partners

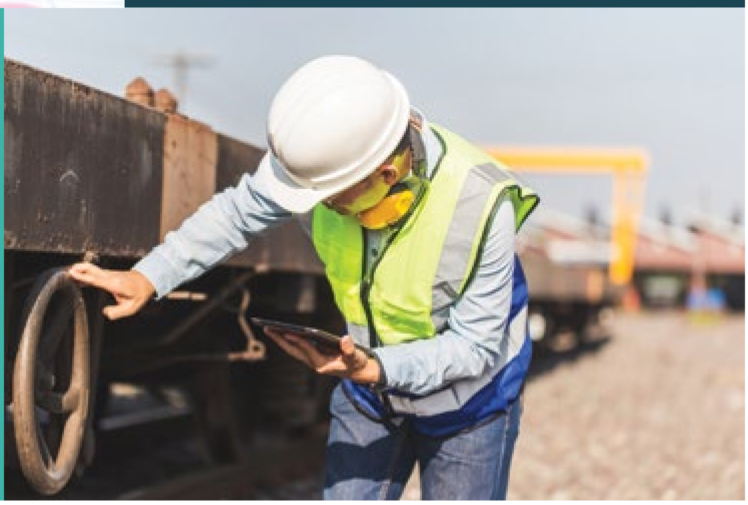
IHHA aspires that this Vision 2030 document will be instrumental in promoting more collaboration amongst the global Heavy Haul rail industry players for the achievement of **A Safe, Competitive, Responsible, Reliable, Integrated and Intelligent Heavy Haul System powered by Rail 4.0.**

RECOMMENDATIONS

This Heavy Haul Vision document has outlined how the Railway of the Future could look like, and highlighted key enablers to pave a way towards the envisage future. It is recommended that Rail operators use this document as a guide towards development of their own organisation's strategies and leverage on the opportunities presented by breakthrough technologies, innovations, and business models.

It is recommended that the Research institutions and suppliers conduct further Research and Development on required enablers highlighted under each of the Themes discussed in this document. This will promote the launch of new products and solutions in the Rail industry.

Rail professionals have an opportunity to use this vision document as a guide to enhancing their skills, competencies and capabilities to enable the achievement of A Safe, Competitive, Responsible, Reliable, Integrated and Intelligent Heavy Haul System powered by Rail 4.0.



Thank you to IHHA members, railway professionals and associates for your unwavering commitment and passion.








Current Global Trends
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Thank you!


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