Technology watch on Robotics and Autonomous Systems (S199)

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Scope of this knowledge search

As a quick knowledge search, this report provides key bibliographical references and limited analysis. It is intended to inform decisions about the scope and direction of possible research and innovation initiatives to be undertaken in this area. It does not provide definitive answers on this issue; and is not intended to represent RSSB’s view on it.

The search may only include what is available in the public domain.

It has been conducted by a team with expertise in gathering, structuring, analysing both qualitative and quantitative information, not by specialists in the field. Experts in railway operations or other personnel in RSSB, or elsewhere, may not have been consulted due to the limited time available. Industry and experts in this field are very welcome to make observations and to provide additional information. Please send comments to knowledgesearch@rssb.co.uk.

For further information or background to this report, please contact RSSB Knowledge and Technology Transfer Services at knowledgesearch@rssb.co.uk.
Executive Summary

TRL and RSSB launched a community of interest for conducting a technology watch on robotics and autonomous systems. After having reviewed the possible themes which could be covered, and considering our respective fields of expertise, it was decided that the technology watch would focus on robotics and autonomous systems for rail asset management and maintenance, and automation in vehicles and transport systems.

The resulting report looks at the fields of robotics and autonomous vehicles to identify some of the latest technological advances and innovations, highlight their possible applications and benefits for the transport industry, and discuss their future trends, challenges and opportunities.

The term “Robotics” is used to define a branch of engineering that focuses on the design, construction and operation of machines specifically designed to perform a particular task (or a range of tasks). They are usually classified according to their application (e.g. military, healthcare, industrial robots, etc.) or their appearance (e.g. drones, humanoid robots, hexapods, etc.).

While robots are usually viewed as physical machines performing some form of physical action, autonomous systems cover a much wider spectrum, which is not defined by physical structures. Autonomous systems are defined as self-monitoring adaptive intelligent systems that have control over their own actions and internal state, and that can operate independently from direct human intervention. This may include robotics or autonomous vehicles, where data acquired by a sensing or monitoring capability are utilised as part of the overall autonomous decision-making process.

Robots can be used to replace or assist humans in any activity that falls under what certain technology analysts have called the “4Ds” type: dangerous, difficult, dirty or dull. Some of the possible application areas include inspection and maintenance, monitoring and surveillance, disaster recovery, customer services and network optimisation.

Some of the technologies identified in the technology watch include drones for maintenance, inspection and surveillance (graffiti deterrence, trespassing monitoring, etc.), rail robots for automatic switch inspection and welding work, laser coating renewal systems, 3D printing robots for structural work, mobile robots for disaster recovery and exoskeletons for personal assistance.

Autonomous systems show great potential for the transport sector with a number of applications already developed, which enable better vehicle performance (tilting trains, automatic suspension, etc.), higher fuel efficiencies (automatic engine optimisation software, hybrid drives, etc.) and better optimised transport networks (semi-autonomous signalling systems, driverless pods and light rail vehicles, etc.). They are especially good in situations where human involvement is expensive, dangerous, difficult or superfluous. Autonomous system applications can be beneficial in manufacturing, maintenance, network optimisation, safety and security, disaster recovery, passenger experience and staff training areas.

Some of the autonomous systems identified in the technology watch include driverless cars, autonomous rail vehicles, driver assistance and cooperative systems and artificial intelligence.

The prospects for more widely adopting robotics and autonomous systems in the transport sector will dependent on a number of factors, such as Technology Readiness Levels (TRL), associated costs, regulations and policies, time scales, performance, reliability, etc. Societal developments will also play a fundamental role, as drivers or barriers.
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1 Introduction

The concept of artificial servants and companions can be traced back to ancient Greece where many mythological stories depicted artificial entities such as the talking mechanical handmaidens built by the Greek god Hephaestus. The clay golems of Jewish legends and the clay giants of Norse legends are not far apart from the idea of Greek automata. These cultural references were however scarce, and mostly relying on the imagination of poets and writers. It was only at the end of the 18th century, with the fascination of Enlightenment scientists and thinkers for mechanical automata, and with the advent of the first industrial revolution, that technological reality started to catch up with fiction.

The term “robot” was first introduced by the Czech playwright Karel Čapek, in his 1920 hit play “Rossum’s Universal Robots (R.U.R.).” The word comes from an old Slavonic word ‘rabota’ meaning servitude, forced labour or drudgery.

Inspired by the works of Isaac Asimov and the science fiction films, robotics came to popularity in the 1950s. Many people then believed that within a few decades there would be mass-produced robots that could do house cleaning, pick up groceries and perform other mundane tasks making daily lives a lot simpler. Scientists speculated that by 2010 robots would already have artificial brains capable of solving complex problems and making moral decisions.

Although contemporary machines cannot yet “think” on their own, the last few decades have yet seen some huge developments in the fields of robotics and artificial intelligence (the “brain” of autonomous systems) with a wide array of industrial applications (welding robots, nanobots, robot cleaners, drones, driverless cars, etc.). This seems to confirm the “law of increased automation” of every technological system found in the literature related to the TRIZ methodology for inventive problem solving.

Robotic and autonomous system innovations are sparking more and more interest in the railway community, and engineers and rail specialists have been thinking about the potential and the benefits that some of these novel technologies could bring to the industry today, and what the future could entail (for example, the “Future of Rail 2050” report published by ARUP illustrates the future imagined place of robotics and autonomous systems in rail, with automated passenger trains, ticketless gates, automatic gauge change, surveillance drones, intelligent robots for unloading and sorting freight cargos, etc.).

TRL and RSSB launched a community of interest for conducting a technology watch on robotics and autonomous systems. After having reviewed the possible themes which could be covered, and considering our respective fields of expertise, it was decided that the technology watch would focus on the applications of robotics for rail asset management, inspection and maintenance, and on automation in vehicles and transport systems. The resulting report looks at the fields of robotics and autonomous vehicles to identify some of the latest technological advances and innovations, highlight their possible applications and benefits for the rail industry, and discuss their future trends, challenges and opportunities.

2 TRIZ is the Russian acronym for "Teoriya Resheniya Izobretatelskikh Zadatch" (теория решения изобретательских задач) meaning the 'Theory of Inventive Problem Solving', developed in 1946 by Soviet inventor and science fiction author Genrich Altshuller and his colleagues. http://www.triz.co.uk/
3 Note: The theme selection process for the technology watch report can be found in the Appendix A.
2 Robots and autonomous systems

2.1 What makes a robot

The term “Robotics” is used to define a branch of engineering that focuses on the design, construction and operation of robotic systems (robots). A robot is a machine that is specifically designed to perform a particular task (or a range of tasks)\(^4\). They are usually classified by their application (e.g. military, healthcare, industrial robots, etc.) or their appearance (e.g. drones, humanoid robots, hexapods, etc.).

Robots can be fully autonomous, semi-autonomous or controlled by human operators. A fully autonomous robot will make all of its decisions and actions without direct human intervention (see section 2.2); semi-autonomous robot will have some degree of autonomy (e.g. some tasks, like balancing or object tracking, will be fully automated, while others will be controlled by human operator) while non-autonomous robots are directly controlled by an operator (e.g. remote controlled CCTV camera that can be rotated 360°).

Figure 1 - Industrial robotic arms developed by Robotics & Drives\(^5\)

A typical robotic system will usually have the following components\(^6\):

- **Body** – the design of a robot’s body will depend on its purpose and required tasks. It may be designed to resemble a human, an animal, a moving platform or anything else depending on the requirements of the device.

- **Actuators** – these are hardware devices that control the movement of robot’s parts. They can be electric motors or solenoids (driven by electric power), hydraulic systems (driven by liquids under pressure) or pneumatic systems (driven by pressurised air).

- **Power supply** – depending on the actuator type, robots may need to be supplied with compressed gas, compressed oil or electrical power.

- **Control unit** – a processing unit that is used to control the whole system, and may include artificial intelligence if this is necessary. Computers are generally used to control robots due to their multi-functionality and flexibility, allowing most robots to be reprogrammed and redeployed.

- **Sensory systems** – these provide robots with environment information and allow their interacting with the surrounding world. Such systems include infrared or ultrasound sensors to determine distances, charged-couple display (CCD) cameras with image-recognition software, sound sensors (usually microphones) with speech recognition software, and olfactory sensors for environments where smell is a factor.

- **End effectors and special manipulators** – robotic arms may be fitted with different end effectors and/or special manipulators depending on the particular application. Typical industrial end effectors include clamps, grippers, blowtorches, drills, spray painters, tool changers, rotary joints, etc.

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\(^4\) The Robotic Industries Association defines the industrial robot as “a reprogrammable, multi-functional machine designed to manipulate material, parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks.”


2.2 What is an autonomous system?

While robots are usually viewed as physical machines performing some form of physical action, autonomous systems cover a much wider spectrum, which is not defined by physical structures. Autonomous systems are defined as self-monitoring adaptive intelligent systems that have control over their own actions and internal state, and that can operate independently from direct human intervention. This may include robotics or autonomous vehicles, where data acquired by a sensing or monitoring capability is utilised as part of the overall autonomous decision-making process.

Some examples of autonomous systems include autonomous space exploration vehicles, intelligent transport systems, automated control for nuclear power plants, autonomous aerial vehicles, automated trading systems used for high-frequency trading, etc.

A fully autonomous system has the following characteristics: it is able to learn from experience, interact and cooperate with other autonomous systems, is flexible in handling the uncertainty associated with its environment and has the means to take rational decisions, leading to a specific goal.

Autonomous systems differ from automated systems, which also can function without human operators but are unable to adapt or make “decisions”. In general, systems can be grouped into six types based on their level of autonomy and control:

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Human operated</td>
<td>All activity within the system is the direct result of human-initiated control inputs. The system has no autonomous control of its environment, although it may have information-only responses to sensed data.</td>
</tr>
<tr>
<td>2</td>
<td>Human assisted</td>
<td>The system can perform activity in parallel with human input, acting to augment the ability of the human to perform the desired activity, but has no ability to act without accompanying human input. An example is automobile automatic transmission and anti-skid brakes.</td>
</tr>
<tr>
<td>3</td>
<td>Human delegated</td>
<td>The system can perform limited control activity on a delegated basis. This level encompasses automatic flight controls, engine controls, and other low-level automation that must be activated or deactivated by a human input and act in mutual exclusion with human operation.</td>
</tr>
<tr>
<td>4</td>
<td>Human supervised</td>
<td>The system can perform a wide variety of activities given top-level permissions or direction by a human. The system provides sufficient insight into its internal operations and behaviours that it can be understood by its human supervisor and appropriately redirected. The system does not have the capability to self-initiate behaviours that are not within the scope of its current directed tasks.</td>
</tr>
<tr>
<td>5</td>
<td>Mixed initiative</td>
<td>Both the human and the system can initiate behaviours based on sensed data. The system can coordinate its behaviour with the human’s behaviours both explicitly and implicitly. The human can understand the behaviours of the system in the same way that he understands his own behaviours. A variety of means are provided to regulate the authority of the system with respect to human operators.</td>
</tr>
<tr>
<td>6</td>
<td>Fully autonomous</td>
<td>The system requires no human intervention to perform any of its designed activities across all planned ranges of environmental conditions.</td>
</tr>
</tbody>
</table>

Table 1 - Levels of Autonomy (from US Navy Office of Naval Research and used by SEAS DTC)

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7 It is important to understand that robots can be autonomous systems
There is no clear distinction between the different types of autonomous systems. The level of autonomy can be correlated with a proportional lessening of the degree of human intervention or interaction.

The development of artificial intelligence (AI) is closely linked with system autonomy, as the goal is to create such intelligent machines that perceive their environment and take actions that maximise their chances of success. In other words, artificial intelligence can be viewed as the “brain unit” of a fully autonomous system.

Autonomous systems have a wide variety of possible applications in fields such as robotics, software engineering, machine automation, network optimisation, image recognition, etc.

3 Potential applications of robotics and autonomous systems

3.1 Robots and robotic systems for rail transport

The transport sector has been one of the first sectors to take the advantage of robotic systems for manufacturing processes. Robots were first introduced for mass production in the automotive industry by General Motors, who installed their first robotic arm to assist in their assembly line in 1961. Ever since, robots have been widely used in both the automotive and the railway industries for a number of manufacturing and maintenance processes (e.g. welding, surface treatment, drilling and riveting, part handling, painting and finishing, etc.), inspection and quality control.

However, only a small fraction of the potential benefits that robotics could bring to the railway and automotive industries is being taken advantage of. It is anticipated that robotics may have a huge impact on many other areas outside manufacturing, which could drastically change the way we see and use personal and public transportation.

Robots could be used to replace or assist humans in any activity that falls under the “4Ds” (Dangerous, Difficult, Dirty and Dull). Some of the possible areas and their applications along with associated benefits are listed below:

- Maintenance and inspection – robotic systems are already used for maintenance and inspection of road and rail vehicles and their respective infrastructures, and could be expanded to automate even more tasks. For example, robots on tracks could be deployed to automatically clean or grind the rails at set intervals (e.g. at night when the lines are less busy) or when unexpected
objects/failures are detected (through sensor networks); wheeled robots could be used for maintaining clean roads (e.g. automated snow ploughs, salt dispenses, etc.); robots could be used for vegetation control; crawling and climbing robots could be used for testing load-bearing cables or ventilation pipes; flying robots (e.g. helicopters, drones, etc.) could be used for aerial mapping or to transport maintenance equipment or parts to remote locations, thus reducing transportation costs and lead times; swarm robots and robot networks could be used in conjunction with 3D printing for various on-board and infrastructure repairs and inspections, improving maintenance time, costs and efficiency; or robotic exoskeleton suits could be used by maintenance staff in order to allow them carry heavier items and reduce work stress. In addition, robots could be used for maintenance and inspection work in dangerous environments which would otherwise have to be carried out by humans (e.g. working on an active lines, in highly-elevated or toxic areas, during storms, for tunnelling, etc.), decreasing the risk of accidents.

- **Surveillance** – robots could be used for a number of surveillance tasks. For example, flying robots could be used for road, railway line and asset monitoring for safety, security or inspection purposes (e.g. drones that track trespassers); drones could be used for aerial mapping and real-time vehicle tracking, improving real-time passenger information system accuracy and providing redundancy to the current safety and signalling systems (rail) or intelligent transportation management systems (road); robotic camera systems could be used to automatically identify, track and alert suspicious behaviour or passenger incidents; robots could be used to patrol along roads and rail lines adding to the overall security and safety of the networks.

- **Disaster recovery** – robotic systems could greatly improve the speed and effectiveness of dealing with accidents. For example, robots could be used in search and rescue operations to search for survivors after road and rail accidents, where the environment might still be dangerous or not accessible to rescue personnel; or they could be used to quickly locate and map incidents allowing faster response.

- **Customer services** – robots could also be adapted to assist public transport passengers and staff, increasing the quality of customer services. For example, robots located at stations could assist elderly or disabled passengers (e.g. autonomous wheelchairs could be adopted that would automatically drive a disabled passenger inside a specially designed carriage); real-time passenger information systems could be enhanced by receiving live feed from drones or sensor networks; entertainment robots could be deployed at stations to entertain passengers whilst they wait; or service robots could be used on-board trains that would provide food and beverages for the customers.

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10 Swarm robotics is a new approach to the coordination of multirobot systems which consist of large numbers of mostly simple physical robots.
Network efficiency – robots could improve the overall efficiency of the railway and road networks by automating and optimising vehicles (fully automated network would reduce delays caused by human factors and decrease the risk of accidents). Flying robot data could be used for real-time network optimisation; robots could be used for material handling at depots (e.g. by using automated storage and retrieval systems), etc.

3.1.1 Drones and Unmanned Aerial Vehicles (UAVs)

Drones are formally known as unmanned aerial vehicles (UAVs), which are defined as aircrafts that do not have a human pilot aboard. Two types of UAVs exist: autonomous UAVs, which operate without the need for a human operator, and remotely piloted UAVs, which are directly controlled by human pilots. Drones are especially good for tasks falling under the 4Ds (see page 9).

Drones used for railway and road transport applications could bring a number of benefits:

- **Reduce operating costs** – drones used for surveillance, areal mapping or maintenance work are small, portable and relatively cheap to operate.

- **Improve operation speed and efficiency** – drones used for accidents and emergency operations are much more flexible than ground vehicles, and could be used to reach remote locations quickly and deliver medical supplies or assess the situation so that the ground control could make better decisions.

- **Reduce risks associated with human operators** – drones working in dangerous and hazardous environments (e.g. checking electric power lines) reduce the risks of human accidents.

- **Improve security** – drones used for surveillance can act as mobile CCTV cameras and deter potential criminals from illegal behaviour.

3.1.2 Mobile ground robots

Mobile robots are defined as robots that have the capability to move around in their environment and are not fixed to one physical location. They can be autonomous or remotely controlled, and can either rely on guidance devices to travel on a predefined path (e.g. rail) or their sensor networks (e.g. moving through a pile of rubble).

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12 Delivery drones are a good example of integration into people’s daily routines. Companies such as Amazon and DHL are already testing their prototype drone delivery systems.


14 Note that remotely controlled UAVs still have some degree of autonomy, e.g. for maintaining speed, height, orientation, etc.
Mobile ground robots and unmanned ground vehicles (UGVs) have been mostly developed for military applications, such as transportation of people and goods, scouting, etc. However, some railway applications do exist, especially concerning infrastructure maintenance and inspection, and emergency response operations.

Some of the potential benefits mobile ground robots could bring to the industry include the following:

- **Reduced costs** – mobile ground robots could reduce the time of some maintenance tasks (e.g. rail welding, sleeper changing, cleaning, etc.) as their application could be automated and optimised to achieve maximum performance.

- **Improved efficiency** – some operations could be performed more efficiently as machines are faster and more accurate (e.g. for inspection purposes, sophisticated sensors on robots could automatically detect imperfections, which would be much faster than doing so manually).

- **Reduced risks** – similarly to drones, mobile robots could be also used in search and rescue operations and in dangerous environments, greatly reducing the chances of incidents involving people.

A large amount of heavy and repetitive tasks involved in the construction of infrastructure (moving and installing concrete sleepers, welding rails, etc.) make this area very attractive for the application of appropriate robotic systems to take over tasks otherwise undertaken by human operators.

3.1.3 **Stationary robots**

Stationary robots include robotic systems which are fixed and unable to move by themselves (e.g. an assembly robot which can only move its robotic arms).

Such robots have the biggest potential in component manufacturing and maintenance applications within the rail and transport industries with the main benefits being reduced costs, lead times, material waste and improved process efficiency.

3.1.4 **3D printing robots**

Additive manufacturing (AM), including 3D printing, is one of the most promising technologies which have been developed or experimented across many types of industries. AM's on-site production and customisation capabilities could be highly beneficial, especially for maintenance activities. The technology could provide quick replacement of components or parts which have become damaged or obsolete. Transport and storage costs would be considerably reduced, or possibly eliminated.

Railways are made up of complex mechanical and electrical systems and there are hundreds of thousands of moving parts. A lot of these parts are specific and were produced in small series. With AM, maintenance services would have the possibility of replacing rolling stock and infrastructure parts extremely quickly and with no transport or storage costs. AM could also contribute to the goal of having self-repairing intelligent assets for the future railways, and would help maintenance and renewal optimisation (MRO) services get the right parts at the right place at the right moment. Another application could be the ability to produce customised protective wear, promoting health and safety at work for staff.

3.1.5 **Robotic exoskeletons**

Robotic exoskeletons are mobile machines consisting primarily of an outer framework worn by a person, which is powered by a system of motors and hydraulics that delivers part of the energy for limb movement. Their primary function is to assist the wearer by boosting their strength and endurance.
Exoskeletons could be adapted to provide benefits for railway workers by allowing them to carry heavier loads and reducing their work fatigue and risk of injuries.

3.2 Autonomous systems for the transport sector

Autonomous systems show great potential for the transport sector with a number of applications already developed, which enable better vehicle performance (tilting trains, automatic suspension, etc.), higher fuel efficiencies (automatic engine optimisation software, hybrid drives, etc.) and better optimised transport networks (semi-autonomous signalling systems, driverless pods and light rail vehicles, etc.). They are especially good in situations where human involvement is expensive, dangerous, difficult or superfluous.  

In the future, autonomous systems (AS) are likely to become even more sophisticated and reliable, allowing for many new possible applications for both railway and automotive sectors, such as:

- **Manufacturing** – AS could further improve manufacturing processes improving their efficiency and reducing manufacturing costs (e.g. machines could have evolving process optimisation algorithms which could optimise the process based on feedback, predictions and external data).

- **Maintenance** – fully autonomous maintenance systems (e.g. autonomous cleaning, inspection, vehicle and infrastructure repairs, etc.) could improve transport network efficiency, reduce maintenance costs and improve employee safety (as less people would need to be working in dangerous environments, e.g. on active rail lines or roads).

- **Network optimisation** – AS could enable autonomous driverless vehicle technologies (such as Google car or SARTRE project), which would reduce traffic collisions, increase road capacity, reduce air pollution, reduce traffic congestion, etc. They could also be used to optimise various other control systems (e.g. traffic lights, railway signalling and warning systems, traffic signs, etc.).

- **Safety** – AS could be used together with robotic technologies to provide smart surveillance systems or vehicle-to-vehicle communication, enhancing the overall safety and security of rail and road networks.

- **Disaster recovery** – autonomous robots or robot swarms could be used for search and rescue, disaster recovery missions, which would improve mission speed, effectiveness and reduce risks.

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16 http://www.sartre-project.eu
17 http://files.publicaffairs.geblogs.com/files/2014/10/intersection_large.png
• **Passenger experience** – AS could bring a number of technologies that would improve both driver and passenger experiences. For example, automated customer service assistants could provide useful information about traffic, timetables, prices, etc. just by verbal communication; personalised navigation software could suggest routes that best fit the individual’s driving style (e.g. avoiding traffic, going through supermarkets, etc.); intelligent driver information and warning systems could provide better information and some automation of responses to warnings, further increasing vehicle safety; self-parking systems could reduce the number of accidents in crowded areas, etc.

• **Staff training** – AS could have a huge influence on staff training. Sophisticated training systems could be tailored to the individual providing higher quality training (e.g. training software could evolve to adapt to the particular driving/working style of the trainee and focus on the weaker areas).

### 4 Developments in driverless car and autonomous vehicle technology

#### 4.1 Autonomous rail vehicles

In metro systems, automation refers to the process by which responsibility for operation management of the trains is transferred from the driver to the train control system. There are various degrees of automation. They are defined according to the basic functions of train operation are responsibility of staff, and which are the responsibility of the system itself. For example, zero grade of automation (GoA 0) would correspond to on-sight operation, like a tram running on street traffic, while GoA 4 would refer to a system in which vehicles are running in fully autonomously without any operating staff on board\(^\text{18}\) (Figure 6).

![Grades of metro systems automation](http://metroautomation.org/automation-essentials/)

According to UITP, the implementation of unmanned train operation systems allow operators to optimise the running time of trains, increasing the average speed of the system, shortening headways up to 75 seconds, and reducing dwell time in stations (in optimal conditions) to 15 seconds.
• **AnsaldoBreda Driverless Metro** – It is a class of driverless electric multiple units and corresponding signalling system manufactured by AnsaldoBreda in Italy. It is or will be used on the Copenhagen Metro, Princess Nora bint Abdul Rahman University, the Brescia Metro, the Thessaloniki Metro, Line 5 of the Milan Metro, Line C of the Rome Metro and the Yellow Line of the Taipei Rapid Transit System. The systems are fully automated, consisting of automatic train protection (ATP), automatic train operation (ATO) and automatic train supervision (ATS). The ATP is responsible for managing the trains' speed, ensuring that doors are closed before departure and insuring that switches are correctly set. The system uses fixed block signalling, except around stations, where moving block signalling is used. The ATO is the autopilot that drives the trains in line with a pre-defined schedule, ensures that the train stop at stations and operates the doors. The ATS monitors all components of the network, including the rails and all trains on the system, and displays a live schematic at the control centre. The system is designed so that only the ATP is safety-critical, and will halt trains if the other systems have faults.

![AnsaldoBreda Driverless Metro in Copenhagen](http://en.wikipedia.org/wiki/File:Danishmetrotrain.jpg)

Figure 7 – AnsaldoBreda Driverless Metro in Copenhagen

• **Véhicule Automatique Léger (VAL)** – VAL is an automatic rubber-tyred people mover technology, based on an invention by Professor Robert Gabillard from the Université Lille Nord de France. It was designed in the early 1980s by Matra and first used for the then new metro system in Lille. The VAL design uses platforms that are separated from the rollways by a glass partition, to prevent waiting passengers from straying or falling onto the rollways. Platform screen doors embedded in these partitions open in synchrony with the train doors when a train stops at the platform. Apart from Lille, the system is used in Paris, Toulouse, Rennes, Chicago, Taipei, Turin, and Uijeongbu.

• **Rio Tinto Iron Ore (RTIO)** – The UK’s global mining company Rio Tinto is developing a project called AutoHaul which aims at running an automated long-distance heavy-haul rail network in Western Australia. According to the company, the removal of driver changeover will result in flexible train schedules, helping in creating extra capacity in the rail network. The introduction of unattended train operation is also expected to improve the safety of RTIO’s rail operations. Rio confirmed that the autonomous rail system had its first proper trial just before Christmas 2014. Fitted with radar, sensory equipment and mapping technology, the autonomous machines can tell when an object is blocking their path and can respond to reduce the likelihood of impact. Up to 41 autonomous trains are expected to be installed in Rio’s Pilbara network by the second half of 2015, but the company is expected to maintain some human-operated trains as well.

• **Wuhan Metro** – It is the first driverless metro in China. The Line 1 of this metro system, located in the seventh largest Chinese city, is driverless and can serve 18,000 passengers per hour. There is an attendant on board at all times to assist passengers. The automatic train uses a Vehicle Control Center, which connects with the on-board redundant microprocessor based system to operate the trains. As timetables change from day to day, each morning the central control operator initiates the day’s timetable information in the system’s computer, which then allows the trains to operate independently.

• **Dubai Metro** – Red Line and Green Line are operated automatically by a fleet of 87 driverless trainsets being built in Japan. To permit fully automated operation, Thales Rail Signalling Solutions is supplying its SelTrac IS communications-based train control and NetTrac central control technology. This is configured for a minimum headway of 90 sec. Maximum speed of the trains is 90 km/h. Platform screen doors with corresponding flashing light signals are installed at every station for the safety of the passengers.

• **Docklands Light Railway (DLR), London** – DLR is an automated light metro system serving the redeveloped Docklands area of London. The system operates at Grade of Automation 3, meaning that trains are driverless but train attendant is present in the vehicle. The system uses minimal staffing on trains and at major interchange stations; the four below-ground stations are staffed to comply with underground station fire and safety requirements.

[Figure 9 – DLR train interior without a driver cab](http://www.railway-technology.com/projects/docklands/docklands7.html)

• **London Underground** – Driverless trains are expected to begin operations on London Underground network in the early 2020s. The automation is expected to allow more trains run on the underground lines at peak times. A member of staff will remain on each train. The trains will be introduced first on the Piccadilly line in 2022, raising its capacity by 60%.²⁴

For further information on the applications of autonomous vehicles and autonomous systems in transport, see the bibliography in Appendix D.

4.2 Special focus on driverless cars

4.2.1 Introduction to driverless car technology

Background: driving-assist technologies

A driverless car can be defined as a road vehicle without a driver which can still navigate roads and reach its destinations using its embedded computer instead of a human driver. Other terms used for this category of cars (or vehicles) are: autonomous cars; self-driving cars; robotic cars; and intelligent cars. The most absorbing feature of driverless cars is a range of important advantages that their operation will offer to society, most notably convenience of travel; safety of drivers, pedestrians and cyclists; improving the efficiency of using transport networks; and improving social inclusion.

Autonomous vehicle operation, in the generic context of all transportation vehicles, is an already mature technology. This is because advances in computer science, including artificial intelligence and machine learning techniques, have allowed robotic systems to be less reliant on human beings once a task is assigned to them. Some of the most significant examples of autonomous navigation operation include: some types of rockets and spacecraft; cruise missiles and torpedoes; submarines and UAVs; and driverless trains. Such vehicles are able to operate and navigate their routes with little or sometimes no guidance or intervention from human operators once a task is assigned to them.

However, driverless car operation on streets and highways is intrinsically a much more challenging phenomenon due to the large magnitude and complex nature of obstacles and interactions – many of which related to human behaviour - which need to be properly dealt with by a car to ensure safe and efficient operation. The most significant instances are: correctly responding to traffic lights, road signs and police instructions; correct reaction and adaptation to other traffic movements of cyclists and pedestrians, varying road layouts and environmental conditions, and various road obstacles such as potholes and road works barriers.

Despite the significant challenges involved, driverless car operation has been envisaged for at least the past half a century (e.g. see Figure 10 and Figure 11). Originally, many companies and research organisations have worked on developing a variety of ‘driver-assist’ automated systems in order to help drivers with their driving tasks in the interest of safety and efficiency. Many of these systems, however, are able to evolve to such a degree that they can form a sub-system of a fully autonomous car. The main examples include:

- **Automatic Braking Technology**, or **Autonomous Emergency Braking (AEB)** (e.g. in W Polo car)
- **Automatic Parallel Parking Technology** (e.g. the system developed for Ford Focus)
- **Lane Departure Warning System** (already installed on many types of trucks in Europe), and **Lane Departure Prevention System** (e.g. in some Nissan cars)
- **Cruise Automation**, or **Active Cruise Control**, technology which enables autonomous driving on highways without the need for a driver to monitor his environment (e.g. the systems currently under test for incorporation into some car models of Audi and Tesla).

**Driverless cars**

The major drive for the development of fully autonomous vehicles is the benefits envisaged, once the technology becomes sufficiently mature, in terms of convenience of travel, drivers’ and public safety, efficiency of transport networks use, social inclusion benefits, and the associated cost reductions (e.g. cost of hiring drivers, cost of accidents, etc.). Section 4.2.2 of this report discusses the most significant benefits expected as a result of driverless car operation. Other applications of driverless vehicles,
particularly in the defence industry, have also fostered research and development efforts (e.g. DARPA 2004 Grand Challenge in the United States).

It is fair to say that traditional car manufacturers over the years have been focusing mainly on developing technologies which can ease the burden on drivers, but without completely replacing drivers. This traditional focus has changed in the last few years. Several companies such as BMW, Audi, Ford and Google are known to be running demonstrations of their driverless technologies with the intention of producing fully driverless cars in the near future. The latest Google Car prototype has attracted significant public attention since it has been designed for autonomous operation from the outset, and apparently excludes an option for a reserved human driver.

In the EU, the first autonomous bus was tested as part of the European CityMobil2 project which aims to demonstrate the feasibility of using automated road transport systems in Europe. This project also aims to develop guidelines to design and implement autonomous driving systems, and to assist with proposing a legal framework for certifying such systems.

Several instances of driverless cars are already operating in controlled environments and for specific purposes. Two examples are:

- **Navia car** (Figure 11) which is an all-electric self-driving shuttle car designed to shuttle passengers around a closed campus; its low 12mph top speed lets it make a full stop for unexpected obstacles.
- **Driverless vehicles at the Heathrow Airport** (Figure 12) which provide transit to the passengers from Heathrow Terminal 5 to the Terminal 5 business car park

The above instances of autonomous vehicles and other existing instances are generally very expensive (compared to man-operated cars), and are only operable in very controlled environments which are associated with much fewer obstacles and layout complexities compared to ordinary road traffic environments. Their operating speeds have been often restricted significantly due to safety considerations.

![Figure 10 – Driverless cars have been envisaged at least since 1950s](image1.jpg)

![Figure 11 – The Navia may be the first commercially available self-driving car](image2.jpg)
Autonomous operation components of driverless cars

In order to be able to operate autonomously, driverless cars need the following three key components:

- A full system of sensors to allow the car to identify various features and obstacles of the environment in which it is operating.
- Sophisticated software to process and interpret the information obtained by its sensors in real time, and subsequently control various driving actions of the car, such as cruise speed, acceleration or deceleration, turning and braking.
- A communication system to allow the car to communicate with other cars on the road, as well as road infrastructures such as junctions and traffic signals.

Sensors

Almost all driverless cars which are being tested for operation in ordinary traffic conditions use more and less the same types of sensors. For instance Google’s driverless car comes equipped with eight different types of sensors; the most significant ones being the following:

![Google’s Self-Driving Vehicle](image)

**Laser**
This sensor gives the vehicle a 360-degree understanding of its environment so the car can sense objects in front of, beside, and behind itself at the same time, all the time. The laser also helps the vehicle to determine its location in the world.

**Processor**
Information from the sensors is cross-checked and processed by the software so that different objects around the vehicle can be sensed and differentiated accurately, and safe driving decisions can then be made based on all the information received.

**Position sensor**
This sensor, located in the wheel hub, detects the rotations made by the wheels of the car to help the vehicle understand its position in the world.

**Orientation sensor**
Similar to the way a person’s inner ear gives them a sense of motion and balance, this sensor, located in the interior of the car, works to give the car a clear sense of orientation.

**Radar**
This sensor detects vehicles far ahead and measures their speed so that the car can safely slow down or speed up with other vehicles on the road.

Drivers also test the vehicles daily, reporting feedback on how to make the ride more safe and comfortable.
Figure 14 – Sensors of a 'Lutz Pathfinder Pod' which is currently tested in the UK

- **LIDAR (Light Detection and Ranging)**\(^\text{25}\) – LIDAR is a remote sensing technology that measures distance by illuminating a target with a laser and by analysing the reflected light. It is the single best way of getting integral information about the car’s environment, and it is currently the most expensive sensor installed on most driverless cars. For Google Cars, this is the roof-top rotating sensor which uses an array of 32 or 64 lasers to measure the distance to objects to build up a 3D map at a range of at least 200m (depending on the version of Google Car), letting the car to see hazards. The latest Google Car uses a 64-beam laser which can also rotate 360 degrees and take up to 1.3 million readings per second, making it the most versatile sensor on the car. Mounting it on top of the car ensures its view is not obstructed.\(^\text{26}\)

LIDAR has nonetheless some deficiencies. For instance, it cannot discern colours and therefore needs additional imaging sensors (cameras) to produce fully-coloured 3D data, useful for object and feature recognition. It is speculated that the imaging sensors and associated image processing algorithms of driverless cars may advance to such a degree in the future that driverless cars will no longer require LIDAR sensors.

- **Cameras** – traditional cameras are also present in a driverless car. Google Car uses a standard camera that points through the windscreen. It looks for nearby hazards such as pedestrians, cyclists and other motorists, and reads road signs and detects traffic lights. Although digital imaging technology is quite mature, the image processing technology which allows still and video images to be interpreted by computer software is an area currently being subject to extensive research and development work.

- **Radars and sonars** – like LIDAR, radars can help a driverless car to detect various traffic and road features around it. Radars are however less precise than LIDARs. Nevertheless they have generally some advantages such as a longer range, a cheaper price (depending on the type of

\(^{25}\) More correctly, the term LIDAR has been created as a portmanteau of "light" and "radar. Informally, it may sometimes be referred to as a Laser Radar.

radar), and also the ability to cover the potential blind spots of a top-mounted LIDAR, e.g. in the immediate proximity of the car.

Autonomous vehicles also employ *millimetre-wave radars* which emit extremely high frequency (short) wavelengths, thus being ideal for detecting objects (cars, pedestrians, and large animals) in a vehicle’s immediate vicinity. In the case of Google Car, the bumper-mounted radar, which is already used in intelligent cruise control system, keeps track of other vehicles in front of and behind the car.

Similarly, the SONAR technique uses sound propagation to navigate, communicate with, or detect objects. The radar system is paired with sonar in some of Google’s test cars.

- **Other sensors** – several other sensors, including the following, are incorporated into Google Car and most likely the other similar driverless cars which are under development and trial tests:
  - External rear-mounted aerials can receive geo-location information from GPS satellites, while an **ultrasonic sensor** on one of the rear wheels can monitor the car’s movements.
  - Internal **altimeters, gyroscopes** and a **tachometer** (a rev-counter) can give fine measurements on the car’s position.

- **Current research activities on sensor technology for driverless cars** – many companies and organisations are engaged in research and development activities on sensor technologies with two distinct objectives:
  - To develop sensors being more suitable for driverless operation (e.g. more precise GNSS\(^{28}\) technology to complement GPS navigation; or better imaging sensors to cope with low-light conditions)
  - To reduce the costs of sensors used for driverless cars (e.g. developing cheaper LIDARs for driverless cars)

  These efforts are expected to improve the performance and reliability of driverless cars and reduce their price, which are all important factors for the market share of driverless cars in the future.

**Driverless car software**

In fact, the heart of driverless car technology is its *software*. The driverless cars’ software uses data from all of their sensors to keep the car safe and get it from A to B. For Google Car, it is estimated that the car computer system receives around 1 gigabytes data per second, which will need to be almost instantly processed to enable continuous operation of the car\(^{29}\). In fact, the raw data obtained from a single sensor source is unable to make a self-driving car work. GPS data, for example, is not accurate enough to keep the car on the road, let alone the correct lane. The data obtained from all sensors must be integrated and processed by the driverless car software at the same time in order to produce meaningful and accurate measurements about the environment (including the nearby traffic and obstacles) in which the car is operating.

In order to obey the highway code and detect various types of hazards, the car software must be able to recognise objects, cars, road marking, signs and traffic lights, pedestrians and cyclists. It must even be able to detect road works and safely navigate around them. It must also incorporate some behavioural rules. For example, the self-driving Google Car can successfully identify a bike and

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\(^{27}\) Apart from Google Car, no indication exists about using SONAR by the driverless cars which are experimented or manufactured by other companies.

\(^{28}\) Global navigation satellite system

understand that if the cyclist extends an arm, the person intends to make a manoeuvre. The driverless car then knows it has to slow down and give the bike enough space to operate safely.

A significant number of advanced mathematical models and computer algorithms have been incorporated into the car operating software to enable various necessary tasks such as lane detection (using an Adaptive Random Hough Transform), and lane tracking and road recognition (using an imaging model embedding the Basic Mean Shift Algorithm). A few books are available which deal with explaining the various elements of driverless software and the models and algorithms embedded in them. Pattern recognition, signal processing, and artificial inference are the main classes of algorithms which are embedded in driverless car software in order to convert the data obtained from the sensors into meaningful measurements, and then use these measurements to perform various driving tasks such as the level of speed and acceleration, and whether or not to change lanes or apply the brakes.

Driverless car software development is considerably more challenging than other similar types of software such as the ones used for operating drones. This is due to a lot of human interaction issues involved in the autonomous operation of a car, particularly in urban environments: related for instance to how to deal with cyclists and various groups of people (e.g. children, the elderly and the disabled) which may behave differently when interacting with the traffic.

Driverless car technology is about teaching a machine to perceive its environment and react accordingly following a set of rules. Perception is hence the core problem which determines the success of a self-driving car. However perception is a multi-faceted problem. It has to do with sensors, with prior knowledge, machine learning, and is sensitive to action and context. Unfortunately, perception is not limited to the context of driving. Self-driving cars need to understand the behaviour of people and things that may become relevant to the driving context (even if their behaviour has nothing to do with driving a car, e.g. kicking a ball).

Improving the software of driverless cars will almost certainly be an ongoing exercise for many years. Due to advances in artificial intelligence, machine learning, and machine perception technologies, driverless cars in the future are likely to be programmed in such a way they can themselves learn to improve their performance as they gain experience in autonomous operation.

The development and operation of driverless cars have given rise or speeded up research and development activities on a wide range of associated areas too. This, for instance, includes devising appropriate systems for testing and validating driverless cars in simulated environments, communication systems for networking cars, and the reliability assessment of sensors.

**Car-to-x communication**

Car-to-x technology is about getting cars and the other components of a traffic network (e.g. road infrastructure, traffic signs, work zones, etc.) to communicate with each other as and when needed, with the aim of increasing safety and improving road travel experience. Using this technology, interactive traffic signs and traffic lights equipped with sensors will also talk to each other and swap information with cars in the area. For instance, intelligent traffic lights can tell a car well in advance what speed will get him through the next green traffic light. Or if a driver is waiting at a red light, the car can tell him how long the wait will be. It could even scout out a free parking place for a car user.31

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Similarly cars can communicate with each other autonomously to warn each other of accidents, and congested spots of the road.

Car-to-x technology is an ideal match for autonomous cars since computer drivers are better than humans in processing large amount of data, without getting distracted from their other tasks, and react in time in response to the information they receive. In fact, it is indicated that the first generations of driverless cars will have to rely on car-to-x technology to navigate some more complex features of their routes such as signalised junctions and level-crossings.

![Figure 15 – A car-to-x screenshot warning of an accident ahead](http://www.daimler.com/dccom/0-5-1456855-1-1456863-1-0-0-1457041-0-0-8-0-0-0-0-0-0-0-0.html)

To develop car-to-x and x-to-car communication technology, several companies such as Daimler (Mercedes Benz-maker), BMW, and Volkswagen are working on a communication system allowing numerous different applications via direct communication between vehicles or between vehicles and a permanently installed infrastructure. The expected results of rolling out car-to-x technology are improved safety, improved navigation, and increased driving efficiency.

**Current limitations and expected future developments**

It is difficult to determine the precise limitations of driverless cars at this moment in time since many prospective driverless car manufacturers have not issued official information about the capabilities of their cars yet. However several sources 32, 33, 34 have provided some relevant (but not verifiable) information:

- Driverless cars struggle in unfamiliar territory when they lack good maps. This is because autonomous cars will require maps that differ in several important ways from the maps we use

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32 [http://www.daimler.com/dccom/0-5-1456855-1-1456863-1-0-0-1457041-0-0-8-0-0-0-0-0-0-0-0-0.html](http://www.daimler.com/dccom/0-5-1456855-1-1456863-1-0-0-1457041-0-0-8-0-0-0-0-0-0-0-0-0.html)
34 [http://www.volkswagenag.com/content/vwcorp/content/en/innovation/communication_and_networking/connected_world/car_to_x.html](http://www.volkswagenag.com/content/vwcorp/content/en/innovation/communication_and_networking/connected_world/car_to_x.html)
today for turn-by-turn directions. The maps need to be high-definition that can tell them where the curb is within a few centimetres.

- Limitations due to the performance of their sensors (e.g. they can make errors when sun blinds their cameras; they are occasionally caught out by the unexpected appearance of new traffic signals; and are not able to dodge potholes and other hazards).
- Difficulty with parking, or navigating through car parks
- Difficulty with operating in adverse weather conditions such as snow and heavy rain

Some of the limitations mentioned above, such as the need for very high definition maps, and sensors to cope with different environmental conditions appear to have been largely resolved already in the majority of the latest prototypes of driverless cars (e.g. Google Car). Other limitations such as the difficulty to navigate through car parks appear to be the subject of research and development activities at the moment.

4.2.2 Benefits of driverless car technology

Improving safety, and efficiency of using traffic networks

Although driverless cars are not yet in operation and therefore no statistics are available to demonstrate their benefits for public safety and improving network use efficiency, there are compelling reasons to consider that they will be overall beneficial:

An astonishing 1.24m people die and as many as 50m are hurt in road accidents each year, 90% of these accidents involving human errors. If automated driving does take off, it’s quite likely that accident rates will dip sharply. This is because computers are so much better at abiding by rules and adhering to safety instructions than humans, and are able to make quick safety critical reactions when needed. For instance AEB technology, which automatically applies the brakes if the driver does not respond in time, has been proven to lower the rate of low speed collisions that result in personal injury claims by around 20%.

It is estimated that drivers and passengers spend around 90 billion hours in traffic jams each year. In some car-choked cities, as much as a third of the petrol used is burned by people looking for a space to park. These problems can be relieved by driverless car operation, bearing in mind that these cars will most likely become ‘connected’ in the near future. This means that driverless cars will be able to communicate in real time with other vehicles and with roadside infrastructure, with the aim to reduce congestion, accidents, and improve on fuel management. It is likely that all cars in an area can be monitored by a central traffic control system which issues due instructions (e.g. diverting them from congested parts of the networks or accident areas) to the cars in a network in order to reduce congestion and accident hazards.

Improving travel comfort, mobility and social inclusion

Driverless cars can make car travel much more convenient by eliminating the burden of driving and its associated effects (stress, tiredness, etc.), and can provide a truly on-demand transport option to many people who are not capable of driving, or are not willing to drive. In this respect, there is a wide range of speculative impacts which driverless cars can have on the everyday life of people, including more freedom of travel particularly for the elderly, children and disabled people, as well as encouraging more cycling and walking by making the road environment safer for them. Many change scenarios have been envisaged: for instance how driverless car will allow much longer commuting distances to

employees, or how better medical care for the elderly will be brought by improving their accessibility to hospitals and care centres. Obviously the extent of these benefits can’t be yet identified.

**Contribution to machine learning and perception technologies**

Because perception is a general capability, it is applicable to many other fields beyond autonomous driving and consequently can generate returns in those fields too. This is an advantage for giant computer software developers such as Google because their research and development activities on driverless cars allow *cross-fertilisation* with their other business areas. As Google has recently bought several leading robotics companies, advances in perception by their self-driving car group could also benefit these business areas and vice versa. Google has also started a mobile phone project (Tango) which aims to use a high end Android mobile phone to create 3D maps of the environment in real time. Advances in this area may also be useful for its self-driving car project.

Driverless car applications have provided a lot of incentives and investment for improving some types of sensors and the algorithms which are used to process the data obtained by these sensors. A few examples include: building cheaper (but with similar functional level) LIDAR sensors, imaging sensors and radars with the ability to function in various climate and environmental conditions, and image processing and recognition techniques. Other industries are expected to benefit from this investment and research and development works due to the fact that many types of these sensors and their associated data processing algorithms can be used in other industries (e.g. driverless vehicles for construction, mining, etc.)

**4.2.3 Concerns over driverless car technology**

**Software reliability**

Software reliability is the main concern with driverless car technology, and is associated with situations in which the presence or intervention of a human driver is deemed necessary during a journey. This is because, similar to other industries like aerospace and healthcare, software errors can result in system malfunction and accidents. However, compelling counter-arguments have been offered by prospective driverless car manufacturers on the following grounds:

- Driverless car manufacturers claim that they have incorporated a lot of proven reliability engineering techniques into the hardware and software of driverless cars (e.g. fault tolerance and redundancy techniques) which minimise the probability of occurring faults, and the consequential safety implications when faults do occur.
- Human driver’s error is the cause of the majority of accidents leading to injuries or fatalities. Driverless car operation can therefore eliminate or substantially reduce these accidents as cars can be programmed to act more safety than humans in many circumstances which are not always handled appropriately by human drivers.

Like many author autonomous systems, the facility for intervention of a passenger (acting as a reserved driver) to override the decision of the driverless car software and to take control of the car is regarded essential, and will therefore remain mandatory by law in most countries.

Much of the current research and development work on driverless car technology focuses on the ‘system safety’ aspects of these cars, so that the hardware and software components are designed and configured to minimise the occurrence of faults, and to add a high degree of fault tolerance to the system. The latter means that when faults do occur, the system will act in the safest way.
Similar to the privacy concerns associated with other digital platforms (smart phones, computers, etc.), some have speculated on the ways the privacy of driverless car users could be violated, and the potential consequences. Several examples include:

- Almost the entire driving records of car users can become available to third parties, hence prone to be used for illegitimate purposes
- Insurance companies can use driving data stored in a driverless car to find reasons for invalidating car users’ insurance contracts
- Some Governments could limit the areas where car users can travel to, and prosecute offenders

Such privacy issues belong largely to the broader subject of privacy violation as a result of using various digital systems, and are being debated and tackled at various levels in modern societies. Human factors and legislative arrangements, together with technological tools, can help to alleviate many of these concerns.

**Vulnerability to cyber-attacks**

Driverless cars are robotic machines which are operated by computers, and therefore can be prone to cybercrimes like other systems operating by digital minds. When driverless cars are networked together, the opportunities for cyber attackers increase even further, with potential catastrophic consequences such as driverless cars being used for criminal or terrorist activities. Currently, there is not sufficient information to be able to assess such threats thoroughly, particularly because driverless cars are not yet operational on streets. However like most other critical systems and infrastructure which are operated reasonably safely by computers in our everyday lives, one can argue that a high degree of cyber-security can be achieved for driverless car computers, through appropriate technological and human factor measures, in order to keep the risk of cybercrimes minimal.

**Adverse impact on travel patterns**

The impact of driverless cars on people’s travel patterns is one of the most controversial and uncertain subjects which are now being speculated. Concerns have already been expressed about a potential increase in using cars, due to driverless cars making it so easy to take road journeys for many groups of people, therefore increasing greenhouse gas emissions and other types of pollution. Various pricing policies and regulatory tools (e.g. road pricing, taxes, setting dedicated road lanes, etc.) can be used in the future to adapt public’s behaviour towards more efficient and wiser use of driverless cars.

4.2.4 **The market for driverless cars**

**Arrival time**

In several countries, driverless car operation is currently being experimented as part of some research projects. For example in the UK, a TRL-led consortium is experimenting driverless car technology as part of the GATEway (Greenwich Automated Transport Environment) project in order to evaluate the feasibility and benefits of this technology for urban environments.

There is plenty of speculations about when autonomous cars will be available in the market to private buyers. The following are some examples:

- According to different analysts, fully autonomous cars will be ready to hit the road as soon as 2017, or perhaps sometime in the 2020s. The timing may be uncertain, but cars are already becoming more autonomous, creeping across a spectrum from current models with adaptive cruise control and assisted parallel parking to future vehicles.
- Google has stated that the cars should be road-ready by early 2016, but considers that testing would take more than two years. At that point, the technology should be ready for the next stage,
i.e. greater pilot testing. Google has announced plans to have 100 of its driverless cars on roads in 2015 for tests.

- Current expectations are that these self-driving cars are at least five years away from being mature enough to create a real, non-prototype product, but it may be far longer until buyers can purchase or hire one for personal use.
- Nissan has announced its intent to offer driverless cars by 2020.
- By mid-2020s, some manifestation of driverless vehicles will be on UK roads.

Although opinions are largely divided about the timescale for the availability and the adoption of driverless cars by the members of the public, it is reasonable to believe it can take at least a couple of decades until driverless cars materialise in a way that they really transform our society.

Pricing of driverless cars

Compared to man-driven vehicles, the price of driverless cars increases with the cost of the sensors used in them, and the cost of their computer software and hardware. There is no clear indication about the cost of software embedded in driverless cars when they reach market, as almost all driverless cars are still at developing and testing stages and their sales level in the future remains uncertain. As sales volumes grow, it is expected that the price of driverless car software will steadily decrease. It is not hard to imagine that at some point in the future, driverless car manufacturers will be able to access free open-source ‘Operating System’- like software designed for driverless operation on roads, and then adapt the software for their own specific products. This approach will result in significant cost reduction on the development and use of necessary software for driverless cars.

The prices of the hardware and most sensors used in driverless cars (e.g. cameras, GPS receivers, etc.) appear to be rather insignificant relative to the overall price of the car, because these sensors are already available at relatively cheap prices. However a significant exemption at the present is the price of the LIDAR sensor which is currently used by almost all driverless cars. The 64-laser unit used in Google’s prototypes is made by Velodyne LIDAR Inc. costs between $75,000 and $85,000. The LIDAR manufacturer's director of sales and marketing has said that this cost reflects the large amount of manual labour involved in assembling the units, and the limited production numbers. Nonetheless the director of the latest Google’s self-driving car project has said that LIDAR prices will drop as volumes rise; this will take some time as new factories will need to be built once the demand volumes accelerate.

One strategy for reducing the cost of LIDAR is to use fewer lasers. Velodyne has a 32-laser unit that costs between $30,000 and $40,000, and plans a 16-laser later that will sell for about $10,000 or less. Using fewer lasers will drive down cost even further. European auto-parts maker Valeo and Audi have announced that LIDARs with as few as four lasers would be sufficient for safe driving at highway speeds. Since 2010, Valeo has been working with LIDAR maker Ibeo Inc. to mass-produce automotive LIDARs for Audi and others for less than $1,000.

Another LIDAR manufacturer, namely ASCar Inc. based in California, is working to develop a “flash LIDAR” with no moving parts. These LIDARs emit a single laser flash and collect the returning data with an image sensor, similar to those used in digital cameras. ASCar plans to supply preproduction samples to car manufacturers and parts makers in 2015 at about $10,000 apiece; but according to the Company’s vice president of business development, the price will go down to $500 or less by the time it is embedded in cars.

Adoption and Market Share

For large parts of society shifting to driverless car operation, this will not be merely a matter of using a more advanced technology, but will involve a significant cultural and behavioural shift. As a result this
is likely to prove a challenging process in terms of persuading more groups of society to use driverless car operation. Other challenges have been raised, such as the loss of cheap work force (car drivers), and the risk of the technology to many non-skilled workers who are currently working as car drivers.

Despite the issues mentioned above and due to the significant benefits envisaged for driverless car operation once the technology becomes sufficiently mature, many experts believe that driverless cars will be received quite well. For instance IEEE projects that up to 75 percent of vehicles in the U.S. will be fully automated by 2040.

It is quite likely that the adoption of driverless cars will be accelerated by the coming boom in electric (and hybrid) vehicles. Driverless cars are related, but of course independent of the propulsion technology used in the vehicle. However, it seems that electric vehicles are a natural fit for automated driving features because people who purchase electric vehicles are likely to be inherently more drawn to new technology, and it should be an easier sell to convince people to give the automated driving option a whirl.

4.2.5 Legislation

One of the biggest hold-ups to the progression of the driverless car technology onto open road may be legislation. The widespread application of driverless cars will entail many laws to be changed. Transportation regulations have been so far based on the concept of vehicles driven by humans, and current traffic laws contain elements that inhibit progress for this new technology. Autonomous vehicles change the concept of what a car is and the laws need to be updated accordingly. Overall, it is commented that laws and regulations should be technologically neutral in principle as much as possible to avoid favouring specific technical approaches.

Across the globe, the US were the first country to introduce legislation to permit the testing of automated vehicles. Four US states have done so, including California, but 15 have rejected bills related to automated driving. In California, a law was passed in 2013 that made the testing and operation of self-driving vehicles on roads possible, as long as they had manual override controls. The Department of Motor Vehicles in California is expected to issue regulations on the operation of self-driving cars soon, after which self-driving cars may become more common place. In Europe, only Germany and Sweden have reviewed their legislation in this area.

In the UK, the Government has announced it wants to become a world leader in driverless technology. The Government plans to publish a code of practice in the spring which will allow the testing of autonomous cars to go ahead. The government has promised a full review of current legislation by the summer of 2017. That review will involve a rewrite of the Highway Code and adjustments to MOT test guidelines, potentially taking into account whether a higher standard of driving should be demanded of automated vehicles. It will also look at who would be responsible in the event of a collision and how to ensure the safety of drivers and pedestrians.

As regulators grapple with autonomous technology, conflicts between country-specific laws could impede the adoption of this technology too. The United Nations has a forum (“WP29”) which aims to avoid such problems by harmonizing vehicle regulations. Many aspects of technical regulations for wheeled vehicles are discussed in a broad range of (informal) working groups. Because of the rapid progress of autonomous technology, the informal working group on Intelligent Transport Systems has recently been renamed and refocused as informal working group on ITS/Automated Driving.

There is still much to work out with regards the legislative aspects of driverless cars, primarily revolving around the question of what a passenger in a self-driving car can and can’t do; will the passenger be able to take control at any moment, overriding the system? As well as questions around what happens
in times of accidents, who is at fault and who has to pay for compensation. These questions are very much concerned with the insurance requirements for driverless cars, and the issue of ‘transfer of risks’, which are discussed in the next section of this report.

4.2.6 Insurance and transfer of risk

As and when driverless vehicles become commonplace, there is likely to be a shift from personal to product liability. In case of accidents, the situation at present is clear: liability rests with the driver. But with less reliance on a driver’s control input and more on sophisticated car technology and the computers operating them, what happens when the car’s computer systems fail? And in the event of an accident, does liability rest with the driver or the hardware and software found in the car itself?

The situation becomes even more complex when cars not only become driverless but when they become ‘connected’ and the driver is not expected to oversee or monitor the vehicle, relying instead on the car to make its own decisions such as planning a route using its internet enabled on-board computer that is also connected to other vehicles.

In such instance, it is likely that liability will follow ‘transfer of risk’, rendering a shift to product liability so that the vehicle manufacturer (including hardware manufacturer and software developer), become liable for an accident. It is imagined that in line with the development of increased automation within aviation, the driver (or more correctly the person in charge of a driverless car) will continue to be held liable in the event of a crash if they are able to step in and intervene, overriding the technology by making control inputs themselves. As with pilots, effective system monitoring for drivers will become a skill and a key safety factor in the prevention of accidents, requiring modifications to the way people learn to drive.

Another subject of interest for insurers is rewarding customers who use driver-assist technologies that will make vehicles safer for customers, and accordingly reduce the insurance claims submitted to the insurers. For instance the AEB technology - which automatically applies the brakes if the driver does not respond in time – has proven to lower the rate of collisions that result in personal injury claims by around 20%. While the principal concern associated with this technology is road safety, it will reduce the frequency of claims submitted to the insurance companies. Therefore insurance companies have incorporated it as a component into their group rating process to deduce insurance premium rates. Put simply, if vehicles are fitted with autonomous braking systems, they enter a lower group rating, which can significantly lower the cost for customers to insure them.

4.2.7 Potential impacts of driverless car technology on the rail industry

A recent Network Rail memo document on driverless cars has listed a range of speculative risks and opportunities to/for the rail industry as a result of driverless cars being rolled out in the future. None of these items however can be evaluated in a robust way at the present time, due to the lack of sufficient information about key influential factors such as reliability of the technology used in driverless cars, future legislation on using driverless cars, or how well driverless cars will be accepted in society.

Among the risks and opportunities identified, there are a few industry-specific potential issues, such as the interaction of driverless cars with level crossings, which are of immediate interest to the industry. It will be important to ensure that driverless cars can identify level crossing signal phases correctly, and react appropriately with no less probability than what would be expected from a human driver. This is likely to be addressed through the car-to-x communication system embedded in driverless cars which creates an extra layer of safety by alerting a driverless car about the status of the signal at the level crossing it is approaching to.
Another potential issue is associated with parking driverless cars at station car parks, which is part of the wider issue of driverless cars’ ability to navigate car parks and park themselves properly. This is the subject of research and development activities by driverless car manufacturers at the present.

The impact of driverless cars on the level of rail patronage in the future is a hot topic. Some may argue that more travellers may change from rail to driverless cars for their journeys due to the additional comfort resulting from eliminating drivers’ tasks. However, driverless cars may increase rail use by providing additional comfort/possibilities for potential rail passengers, for instance by making it cheaper and more convenient to reach railway stations. Obviously, these counter arguments cannot be evaluated until driverless cars become available in the market in future years.

4.3 Autonomous road vehicles

- **Development of autonomous military truck convoys** – US army have been carrying out tests where they ran an unmanned convoy of seven different tactical vehicles at over 40 mph (64 km/h). The test was part of the US Army Tank Automotive Research Development and Engineering Centre’s (TARDEC) 30-Year Ground Vehicle Strategy, which sees man-optional lorries as commonplace, with many vehicles completely driverless, believing that the technology for autonomous vehicles may be ready for the field by 2025.

The current program revolves around two kits designed for flexibility: the first is an “autonomy kit” based on Light Detection and Ranging (LIDAR) and other sensors (similar to those use in Google’s self-driving cars). The kit’s function is to map out the road ahead and keep the vehicle on the right course without hitting anything. The other kit is “by-wire drive,” which deals with the actual driving by controlling the throttle, brakes, and steering.

In order to move from a single convoy of autonomous vehicles to one of robotic squadrons, TARDEC has instituted its Applied Robotics for Installations and Base Operation (ARIBO), which aims at finding immediate applications for robotic technologies. The program will utilise existing Army installations as testing grounds where autonomous vehicles will be used for transport from distant parking areas and for transporting wounded soldiers. Eventually, they are expected to transport food and ammunition.

![Figure 16 - A convoy of autonomous military trucks](http://www.gizmag.com/us-army-autonomous-vehicles/32796/)
4.4 Driver assistance and cooperative systems

- **Jaguar Land Rover’s Smart Assistant** – researchers at Jaguar Land Rover (JLR) have developed “Smart Assistant” technology designed to cut down on cognitive distractions that increase accident risks by automating some of the non-driving tasks. The Smart Assistant may help reduce driver distraction by learning driver’s behaviours and automating tasks such as mirror adjustment, seat and steering wheel settings, route planning, temperature control, and integrating driver’s acceleration style and following distances into the Auto Adaptive Cruise Control.

![Figure 17 - Jaguar Land Rover Smart Assistant](http://www.gizmag.com/jaguar-self-learning-smart-car/32901/)

The system identifies the driver based on his smartphone or a similar device – as the driver walks up to the car, it adjusts the vehicle settings accordingly. JLR have plans to integrate the Smart Assistant system with the cloud, extending its use beyond the daily commute (e.g. allowing to apply personal Smart Assistant preferences to borrowed or rented vehicles).

Currently, JLR’s Smart Assistant is still in development and no specific release date has been announced.

5 Drones and robots for the railway industry: recent developments

5.1 Surveillance and security applications

- **Drones for graffiti deterrence in Germany** – Deutsche Bahn (DB), Europe’s largest railway and rail infrastructure operator began using miniature helicopter drones in an effort to combat graffiti-spraying gangs. Removing graffiti costs DB €7.6 million a year, and it is hoped that drones will help lower this annual cost. DB reported 14,000 incidents of graffiti in 2013 along its tracks, bridges and railway stations.

  The drones used are mid-range off-the-shelf helicopters. The metre-wide drones, each costing around €60,000 can fly for up to 80 minutes at a speed of 33 mph (53 km/h), and can operate autonomously or be remotely controlled by a human operator. The drones’ motors emit little noise, making them ideal for surveillance. The idea is to use airborne infrared cameras to collect evidence, which could then be used to prosecute vandals who deface property at night.

• **Riot surveillance drones for Jerusalem’s light rail** – drones are being deployed on Jerusalem’s light rail network to act as extra surveillance following riots which saw stations and tracks of the line destroyed. “With UAVs, you get great high-resolution images taken from a birds-eye perspective, giving you the flexibility to zero in on any potential trouble spots in a way that ground level cameras cannot accomplish.” The UAVs can record video and images with high resolution from a bird’s eye perspective, with the possibility to zoom in on any trouble spot in a way that cannot be accomplished by ground cameras. These images can then be analysed by the police (see Bladeworx picture below).

![Figure 18 – Deutsche Bahn drones for graffiti deterrence](http://www.railway-technology.com/uploads/newsarticle/1046023/images/207048/large/microdrones-l.jpg)

• **Use of UAVs to prevent elephant’s trespassing on the railways in India** – the Indian railways and environment ministries have decided to consider deploying unmanned aerial vehicles (UAVs) to prevent elephants from colliding with high speed trains on the tracks. According to railway statistics, 65 elephants have been hit and killed by trains since 2010, mainly in the Northeast Frontier Railway region which covers parts of Bihar, Assam and West Bengal.

   It has been considered that UAVs could be used to track elephant movements near rail tracks and warn train drivers in the vicinity to slow down.

   ![Figure 19 – Bladeworx drone for security surveillance of the railway in Jerusalem](http://cdn2.hubspot.net/hub/330950/file-1548489176-jpg/blog-attachments/Bladeworx.jpg)

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Indian Institutes of Technology (IIT)-Kanpur Director Prof Indranil Manna said the institute would work closely with the concerned ministries to develop a UAV that specifically tracks elephants. “This UAV has to be equipped with night visibility systems through infrared sensor imaging or so. Also, this UAV has to basically keep under surveillance elephant movement in certain pockets of deep forest around railway tracks as herd movements in open areas are usually relayed by local sources,” he said.

- **Drones for railway line and intersection aerial mapping in Australia** – DroneMetrex has announced the successful completion of a high-precision railway mapping project in Australia. The company’s *TopoDrone-100* flew over a crossing intersection of a railway and a bitumen road, mapping 0.5km on each of the four sides of the approach. The UAV’s image captures were particularly reliable and accurate as TopoDrone-100 is a photogrammetric mapping system, which addresses geometric errors (tip, tilt, yaw, forward and lateral motion, blur) from the start and eliminates them right at the point of capturing the data.

The mapping project was aimed, in the first instance, at creating 3D “real world” for obscurity analysis when approaching an intersection from a train driver’s perspective, and from a vehicle driver’s perspective. Secondly, high accurate mapping was performed for future civil works involving repair as well as upgrading of the existing railway.

The use of drones for aerial mapping is cost-efficient and easier from an operational point of view: usually aerial photography requires Lidar and corridor mapping from large manned aircrafts, which can be very expensive, and conventional ground surveying techniques (which are usually the alternative solution), imply the temporarily closure of the railway in order to observe health and safety standards.

![Figure 20 – Digital orthophoto mosaic of the railway with Topodrone-100](http://geospatialpr.com/2013/08/15/dronemetrex-maps-a-railway-with unsurpassed-accuracy-from-its-topodrone-100/)

### 5.2 Maintenance and inspection applications

- **Drones for infrastructure checks and monitoring** – checking for cracks, rust, and other wear and tear on bridges and other infrastructure can be a hard and dangerous task for civil engineers. A system that combines vibration sensors and quadcopter drones has been designed at Tufts University to keep an eye on bridges in real time and alert engineers.
Conventional sensors’ batteries are usually dedicated to sensing tasks, and cannot be allocated to permanent or frequent wireless communication of their data. The solution proposed by Tuft University is to use drones to download measurement data from the bridge sensors, which would be stored locally on RFID tags. A small group of drones could operate under the bridge, flying close enough to the sensors to download the data and then returning to a nearby charging station or mobile base and sharing the data with a server. Drones could also be programmed to take pictures for redundancy to validate findings (e.g. to check whether there is rust on a nearby beam, etc.).

However, working beneath a bridge could present problems for drones as they would not be able to maintain GPS connection. Rather than relying on GPS, the proposed robots could navigate by QR codes placed next to sensors, which would function like markers on a map, informing the drone about its location and directing to the next marker. Since factors like strong winds and limited visibility could complicate navigation beneath bridges, it has been also suggested to distribute navigation tasks across a network of drones. Working together, multiple robots would be able to compare positions and cross-check each other’s flight paths to ensure they remain accurate.

Figure 21 – A network of drones for bridge inspection

- **Drones with infra-red sensors for switch-point checks in the Netherlands** – Dutch railway company ProRail uses drones equipped with infrared sensors to check the switch point heating systems on its tracks. Using the drone’s images, the company can see whether the switch point heating systems are operating correctly. Checking the switch points manually is labour-intensive and also dangerous for employees.

- **Drones for pre-inspections in the USA** – Union Pacific is looking at drones to improve the efficiency of maintenance on the network. It is considering using drones for primary inspection and then sending humans to do another final inspection if something is found by the drones. However, Union Pacific is at the early stages of its thinking on the subject.

- **Drones for maintenance checks at height** – EasyJet has announced it will be the first airline to use drones to help do routine checks on its fleet. Unmanned drones will be used for maintenance checks on 220 Airbus A319 and A320 aircrafts, cutting down the inspection time. Also, using drones to work at height is safer than having people go up on a rig. The flying inspection robots are being developed by Bristol Robotics Laboratory, a collaboration between University of Bristol and...
and the University of West England. The drones are fitted with high definition video cameras, and can also use lasers to scan the outside of the aircraft. One of the main challenges, however, is to get them to work outside in windy conditions.

![Drones](image1.png)

**Figure 22 – EasyJet drone checking an aircraft**

- **Network Rail’s monitoring drones for civil engineering reconstruction work in the UK** – unmanned aerial vehicles can also be used as a means of quick and easy inspection of large areas. Network Rail has used such drones after the 2013 winter storms’ damage to the infrastructure on the South Coast. ‘Orange hornet’ drone was used to monitor the rebuilding of around 100 metres of sea wall in Dawlish, Devon.

More recently, Network Rail has sent in a second battalion of the ‘orange army’ to tackle a huge landslip that is threatening the Great Western Main Line about a mile west of Dawlish.

![Drones](image2.png)

**Figure 23 – Drone aerial view of the Dawlish sea front**

- **Automatic railway switch inspection** – a robot named Felix produced by the Loccioni Group in Italy is able to perform automatic inspection of rail switches. The system processes, displays and stores real-time measurements, creating specific condition reports.


A few examples of Felix robotic system’s measurements include track gauge, sliding average on 100m track gauge, cross level and break spaces. One of the benefits of the system is improved quality and speed of measurements while avoiding errors in data acquisition and data transfer.

Figure 24 – Felix mobile robot for inspection of railway switches

- **Rail welding robot manufactured by Plasser & Theurer** – the new APT 1500 R welding robot performs an automated welding sequence without manual interaction, thus achieving a high level of welding quality. The operation is briefly described as follows: the rails to be welded are lifted automatically into the welding head, placed in position with the help of automatic height centring and running edge alignment and a special measuring system monitors the process continually. The welding gap between the rail ends is also produced automatically, if necessary by pulling the rails together. At the same time, all major welding parameters are recorded and stored.

Figure 25 – Plasser & Theurer’s APT 1500 R welding robot

- **Advanced Robotic Laser Coating Removal System (ARLCRS)** – a consortium of organisations in the US have worked together to develop and demonstrate a system that uses high-powered lasers to remove coatings from fighter and cargo aircraft. The resulting robot was named the

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Advanced Robotic Laser Coating Removal System (ARLCRS). The automated laser de-coating technology is expected to significantly reduce labour, waste volume, environmental risk, and overall cost, as more traditional coating removal processes use abrasives or chemical paint removers and generate hazardous wastes and air emissions. The robots’ advanced sensors also detect, classify and record the condition of the aircraft surfaces as stripping proceeds.

Figure 26 – ARLCRS Robot removing coatings and conduction inspection on aircraft body

- **3D printing for reverse engineering** – the 3D printing/additive manufacturing company 3T RPD, using aviation-specification flame retardant plastic with additive manufacturing, was able to reverse-engineer spare parts for onboard ventilation and communication systems, despite the original toolings no longer being available. The polyamide used contains a halogen-based flame retardant which is released in the event of a fire, starving the flames of oxygen. It also has good mechanical properties and tensile strength, which result in strong but lightweight parts.

Such 3D printing robots and machines could be used for on-site reverse engineering and part manufacturing.

Figure 27 – PA 2241 Flame retardant plastic material produced with plastic additive manufacturing techniques


• **3D printing robots for civil engineering** – a 3D robot system named Minibuilders was developed by the Institute for Advanced Architecture of Catalonia in Spain, which comprises of three types of robots for printing simple three-dimensional structures.

The rail industry could benefit from such 3D printing robots by using them to manufacture various components for rolling stock, track infrastructure, and electrification systems.

![Figure 28 – The Minibuilder robot system, constructing a hut](image)

5.3 Disaster recovery applications

• **EU’s Aerial Robotics Cooperative Assembly System (ARCAS)** – a self-organised fleet of autonomous flying robots, equipped with multi-joint manipulator arms, are being developed as part of an EU-funded project and are foreseen as useful helpers in all situations too dangerous for human workers.

The robots will be guided by positioning sensors, GPS and 3D maps, and will be equipped with smart software, capable of evaluating weather conditions or understanding their own mistakes and take a corrective action.

The cooperating robots can grasp objects, transport and deposit material, including industrial parts, debris or pieces of space stations. They could be used to clean up after nuclear accidents, erect antennas on mountain tops, speed up construction work or examine piping systems.

Part of the EU-funded ARCAS project, the robots have recently been tested in Spain. The indoor test in Spain’s Advanced Aerospace Technologies Centre in Seville used 10 mini-prototypes working together in an organised way.

The ARCAS team expects that the robots could first be deployed to carry out inspections and maintenance work on oil and gas pipelines and electricity networks.

- **Mobile robots for disaster recovery** – recovery efforts to deal with natural and man-made disasters often involve human aiders to operate under tough and dangerous environments and situations. Public transit vehicles and stations are at high risk to such threats, due to the potential catastrophic consequences.

Efforts have been made to develop mobile robots with dexterous manipulation capabilities which can aid in such circumstances by taking over some of the tasks currently undertaken by human aiders (e.g. search and rescue of the victims, extinguishing fires, clearing away debris, and even driving cars.

The DARPA\(^5\) Robotics Challenge (DRC) has been established to support the development of robots capable of assisting humans in responding to natural and man-made disasters. DRC was created in response to the 2011 Fukushima nuclear meltdown, in which a crippled Japanese nuclear plant leaked 300 tons of radioactive water into the ground after a devastating earthquake and tsunami struck the region. Participating teams, representing some of the most advanced robotics research and development organisations in the world, have collaborated and innovated on a very short timeline to develop the hardware, software, sensors, and human-machine control interfaces that will enable their robots to complete a series of challenge tasks selected by DARPA for their relevance to disaster response.

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\(^{50}\) DARPA stands for the Defence Advanced Research Projects Agency organisation in the United States
One example of such robots developed to take part in the completion is RoboSimian, a simian-inspired limbed robot that will use deliberate and stable operations to complete challenging tasks under supervised tele-operation.

Created by engineers at NASA’s Jet Propulsion Laboratory (JPL), RoboSimian is a four-legged machine that looks like an unholy cross between a spider and a chimp. The robot can walk on all fours, or fold in its hind legs and sit back on its wheeled haunches to wield its two dexterous arms.

During DRL trials in December 2013, RoboSimian's unique design made some tasks more difficult than others — driving a vehicle, for one — but its long, sturdy arms and deft hands helped the robot pick up valuable points in activities such as clearing away debris and turning valves.

RoboSimian finished the trials completion in fifth place. A two-legged robot built by engineers at SCHAFT Inc., a Japanese robotics firm, won the competition scoring the most points across tasks that tested the robots' mobility, dexterity, perception and autonomous operations.

The final DRC completion is yet to take place in June 2015 among eight teams who obtained the highest scores during the trials.

One of the fundamental obstacles ahead of increasing the performance of robots, is generating enough power inside robots. This is described by the winner of the initial stage of DRC challenge as follows:

“One of the big problems of humanoid robots is the weakness of robot’s power, . . . The strongest robot with electric motor can generate one tenth power as much as actual human beings can generate. Our team’s robot can generate ten times as much as the strongest robot, which means that our robots can generate the same power of an actual human being can generate.”

5.4 Personal assistance applications

- **The chairless chair** – wearable “Chairless chair” designed by noonee is a device that enables workers to rest their legs for sitting and while moving. The device functions like an exoskeleton — when it’s not activated, wearer can walk normally or even run; at the touch of a button it locks into place allowing the wearer to sit down on it.

51 [http://i.ytimg.com/vi/_lEgzyNGx6M/maxresdefault.jpg](http://i.ytimg.com/vi/_lEgzyNGx6M/maxresdefault.jpg)
Exoskeletons for carrying heavy loads – Daewoo Shipbuilding and Marine Engineering staff have been trialling wearable robotics (exoskeletons) with hydraulic joints and electric motors. Weighting 28 kilograms, the exoskeleton has a frame made of carbon, aluminium alloy and steel. The “suit” supports itself and is engineered to follow the wearer’s movements. With a 3-hour battery life, the exoskeleton allows users to walk at a normal pace and, in its prototype form, can lift objects with a mass of up to 30 kilograms. A system of hydraulic joints and electric motors running up the outside of the legs links to a backpack, which powers and controls the rig. Research is currently underway to increase lifting capacity to 100kg.

6 Challenges and opportunities for technology adoption

6.1 Challenges for technology adoption to transport sector

The success of adopting robotic systems for use in transport sector is dependent on a number of factors, such as Technology Readiness Level (TRL), associated costs, regulations and policies, time scales for adjusting, performance, reliability, etc. Some of the main challenges that the industry needs to overcome include the following:

- **Technological development** – many potential technologies are currently only in the early development stages (e.g. vehicle-to-vehicle communication, internet of things, etc.) meaning that huge investments and scientific breakthroughs might be necessary before a certain technology could be adapted to specific transport applications.

- **Policy Issues** – some technologies, such as driverless cars or drones, are already causing a headache for policy makers as various public concerns are made over technology safety, reliability or privacy issues. Not all aspects of robotic and AS technology use and implications are covered by current regulations, meaning that some time might be needed before any new technologies could reach the public.

- **Social and ethical issues** – robotic and autonomous systems could cause negative reactions from the public raising various ethical and moral concerns. One example of such grey areas is the accountability of autonomous systems: who is responsible? The operator of the system or the designer of the system? Does the human responsibility lie for system’s functioning or malfunctioning?

- **Reliability issues** – concerns might rise with public safety as robots and autonomous systems become more widespread. Even though machines used in public spaces are programmed to avoid colliding with and injuring people, human nature and its unpredictability means that this cannot be hundred per cent ensured. Also, all systems are prone to failures from time to time. However, this can be reduced with built-in redundancy and monitoring systems to minimise all possible risks.

6.2 Opportunities for the future

Robotic and autonomous systems could offer a large range of benefits, therefore it is crucial to identify what opportunities exist to develop these technologies and maximise their value to the transport sector.

A study by Aerospace, Aviation & Defence Knowledge Transfer Network (AAD KTN) has identified five main enablers for developing robotic and autonomous systems in the UK:

1. Government environmental and energy policies - renewable energy sources & nuclear
2. Integrated organisational framework in social and healthcare sectors
3. Cross sector knowledge transfer
4. Release of military AS skills into commercial arena
5. Investment in AS development and manufacture

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54 [https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c](https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c)
The report has also outlined main transport sector opportunities for short, medium and long terms (Table 2) as well as a set of recommended actions for autonomous system development based on ease of implementation and impact to the sector (Figure 33).\textsuperscript{55}

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<td>TRANSPORT</td>
<td>Ongoing work on development of Intelligent Transport Systems; Continued work on reduction of emissions</td>
<td>Interim emissions targets should be achieved; Development of AS in response to pressure of increasing personal road transport</td>
<td>Working towards achievement of 2050 emissions targets, development of higher levels of autonomy</td>
<td>2050 emissions targets should be achieved through increasing use of autonomy.</td>
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<tr>
<td>CROSS-SECTOR AS</td>
<td>Culture changes and new approaches through cross-sector working; Understand and develop new AS value-chains; AS co-ordinating body</td>
<td>Cross-sector system of systems demonstrators</td>
<td>Increasing acceptance of autonomy accelerates wider opportunities</td>
<td>Autonomy and AS becomes the accepted approach to effective delivery sector-wide.</td>
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Table 2 - Timeframe for Development of AS for transport\textsuperscript{56}

\textsuperscript{55} More general analysis of opportunities associated with autonomous systems can be found in appendix C.

\textsuperscript{56} \url{https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c}
APPENDIX A: From sources to theme selection

Identified sources of information

- **Academic journals specialised in robotics**, such as Journal of mechatronics, International journal of robotics research, IEEE Transactions on robotics, Journal of robotics and autonomous systems
- **Robotics news websites**: Robot magazine, Sparc robotics project, International federation of robotics website, Robotic Industries Association (USA), British Automation & Robotics Association
- **General technology news**, such as The Engineer magazine, Science Daily, New scientist, IEEE spectrum technology news, MIT Technology review
- **Technology forums**, e.g. TTI Vanguard (Advanced Technology Conference Series)
- **Centres of Excellence** conducting research on robotics: The Robotics Institute at Carnegie Mellon University, Autonomous Systems and Robotics research centre – University of Salford, Autonomous Systems and Robotics Research Group – University of Sheffield, Centre for Robotics Research (CoRe) - King’s College London
- **Government/Administrative organisations** funding or promoting robotics technology: NASA Website - Autonomous Systems and Robotics portal,
- **Industries/Manufacturers of robots**, e.g. Boston Dynamics
- **Competitions/Awards**: DARPA Robotics Challenge, RoboCup annual competition

Associated related topics and robotics word cloud

- Mechatronics
- Precision mechanical engineering
- Electronic control
- Autonomous systems engineering
- Man-machine interface
- Kinematics, dynamics, control
- Simulation of robots
- Intelligent machines and systems
- Design of robotic mechanisms
- Man-machine interface and integration
- Computer-aided engineering
- Robotics in manufacturing and flexible automation
- Computer vision
- Cybernetics
- Machine learning, pattern recognition
- Swarm robotics; collaborating robots
- Recovery, inspection, and maintenance robots
- Drones

Theme selection

- Robotics for inspection and maintenance
- Robot drones
- Mobile robots for disaster recovery
- Additive manufacturing (3D printing) and reverse engineering
- Robotics technology for construction of rail infrastructure
- Robotics technology for energy generation
- Swarm robotics
APPENDIX B: Future of Rail 2050 (ARUP)

In “Future of Rail 2050” report published in the summer 2014, ARUP unveiled their vision of the future of rail travel in light of trends such as urban population growth, climate change and emerging technologies. This vision is dominated by the ubiquity of robots and drones, or “unmanned aerial vehicles (UAVs).

The following two pages illustrate this vision, showing where robotic and other autonomous systems are the most likely to have an impact: in the transportation of goods and people itself, logistics, maintenance, and security.

Figure 34 – ARUP “Future of Rail 2050” infographic illustrates some of the many futuristic aspects to rail travel we may see in the future.

Figure 35 - ARUP “Future of Rail 2050” infographic illustrates some of the many futuristic aspects to rail travel we may see in the future.
**APPENDIX C: Analysis of opportunities – landscape mapping for autonomous systems**

Landscape mapping for autonomous systems provides an initial view of specific opportunities across a number of sectors and their outline frames, showing some of the underpinning trends, drivers and capabilities:

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**Figure 36 – Landscape map for autonomous systems produced by AAD KT**

58 [https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c](https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c)
APPENDIX D: Autonomous systems literature search


In this article, the first driverless metro in China is discussed. This metro, which is located in the seventh largest Chinese city, Wuhan, has been built in order to help curtail some of the area's growing traffic congestion problems resulting from a local population that owns over 600,000 cars in the area. The Line 1 section of this rail links Huangpu Lu and Zongguan, which follows an older Chinese Railway's line. This line can service 18,000 passengers per hour. The Wuhan Rail Transit Co Ltd's (WRTC) rail, while driverless, in fact has an attendant onboard at all times to assist passengers. The automatic train uses a Vehicle Control Centre, which connects with the on-board redundant microprocessor based system to operate the trains. As timetables change from day to day, each morning the central control operator initiates the day's timetable information in the system's computer, which then allows the trains to operate independently.


Faced with the renovation of two of its lines, Madrid Metro wanted to increase its capacity on both lines without extensive changes to the infrastructure. Additionally, the system needed to have the ability to evolve into a fully automated system. The above requirements made it clear that only a CBTC system could achieve that. Bombardier is now installing its first CBTC system on a metro in Europe as a result of a Euro 104 million contract from Madrid Metro. Cityflo 450, Bombardier’s CBTC, features moving block operation with driver semiautomatic train operation using radio communication between train and wayside. Furthermore, Cityflo 450 can in the future be upgraded to Cityflow 650, a fully automated system.


A high-speed train (HST) system has been proposed for intercity travel in California between the major metropolitan centers of Sacramento and the San Francisco Bay Area in the north, through the Central Valley, to Los Angeles and San Diego in the south. The HST system is projected to carry as many as 68 million passengers annually by the year 2020. The project involves a train system capable of speeds in excess of 200 miles per hour (mph) (322 kilometers per hour [kph]) on a fully grade-separated track, with state-of-the-art safety, signaling, and automated control systems. This Final Program EIR/EIS analyzes a proposed HST Alternative and compares it with a No Project/No Action (No Project) Alternative and a Modal Alternative (potential improvements to the highways and airports serving the same intercity travel demand as the HST Alternative). This report identifies preferred corridors/general alignments, general station locations, recommended mitigation strategies, recommended design practices and further measures to guide development of the HST system at the project level to avoid and minimize potential adverse environmental impacts.

Safety is often seen as the guarantee of proper performance in public transportation, and railways are frequently considered perhaps the safest means of travel. This article examines the advances in technology that make it possible to use the same basic network infrastructure to transmit both train control and security data, while increasing the range and quality of services available. The article focuses on closed-circuit television (CCTV) and communication based train control (CBTC) systems interfacing that avoids network duplication while enhancing passenger security and providing significant cost savings to operators.


This book presents the papers that were presented at COMPRAIL 2006, and it represents the latest research, development and application of computers to the management, design, manufacture and operations of railways and other passenger, freight and transit systems. The conference attracted a large number of papers, divided into the following sections: planning; safety; passenger interface systems; decision support systems; computer techniques; converting metros to driverless operation; advanced train control; train location; dynamic train regulation; timetable planning; operations quality; communications; energy management; power supply; dynamics and wheel/rail interface; freight; and condition monitoring. This book updates the use of computer-based techniques, promoting their general awareness throughout the business management, design, manufacture and operation of railways and other advanced passenger, freight and transit systems. It will be of interest to railway managers, consultants, railway engineers (including signal and control engineers), designers of advanced train control systems and computer specialists.


At approximately 12:45 a.m. MDT, July 27, 2006, an eastbound Union Pacific (UP) freight train ZLADV-26 (Train no. 1), traveling on main track, struck westbound UP train KG1LA-24 (Train no. 2) that was stopped at a siding. The accident occurred at the Champlin (Utah) Siding, milepost 676.2, Lynndyl Subdivision. Champlin is located approximately 10 miles north (timetable east) of Lynndyl, Utah. For the purpose of this report all directions are established by the time table in effect. Train no. 1, consisting of four locomotives, 75 loads, no empties, 6617 feet long and 5229 trailing tons, was traveling on the main track between west and east Champlin to meet westbound Train no. 2 when it failed to stop for a red control signal at East Champlin. Westbound Train no. 2, consisting of five locomotives, 112 loads, no empties, 8007 feet long with 6680 trailing tons, was stopped through the switch at the East Champlin Siding and the rear of the train was standing on the main track. Train no. 1 passed the stop signal at East Champlin and struck Train no. 2, derailing two locomotives of its train and three cars on Train no. 2. Speed at the point of impact was recorded as 27 mph.. There were no injuries and no hazardous materials involved. The investigation revealed that the engineer of Train no. 1 was not qualified to operate a locomotive over the territory. Damages were reported as: equipment, $61,222; track, signal and structures, $49,000. At the time of the accident, it was dark and clear, temperature was 70 degrees Fahrenheit. The probable cause of the accident was the failure of the engineer on Train no. 1 to stop short of a controlled signal displaying a stop indication. A contributing cause is operation of a locomotive by uncertified/unqualified person.

This article focuses on Vancouver, British Columbia's TransLink system as well as profiling the system's CEO, Pat Jacobsen. TransLink evolved out of the BC Transit system, which the article describes as being created in order to provide the BC general area with public transportation, regional roads, and urban and suburban roads. British Columbia faces idiomatic growth situations as well, since the city is girded by the ocean, the U.S. border, and a mountainous region. This layout curbs sprawl, which this article describes as advantageous to TransLink. The article offers an historical overview of the system, its fleet, and the system's administrative structure. A section is devoted to TransLink's SkyTrain service which involves 30 miles of track with two different lines. SkyTrain is a driverless system combining standard train technology with a people mover system. The article closes with a look at TransLink's plans for the 2010 Winter Olympic Games.


This booklet contains selected data on the transport sector of a large number of UNECE member countries. It compiles for each country the length of motorways and roads as well as rail lines and inland waterways. It also contains data on the vehicle fleet and rolling stock, traffic volume by mode and road accidents.


APTA's 2007 Rail Conference provides attendees with the most comprehensive learning and networking experience possible. The conference includes a complete slate of technical sessions relevant to the operation, management and maintenance of rail and fixed guideway systems. The conference was sponsored by the American Public Transportation Association (APTA) and was held June 3 through June 6, 2007 in Toronto, Ontario, Canada. The conference included eight tracks which were: (1) Public Transportation: Wherever Life Takes You Developing Tomorrow's Workforce Today: Program that Rock!; (2) Safety and Security for Incident Management and Integrated Response and Integration of Transit and Security Operations Control Centers; (3) Planning and Finance: Advancing Transit's Agenda through Strategic Planning; (4) Capital Projects: Commissioning, Construction Claims and Rick Management, Delivery Options, Maintaining Infrastructure During Intermodal Expansion or Rehabbing, Practical Sustainable Design for Capital Projects; (5) Operations and Maintenance: Managing Data Overload, Ridership: Accommodating and Increasing Core Capacity—How Systems are Managed, Shared Use of Track, Shared Corridors; (6) A Primer: Planning, Construction and Operations Continuum Initiating and Planning: A Project Primer; (7) Commuter and High Speed/Intercity Rail and Intermodalism; and (8) Technical Forums which included Advances in Rolling Stock Technology, Communications, Communications Based Train Control (CBTC) Systems, Heat and Smoke Movement and Exiting During Station Fires, Integrating Crashworthiness in All Rail Modalities: Opportunities and Risks, Light Rail Project Update, Noise and Vibration, Renewable Energy for Transportation—Opportunities and Motivations, Signal Systems, Streetcars: A New Wave, Surface Track, and traction Power.


A June 1997 incident in which two teens were fatally injured by a train on a bridge in Pittsford, NY, spurred the U.S. Department of Transportation's (USDOT) Federal Railroad Administration's (FRA) Office of Safety to conduct research into trespass prevention at railroad rights-of-way (ROW). The USDOT/Research & Innovative Technology Administration's (RITA) John A. Volpe National Transportation Systems Center (Volpe Center), under the direction of FRA, conducted a 3-year demonstration of an automated prototype railroad infrastructure security system on a railroad bridge.
This commercial-off-the-shelf (COTS) technology system was installed at the bridge in Pittsford, NY, where the two teen fatalities had occurred. This video-based trespass monitoring and deterrent system has the capability of detecting trespass events when an intrusion on the railroad ROW occurs. Once a trespass event occurs, the system transmits audible and visual signals to the monitoring workstation at the local security company, where an attendant validates the alarm by viewing the live images from the scene. The attendant then issues a real-time warning to the trespasser(s) via pole-mounted speakers near the bridge, contacts the local police, and, if necessary, the railroad police. All alarm images are stored on a wayside computer for evaluation. The system was installed in August 2001 and evaluated over a 3-year period, ending in August 2004. The safety benefits of this prototype system were reviewed and found to be very favorable. At least 5 lives were potentially saved during 3 separate trespassing incidents over the 3-year evaluation period. This interactive system can serve as a model for railroad infrastructure security applications at other railroad ROW or bridges prone to intrusion. After the evaluation period was completed, FRA formalized a technology transfer agreement with CSX Transportation (CSXT) that handed over control of the wayside system to the railroad.


This article describes in detail the new Metrobus light metro under construction in the Italian city of Brescia. With a population of about 190,000, the city's officials looked at various options—light rail, trolleybus, metro and others—before settling on a driverless metro system that should be able to handle increasing traffic for the next 30 years. The project will use many technologies already in use in the Copenhagen metro system. The article lists seven reasons the system will use driverless technology, and describes in detail the schedule of construction and the trainsets that will be used.


This article describes in detail the planned Dubai Metro, from its budget and builders to its cars and stations. Construction on the Red Line, which runs along the coastline from its depot in Rashidiya near Dubai's airport, began in March of 2006 and is about half finished. Work on the Green Line, which links the business districts on either side of Dubai Creek, is expected to be 50 percent completed by end of 2008. Both lines will be operated automatically by a fleet of 87 driverless trainsets being built in Japan. The five-car trains will carry seated and standing passengers, and part of one coach will be reserved for women and children. A comprehensive metro system is needed to deal with increasing congestion on city streets.


The implementation of high-speed rail (HSR) technology, at speeds of 80 to 110 miles per hour (mph) on corridors with pre-existing conventional rail service (up to 80 mph), requires upgrading the crossing activation technology with additional emphasis on safety by adding four-quadrant gates. Frequently, these crossings cannot be closed or grade-separated, and they are equipped with insufficient warning devices to support HSR operations. One solution, four-quadrant gates with inductive loop vehicle detection, was installed at 69 grade crossings on a 120.7-mile segment of the future 280-mile HSR corridor between Chicago and St. Louis. This segment will carry passenger trains at speeds up to 110 mph, including at many of the highway-rail grade crossings. These and other infrastructure improvements were completed to reduce the Chicago to St. Louis travel time from 5.5 hours to 3.5 hours and increase the number of daily round trips in each direction from three to five. The project
conducted a reliability analysis of the four-quadrant gate/vehicle detection equipment based on maintenance records obtained from the Union Pacific Railroad, the owner and operator of the grade crossings. The results of this analysis were used to assess the impact of the equipment reliability on the proposed HSR timetable. The study showed that the total average delay to the five scheduled daily high-speed passenger roundtrips was an estimated 10.5 minutes, or approximately one minute per train. Overall, extensive analysis of the trouble ticket data showed that the four-quadrant gate and vehicle detection equipment are as reliable as the conventional crossing gate while providing additional protection.


This article describes construction progress on the Sin Bundang line in the suburbs of Seoul, South Korea, which is due to open in 2010. The 18.5-kilometer line will connect Bundang in Gyeonggi province, a planned city for 450,000 with an emphasis on sustainability. The article describes the public-private partnership that has undertaken the project. The signaling and automation equipment, which allows for a fully-automatic driverless operating system, is also described. The article includes a map of the subway system around Seoul and out to Bundang.


This monograph contains papers accepted for presentation at the 12th International Conference on System Design and Operation in Railways and other Transit Systems (COMPRAIL), held in Beijing, China in 2010. The editors emphasize the advantages of rail transport over other systems in terms of capacity, punctuality, fuel savings, weather resistance, and reduced pollution. The monograph offers 88 chapters in nine sections: advanced train control, traffic control and safety of high-speed railways in Asia, computer techniques, planning, Maglev and high speed railways, metro and other transit systems, energy supply and consumption, dynamics and wheel/rail interface, operations quality, monitoring and maintenance, safety and security, and timetable planning. Computer-based technologies and their role in the safety and efficiency of rail transit systems form a theme that is revisited throughout the monograph. Each chapter also includes an abstract, numerous line drawings and tables, and a list of references.


This article describes how Argentina was the first country in South America to privatize its national railway network, a process that started in 1990. The network was divided into smaller units either by region or track gauge, which were let as private concessions that typically ranged for 30 years. The new operators agreed to invest an initial amount and pay fees to the government for operating their railway. Unfortunately, the government failed to regulate the concessions effectively and the concessionaires only invested in the most profitable parts of their networks and abandoned the rest. The Union Pacifico Railway (FCUP) project seeks to reverse this trend by reactivating a 255 km gauge-line linking Chamaico, Union and General Alvear that closed in 1978. FCUP will also improve rail connections to Brazil and Chile among the Sao Paulo-Buenos Aires-Santiago-Valparaiso arc as well as to Uruguay and Paraguay using existing bridges over the Parana and Uruguay rivers. FCUP is an autonomous entity, independent of the various provincial authorities. Such authorities rarely have the same priorities and common overall strategic vision that makes it very difficult to reach a consensus.
About 4:44 p.m., eastern standard time, on November 28, 2008, a three-car train operating along a fixed guideway on Concourse E at Miami International Airport near Miami, Florida, failed to stop at the passenger platform and struck a wall at the end of the guideway. Although a maintenance technician was monitoring train operations from the lead car of the train when the accident occurred, the train was operating in fully automatic mode without a human operator. The maintenance technician and five passengers on board the train were injured in the accident. One person on the passenger platform also required medical attention. The National Transportation Safety Board determines that the probable cause of this accident was the installation of a jumper wire that prevented the overspeed/overshoot system from activating to stop the train when the crystal within the primary program stop module failed. As a result of its investigation of this accident, the National Transportation Safety Board (NTSB) makes safety recommendations to the U.S. Department of Transportation, to the 50 states and the District of Columbia, to Miami-Dade County, and to Johnson Controls, Inc. The NTSB also reiterates a previously issued safety recommendation to the U.S. Department of Transportation.

On July 20, 2010, about 5:39 p.m., eastern daylight time, an inbound Miami-Dade Transit (MDT) Metromover, traveling about 10 mph along a fixed guideway, struck the trailing end of another Metromover. The struck Metromover was stopped at Brickell Station near downtown Miami, Florida. There were a total of 45 passengers on board the two Metromovers. These Metromovers operate in a fully automatic mode without human operators. Sixteen passengers incurred minor injuries and were transported to, treated by, and released from local hospitals. At the time of the accident, weather conditions were clear, with winds of 20 mph and a temperature of 87° F. Total damages were estimated at $406,691. The National Transportation Safety Board determines that the probable cause of the accident was the Miami-Dade Transit rail traffic controllers’ decision to restart automated train operations without accounting for the location of all Metromovers following a safety shutdown after the signal rail had been damaged by a defective Metromover guide wheel. Contributing to the accident was inadequate oversight by Miami-Dade Transit.

In order to protect civilians against both intentional and unintentional threats, rail transportation has become increasingly automated, due to the considerable danger posed to passengers riding on modern railways by human errors, as well as deliberate sabotage. This book features a collection of state-of-the-art methodological and technological notions on the protection of rail transportation infrastructures, as well as the subject of ‘real-time safety-critical’ railway control systems. Topics covered are as follows: Automatic Train Operation (ATO); Railway Interoperability; Driverless systems; Innovative Railway Control and Monitoring Systems; High-Assurance Systems Engineering; Risk Assessment and Hazard Analysis; Protocols for Real-Time Distributed Systems; Human Machine Interaction and Human Factors; Formal Methods in Software Development; and Computer Dependability.
This issue contains 18 papers concerned with transit. Specific topics addressed include: transit fleet resource allocation; benchmarking disaggregate customer satisfaction scores of bus operators; statistical equivalence of onboard versus online surveys of transit customers; the operational performance of public transportation agencies; intraurban rail access; measurement of train delay impacts; low-frequency automated vehicle location data for monitoring and control of bus performance; and large-scale transit schedule coordination. Other topics addressed include: dynamic system optimal routing; high-load transit line passenger transmission and productiveness efficiencies; the benefits of real-time transit information and impacts of data accuracy on rider experience; the calibration of a public transport performance measurement system; pedestrian route choice of vertical facilities in subway stations; the effects of fare payment types and crowding on dwell time; unbanked transit riders and open payment fare collection; business perceptions of fixed-guideway transit projects; passengers’ perception of and behavioral adaptation to unreliability in public transportation; and the effect of parking charges at transit stations on park-and-ride mode choice.


Feedback is an ancient idea, but feedback control is a young field. Nature long ago discovered feedback since it is essential for homeostasis and life. It was the key for harnessing power in the industrial revolution and is today found everywhere around us. Its development as a field involved contributions from engineers, mathematicians, economists and physicists. It is the first systems discipline; it represented a paradigm shift because it cut across the traditional engineering disciplines of aeronautical, chemical, civil, electrical and mechanical engineering, as well as economics and operations research. The scope of control makes it the quintessential multidisciplinary field. Its complex story of evolution is fascinating, and a perspective on its growth is presented in this paper. The interplay of industry, applications, technology, theory and research is discussed.


In this paper, the authors review the main concepts and methods to perform capacity analyses, and present an automated tool that is able to perform several capacity analyses. Capacity is extremely dependent on infrastructure, traffic, and operating parameters. Therefore, an in-depth study of the main factors that influence railway capacity is performed on several Spanish railway infrastructures. The results show how the capacity varies according to factors such as train speed, commercial stops, train heterogeneity, distance between railway signals, and timetable robustness.


Data fusion schemes for train localization and parting detection for the "Train Collision Avoidance System" (TCAS) in Indian Railways are described and evaluated. The requirements and constraints for the application are reviewed and the relevance of related technologies reported with the TCAS problem is discussed. The autonomous component of train localization in TCAS should (i) determine the longitudinal (along track) position of the train, (ii) provide reliable velocity measurement for automated braking and (iii) detect accidental train parting by comparing the longitudinal positions of the engine and the last carriage. This paper examines whether the above duties can be performed during GPS outage and GPS dark regions, without using track-side aids. The system engineering issues for selecting sensors and short-listing of data fusion options are discussed in the context of the above requirements. A number of data fusion solutions including a new proposed scheme for
longitudinal localization are discussed and compared with two solutions reported earlier. A novel scheme for detecting train parting situation, based on fusion-filters and fault detection approach is also described and its performance evaluated. All the reported schemes use odometer and accelerometer. Parametric performance analyses are performed to select appropriate algorithms, sensor specification and tuning parameters. Representative simulation results are included.


This paper discusses a research project that explores the potential of dispatch decision making that includes reduction in energy consumption. A number of variables are used to support decision making in this process, including train delay and energy consumption. These criteria are used in control centers when disruptions in train traffic or scheduling occur.


Current practices for inspection of railcars and locomotives include both manual and automated systems. However, inspection of railroad equipment undercarriages is almost entirely a manual process. Visual inspections by humans are performed either in a pit or trackside. The equipment is usually stopped over the pit or run slowly past the trackside inspector. In the latter case, it is not possible for a human to have an unobstructed view of the undercarriage as a train rolls by. Automated inspection by electronic systems has the potential to overcome certain limitations of human inspection. The report describes the Innovations Deserving Exploratory Analysis (IDEA) project conducted to develop a new approach to undercarriage inspection by means of machine vision analysis. This approach uses multispectral imaging from cameras viewing the undercarriage from a below-the-track perspective. Imaging using both visible and infrared spectra provides a means by which incipient failure detection can be addressed. Detection of missing, damaged, and foreign objects can also be identified using this approach. By extracting frames from video recordings in both spectra, panoramic images of the entire train can be created and analyzed. These images are further subdivided into individual railcar panoramas that can be matched to templates of railcars in known good condition to detect missing and foreign objects. More detailed diagnosis can be provided by using specific component-level templates allowing identification of damaged and overheated subcomponents. In addition, comparisons can be made of duplicate component systems during operation, such as disk brakes, to discover thermal outliers indicating improper function. A prototype of this machine vision inspection system has been developed and tested at a passenger car service and inspection facility. This investigation demonstrates the feasibility of a machine vision system to provide undercarriage inspection capabilities, as the train passes over the pit, aiding inspection crews and repair personnel. The system provides a clear and unobstructed visible spectrum assessment of the undercarriage in addition to an assessment from the thermal spectrum as well. The joint analysis of these undercarriage views can
provide automatic detection of components in need of repair and also those that may be over worked or near failure. This allows the inspector to be aware of indications indicative of component problems that are developing, which may fail in the future. Therefore the system has potential for providing advanced warning, allowing additional time for repair personnel to plan repairs prior to possible in-service failures.


This study presents an overview of applications of speed optimisation as a control measure for intelligent traffic management in rail-bound public transportation systems. The concept of operational target points and target windows is introduced. Speed and dwell time control are used to reach these targets, thereby improving throughput through system-related bottlenecks and reducing energy consumption. Different rail-bound transportation systems are compared and requirements for the application of speed control are derived. Case studies for three different rail-bound passenger transportation systems are presented that demonstrate the potential effects of these control methods on energy consumption and timetable deviation. These control strategies can be implemented using driver advisory systems (DAS) or fully automatic train operation (ATO).


Vehicular ad hoc networks (VANETs) are classified as an application of mobile ad hoc network (MANET) that has the potential in improving road safety and in providing travellers comfort. Recently VANETs have emerged to turn the attention of researchers in the field of wireless and mobile communications, they differ from MANET by their architecture, challenges, characteristics and applications. In this paper we present aspects related to this field to help researchers and developers to understand and distinguish the main features surrounding VANET in one solid document, without the need to go through other relevant papers and articles starting from VANET architecture and ending up with the most appropriate simulation tools to simulate VANET protocols and applications.

This paper describes a new method of real-time train monitoring based on the ZigBee/IEEE 802.15.4 protocol. The system consists of a mobile device embedded in the moving train which transmits parameter signals that are being measured by a base unit with the help of routers. When applied, the technique monitors and controls vehicles operating on permanent routes, making a real-time evaluation of their performance and location, and allowing an effective planning of trains. It consists of a low cost, low power consumption and safe modular technology capable of monitoring many different variables simultaneously.


Robust and interoperable wireless communications are vital to Positive Train Control (PTC). The railway industry has started adopting software-defined radios (SDRs) for packet-data transmission. SDR systems realize previously fixed components as reconfigurable software. This project developed a railway cognitive radio (Rail-CR) which implements Artificial Intelligence (AI) decisionmaking in concert with an SDR to adapt to changing wireless conditions and learn from past experience. Objectives of the project included developing a concept of operations for wireless link adaptation based on use-case scenarios for packet radio systems, designing and implementing a decisionmaking architecture on an SDR, designing strategies for radio environment observations, defining operational objectives and performance metrics, and designing and exercising a test plan to demonstrate performance under varying conditions. The decisionmaking architecture of the Rail-CR begins with observations of the wireless environment and performance metrics. The architecture enables adaptation to new situations and the capability to learn from past decisions. The Rail-CR was tested under a variety of interference conditions designed to simulate real-world experiences. Results show that a radio operating with no-cognition was unable to mitigate interference conditions causing either significantly high errors or a loss of connectivity. The Cognitive Engine (CE) successfully overcame the interference by changing configurable parameters.


Wireless communication plays a vital role in the success of railroad operations. This article describes an effort toward developing a railroad-specific cognitive radio (rail-CR) that can meet the needs of future wireless communication systems for railways by making positive train control communication more interoperable, robust, reliable, spectrally efficient, and less costly to deploy and maintain. Rail-CRs are a cutting-edge research area that combines artificial intelligence with software-defined radios (SDRs) with the goal of improving on existing radio performance. SDRs are radios in which capabilities are flexible because of realizing some functionality in software as opposed to a purely hardware platform. By using situational awareness from the radio in the form of observable parameters, a cognitive engine uses software-based decisionmaking and learning algorithms to determine whether a change in the radio parameters is required based on sets of predefined goals.


Ansari, K. (2014). "Development of an inter-vehicle communications & positioning platform for transport safety applications."
Recent centuries have seen a succession of transport technologies, each offering improvements in speed, carrying capacity and/or operational flexibility. Having overcome many physical barriers to freedom of movement, humanity now faces two major, related challenges: dwindling reserves of fossil fuels, and anthropogenic climate change. In these circumstances, rail transport has significant potential advantages over the more energy-intensive modes of road and air. Railways dominated 19th century land transport, peaking in importance in the early 1900s. Market share then declined in the face of competition from road transport and aviation, although rail retained significant passenger and freight transport roles. Major improvements in railway operating efficiency were introduced later in the 20th century, including: the switch from steam to diesel and electric traction; containerization and focus on long-haul, unit-train freight operations; and the development of high-speed passenger rail services in Japan and Europe, enabling rail to compete successfully with air travel over distances of up to 800 km. The UK Government’s Foresight Programme commissioned a report entitled Intelligent Infrastructure Futures, for which four scenarios were developed of how society might be in 2055. These scenarios are: ‘Perpetual Motion’, ‘Urban Colonies’, ‘Tribal Trading’ and ‘Good Intentions’, each having its own implications for the future of transport. This paper considers the implications of each scenario, and of the underlying/overriding issues of peak oil and climate change, for the possible role and significance of rail transport in meeting our transport needs in the mid-21st century and beyond.


This paper addresses the Internet of Things. Main enabling factor of this promising paradigm is the integration of several technologies and communications solutions. Identification and tracking technologies, wired and wireless sensor and actuator networks, enhanced communication protocols (shared with the Next Generation Internet), and distributed intelligence for smart objects are just the most relevant. As one can easily imagine, any serious contribution to the advance of the Internet of Things must necessarily be the result of synergetic activities conducted in different fields of knowledge, such as telecommunications, informatics, electronics and social science. In such a complex scenario, this survey is directed to those who want to approach this complex discipline and contribute to its development. Different visions of this Internet of Things paradigm are reported and enabling technologies reviewed. What emerges is that still major issues shall be faced by the research community. The most relevant among them are addressed in details.

This paper describes how wireless mesh technology is emerging as the next natural municipal utility, and has significant implications for transit rail systems. Potential areas of application include VoIP communications, environment and fare telemetry, facility surveillance, in-train and in-station advertising, and integration with municipal first responder networks. The IP centric 802.11 wireless mesh systems offer a robust, self-defining, self-repairing, low cost, incremental infrastructure solution for transit systems. They are being implemented as a municipal solution to provide Internet connectivity, utility telemetry, and first responder communication. The paper provides an overview of the wireless mesh technology and describes areas of potential impact for wireless mesh in transit rail systems. It also provides examples of parallel deployments in municipal, campus, and industrial environments.


This paper presents results on the running test for Automatic Train Protection (ATP) on-board equipment, a research project to ensure the safety and operational efficiency of electrical multiple unit (EMU) type trains. At the Korea Railroad Research Institute (KRRI), EMU type trains have been developed for the speed-up of existing lines and for passenger service improvement where the Korea Train Express (KTX) is not available. Progress has also been made on the operation trial test of 120,000 km with the use of Automatic Train Stop (ATS) equipment in existing lines, for the reliability assessment of the developed EMU type trains. The Ministry of Land, Transportation and Maritime Affairs (MLTM) has decided to accelerate the speed to more than 200km/h for the 6 existing lines including Jungang-line and Chungbuk-line where KTX has not operated. Because of this decision, the train control system is to be changed from ATS to ATP. An ATP on-board unit should be installed in EMU type trains and the operational suitability verified. Therefore, the authors have trial tested the same ATP on-board unit on EMU type trains that were used in the ATP construction project on Gyeongbu-line and Honam-line.


This paper describes how the new generation of supervision systems in the railway industry can achieve operation from display process variables to all automated control where the human just monitors the automaton. In the railway specific industry, supervision is organized in switching zones and aims to be centralized in an Integrated Control Center. These centers implement integrated and computer based systems that perform train protection, train operation and supervision. Thus railway dispatchers using supervision have their tasks considerably simplified. Although considered today as not safety critical, railway supervision systems can contribute to safety in some scenarios where an appropriate decision of a supervision operator could notably reduce the severity of accidents. That is in particular the case for residual scenarios (intervention of maintenance teams on the tracks, manual operation of trains not protected by train protection system, coupling/uncoupling, emergency requiring
the stopping and evacuation of a train etc) only covered by procedure, thus requiring human intervention by a person supposed correctly informed on the state of the system, thanks to the data provided by the supervision system.


This paper describes how Communication Based Train Control (CBTC) systems are known as comprehensive, integrated and intelligent control systems for rail systems and these include mainline railways, light rails and underground lines in cities. With the development of modern data communication, computer and control techniques, CBTC represents the future direction of rail control systems. CBTC presently has been used in light rail and underground lines in cities. It has not been implemented in mainline railways for many reasons. In future decades, rail systems will be in rapid development periods throughout the world. CBTC is known as the brain and nerve centre of rail systems, and ensures the safety and efficiency of rail systems. It is necessary for CBTC to be researched and developed further. In Europe, there is the European Train Control System (ETCS). In China, there is the Chinese Train Control System (CTCS). In Northern American and Japan, there are advanced train control systems or moving block systems. However, there is no standard for development and design of CBTC in the world at present. In this paper, efforts are made towards the establishment of a CBTC standard which directs the development and design of CBTC systems. The configuration of CBTC systems is first described. The key technical issues are addressed. The fundamental modular of CBTC and its interface requirements are defined. The transit methods from the present train control systems based on track circuits, transponders and other traditional means to CBTC systems are also put forward.

Blinge, M. “Policy measures to realise green corridors—a stakeholder perspective.” Research in Transportation Business & Management(0).

The findings from the implementation of economic incentives in Europe, such as CO2 tax and road user charges are encouraging, but it is likely not enough to reduce the CO2 emissions from the freight transport sector. Creating so-called Green Corridors is one of many measures taken by the EU as a step to form a more sustainable freight transport sector. The aim of this article is to identify stakeholder perspective on concepts for efficient policy measures and incentives to realise a successful implementation of a Green Corridor. A literature study and interviews with experts were used as input for a workshop where stakeholders from academia, authorities and the transport industry jointly developed concepts for new policy measures to create a Green Corridor. A combination of positive incentives, agreements, taxes and regulations is needed to make transport companies willing to participate. A promising pathway employs measures that ensure punctuality and accessibility, but also removes bureaucratic and infrastructural bottlenecks. In return, the transport operators must use significantly improved environmental technology in the corridors. Cooperation between actors is needed in order to increase the load factor in the system, by increasing the transparency and offering free capacity to other operators in the corridor.


This paper shows how temporal difference learning can be used to build a signalized junction controller that will learn its own strategies through experience. Simulation tests detailed here show that the learned strategies can have high performance. This work builds upon previous work where a neural network based junction controller that can learn strategies from a human expert was developed (Box and Waterson, 2012). In the simulations presented, vehicles are assumed to be broadcasting their position over WiFi giving the junction controller rich information. The vehicle's position data are pre-processed to describe a simplified state. The state-space is classified into regions associated with junction control decisions using a neural network. This classification is the strategy and is parametrized by the weights of the neural network. The weights can be learned either through supervised learning with a human trainer or reinforcement learning by temporal difference (TD). Tests on a model of an isolated T junction show an average delay of 14.12 s and 14.36 s respectively for the human trained and TD trained networks. Tests on a model of a pair of closely spaced junctions show 17.44 s and 20.82 s respectively. Both methods of training produced strategies that were approximately equivalent in their equitable treatment of vehicles, defined here as the variance over the journey time distributions.


This paper describes how, in late 2005, the Paris Transport Authority (RATP) awarded Siemens the contract for upgrading the oldest line of the Paris metro to a driverless line. This paper explains the motives of RATP and focuses on the technical challenges for upgrading automatic train control (ATC) from driver attended to driverless operation. This paper also presents the communications-based train control (CBTC) solution selected by Siemens and explains the reasons why it matches the requirements.


In November 2005, RATP – Paris Urban Transport Operator – awarded Siemens a contract to upgrade the oldest line of the Paris metro to driverless operation. This paper discusses RATP's motivations and focuses on the technical challenges for upgrading the automatic train control (ATC) from driver-based to driverless operation. This paper also presents the Communications-Based Train Control solution engineered by Siemens.


Advances in free-propagation radio technology provide the opportunity for significant advances in control system for Automated People Movers (APMs.) For mass transit authorities, using free-propagation radio for track-to-train data transmission provides a number of benefits. The free-propagation radio communication system engineered by Siemens is the outcome of more than thirteen years of development and field experience in radio propagation in the harsh underground metro environment. It has been designed to support both attended and driverless train operations. It is now fully installed on the Canarsie Line of New York City Transit. It will equip the five lines of the OURAGAN re-signaling program undertaken by RATP (Paris), Line 9 in Barcelona (Spain) and Line 2 in Budapest (Hungary). The paper describes the recent advances in the field of wireless communication with an emphasis on their application to APMs.

Communications-based train control systems are now widely recognized as the state of the art in automatic train control. The numerous safety, operational and maintenance benefits they offer to mass transit authorities make them an attractive answer to fulfill their expectations. This paper presents the Trainguard MT CBTC solution and addresses specific issues of resignaling lines in revenue service and upgrading driver operated CBTC to a fully automatic driverless solution. In addition to the challenges posed by the design and testing processes of the technology, the magnitude of the changes to the human side of the operation (train operation, maintenance, and engineering) and the management of this scope of change, have generated a number of key lessons learned that NYCT is currently deploying in the design and planning of the next CBTC project; the Flushing Line. The Flushing Line is a more complex operation that Canarsie and will require the modification of rolling stock that was delivered with very little consideration of CBTC installation in its design. Flushing will also involve CBTC equipment supply from two different suppliers. This paper examines several lessons learned from Canarsie and describes the subsequent changes in the Flushing Line project as a result.


Track clearance green phases are used at railroad-preempted intersections to provide time to clear the railroad tracks of highway vehicles before a train arrives. This paper outlines performance measures based on high-resolution, real-time traffic signal event data that can be used to assess the maximum right-of-way transfer time to track clearance green phases as well as the synchronization of the track clearance phase with the railroad gate warning system located at the crossing. These performance measures were applied to a railroad-preempted intersection over a 13-month period. Right-of-way transfer times from more than 5,002 preemption events demonstrate the importance of using automated methods for validating design assumptions for right-of-way transfer time made by traffic engineers. Track clearance performance measures tabulated over 7,648 preemptions demonstrate the need for using a longer fixed, worst-case green time for track clearance or an extensible track clearance interval that terminates when the gates descend. The parameter description on how to get gate descent information can be inferred from either the active warning-time (flashing-light signals) activation or a separate gate-down circuit. The paper concludes with recommendations for incorporating these performance measures in traffic controller firmware to address recommendations proposed in 1996 by the National Transportation Safety Board after the Fox River Grove, Illinois, railroad–grade crossing crash in 1995.


The Canada Line, Vancouver's new automatic light subway, was completed almost four months ahead of schedule, opening August 17, 2009. It is fully driverless, including the depot. During its first eight hours of operation alone, it carried 80,000 passengers, with many more expected to ride daily in the future. A public-private partnership project valued at US$1.76 billion, the Canada Line is 19 km long and Vancouver's third fully automatic light metro line after the Millennium SkyTrain and Expo lines. It is partially funded by the Vancouver Airport Authority, TransLink, and city, provincial, and federal governments. InTransit BC, a joint venture company owned by two pension funds and SNC-Lavalin
was awarded a 35-year contract to design, build, partially finance, maintain and operate the line at the end of July 2005. TransLink set up a separate company, Canada Line Rapid Transit, to act as the client on behalf of the public-sector funders.


This article examines the issue of driverless train systems and considers the role of the driver in modern systems that already have some automation. The author describes the important role the driver plays in protecting against train failures with overrides and bypasses and the value in the driver's ability to adapt to unusual situations. The article also highlights transportation systems around the world that are successfully implementing driverless systems.


The prospect of English Channel cross traffic having on-track competition has been created with the opening of the international passenger services market. Eurostar, which has been providing high-speed rail service between London, Paris, and Brussels for fifteen years, has responded by making restructuring to be a stand-alone company its top priority. The author examines relevant issues for Eurostar, including the overnight transfer of its London terminus from Waterloo to St. Pancras in November 2007, as well as progressive reform, response to liberalization, expansion and growth, connections, fleet renewal strategy, and development of a domestic high speed network in the United Kingdom. An insert provides information on Eurostar's "Tread Lightly" environmental initiative.


This paper describes how accurately estimating station dwell time is critical for timetable planning. Its importance has increased as railways seek to improve timetable stability and network efficiency, while serving more passengers and different types of transport services. This research consisted of developing a station dwell time model in cooperation with the Swiss Federal Railways (SBB). The proposed model estimates dwell times based on the input parameters: vehicle type (number, position, width and level of doorways), infrastructure (platform level) and demand (number and distribution of passengers). The research divides dwell time into five sub-processes: door-unblocking, opening doors, passenger boarding/alighting, closing doors and train dispatching. Each sub-process was evaluated separately to understand its influence on dwell time. The SBB's automatic passenger counting system was used to record the number of passengers boarding and alighting at each door and the beginning/ending time of each sub-process. During eight months over three million measurements were made on four different vehicle types operating on 20 different routes. These data were analyzed and used to develop the dwell time model. This paper describes the research methodology, the structure of the dwell time model, the data collection system and presents a summary of results including statistical distribution and influence factors of sub-process times.

This project had two main objectives. The first was to improve the safety of transit workers, specifically right-of-way safety for rail transit workers through demonstration of advanced track inspection techniques that limit the inspector’s exposure to rail right-of-way by visually inspecting the condition of the tracks from a safe location. The second objective was to enhance the quality of inspection by the use of objective, high-quality video systems capable of recording detailed images of the track and its main components at train speeds, coupled and synchronized with the use of multiple measuring systems installed onboard a Track Inspection Car. This report describes the use of those systems under a Pilot Project performed by MTA-NYCT using its TGC4 car on a segment of the Flushing Line (#7 Train) in New York City and includes a discussion of the results and benefits found by the use of the video and measuring systems together.


The integration of large infrastructure with energy-harvesting systems is a growing field with potentially new and important applications. The possibility of energy harvesting from ambient vibration of bridges is a new field in this regard. This paper investigates the feasibility of energy harvesting for a number of trains considering their passage over a bridge. The power that can be derived from an energy-harvesting device due to a train crossing a bridge at different speeds is compared against typical demands of small wireless devices and is found to be adequate for powering such devices. These estimates of harvested energy also relate to the individual signatures of trains. In this work, the modeled dynamic responses of a bridge traversed by trains are compared against full-scale experimental analysis of train–bridge interactions. A potential application in structural health monitoring (SHM) using energy harvesting has also been demonstrated and compared with laboratory experimental data. Consistent and monotonic damage calibration curves have been constructed using estimated harvested energy.


The State of Rhode Island, unlike other states in New England, has a unique opportunity to develop an intermodal transportation hub at T.F. Green Airport in Warwick due to close proximity of travel modes, namely air and rail. The current plan for the hub includes a train station, a consolidated car rental facility garage and an Automated People Mover connecting the proposed train station with the airport terminal. This study focuses on the proposed intermodal transportation hub at T.F. Green Airport. Specifically, the study has four objectives. First, it reviews and analyzes the current conditions and status of the proposed intermodal transportation hub. Second, drawing from the findings of the current conditions, the study presents a list of primary prospects and challenges facing the development of the intermodal transportation hub at T.F. Green Airport in Warwick. Third, the study examines six intermodal airports to learn the best practices in planning and development of the intermodal transportation facilities. These are: Miami Intermodal Center; Portland International Airport; Newark Liberty International Airport; Baltimore Washington International Airport; Frankfurt International Airport and Zurich International Airport. Lastly, using the lessons learned from the review of best practices, the study offers policy recommendations to address the key challenges facing the development of the proposed intermodal transportation hub at T.F. Green Airport. The study concludes that although the proposed intermodal transportation hub is a challenging and complex project, its successful development is within reach and the State of Rhode Island and the City of Warwick stand...
to benefit from it greatly. Benefits in the areas of economic development, improved environmental quality, and greater transportation alternatives clearly outweigh the possible drawbacks of the project. Three practical requirements for the success of the project are: Communication, effective collaboration and consensus among the various stakeholders of the project; creative financing to share the benefits and costs of the project among different stakeholders; and the management of the negative environmental externalities of the project. The proposed intermodal transportation hub at T.F. Green Airport has the potential to become a national model and a vibrant, urban, transit-oriented district in the City of Warwick functioning as a new gateway to the State of Rhode Island. This vision and its associated benefits should compel the State of Rhode Island and the City of Warwick to proceed with the development of the proposed intermodal transportation hub at T.F. Green Airport.


Many countries have busy rail networks with highly complex patterns of train services that require careful scheduling to fit these to the existing infrastructure, while avoiding conflicts between large numbers of trains moving at different speeds within and between multi-platform stations on conflicting lines, while satisfying other constraints and objectives. However, the construction and coordination of train schedules and plans for many rail networks is a rather slow process in which conflicts of proposed train times, lines and platforms are found and resolved 'by hand'. Even for a medium size rail network, this requires a large numbers of train schedulers or planners many months to complete, and makes it difficult or impossible to explore alternative schedules, plans, operating rules, objectives, etc. As a contribution towards more automated methods, we have developed heuristic algorithms to assist in the task of finding and resolving the conflicts in draft train schedules. We start from algorithms that schedule trains at a single train station, and extend these to handle a series of complex stations linked by multiple one-way lines in each direction, traversed by trains of differing types and speeds. To test the algorithms we applied them to scheduling trains for a busy system of 25 interconnected stations, with each station having up to 30 sub-platforms and several hundred train movements per day. We here report on the results from many hundreds of test runs. To make the tests more challenging, the algorithms start from initial draft timetables that we constructed so as to contain very large numbers of conflicts to be resolved. The algorithms, implemented in C code and run on a Pentium PC, found and resolved all conflicts very quickly. A further purpose of the algorithms is that they can be used to simulate and explore the effects of alternative draft timetable, operating policies, station layouts, and random delays or failures. (A) "Reprinted with permission from Elsevier".


This paper focuses on transit operations control, which involves the implementation of a metro line's operations plan on a daily basis and impacts the quality of service experienced by passengers. A framework is developed to evaluate rail operations control strategies with the purpose of identifying limitations and suggesting alternative approaches for or validating the effectiveness of certain strategies. The framework includes automated collection of service and passenger demand and it supports a multiperspective analysis methodology that can inform operational policies and plans. This paper is unique in its use of automatically collected data, its consideration of the operation control decision environment, and its acknowledgement that service reliability depends on many factors endogenous to it. The methodology's versatility allows for insights that would not otherwise be gained.
The authors apply the framework to the London Underground, but suggest that its structure and procedures are transferable to other metro systems.


The €3.2 billion Danish "Signalling Programme" is one of the largest railway modernizations in the world to provide a total replacement of the signalling systems in Denmark. This paper focuses on the potential benefits to be delivered to the passengers, such as improved punctuality and increased capacity, by implementing advanced train control systems on both the main lines rail network (Fjernbane) and the Copenhagen suburban rail network (S-bane). The main lines network will be fitted with the European standard train control system: ERTMS Level 2, while the Copenhagen S-bane network will be fitted with a Communication Based Train Control (CBTC) system using Automatic Train Operation (ATO). This paper also focuses on the possibility of implementing automatic driving operation (ATO) to the ERTMS level 2 solution for regional and high speed lines.


For urban metro systems with platform screen doors, train automatic stop control (TASC) has recently attracted significant attention from both industry and academia. Existing solutions to TASC are challenged by uncertain stopping errors and the fast decrease in service life of braking systems. In this paper, the authors try to solve the TASC problem using a new machine learning technique and propose a novel online learning control strategy with the help of the precise location data of balises installed at stations. By modeling and analysis, it is found that the learning-based TASC is a challenging problem, having characteristics of small sample sizes and online learning. The authors then propose three algorithms for TASC by referring to heuristics, gradient descent, and reinforcement learning (RL), which are called heuristic online learning algorithm (HOA), gradient-descent-based online learning algorithm (GOA), and RL-based online learning algorithm (RLA), respectively. An extensive comparison study on a real-world data set collected in the Beijing subway is performed. The experimental results show that these approaches control all stopping errors in the range of ±0.30 m under various disturbances. In addition, these approaches can greatly increase the service life of braking systems by only changing the deceleration rate a few times, which is similar to experienced drivers. Among the three algorithms, RLA achieves the best results, and GOA is a little better than HOA. As online learning algorithms can dynamically reduce stopping errors by using the precise location data from balises, it is a promising technique in solving real-world problems.


This paper reports on an analysis of statistics on derailment of freight trains in the Russian Railways. Some results of simulation of vehicle-track interaction and experimental studies on moving of empty cars along track sections with diverse combination of horizontal and vertical irregularities are presented. An overview of guidelines to provide safety of heavy and long train operation is also presented. Technical means of rolling stock and track condition monitoring that is used and developing in the Russian Railways is described. Existing and developing wayside and onboard automated monitoring systems enabling continuous control over moving rolling stock and track are discussed. In order to provide safety of heavy haul operation, a general concept of a complex system of safety management based on monitoring of rolling stock and track is suggested.


Chow, W., et al. (2014). Impacts of Real Time Passenger Information Signs in Rail Stations at the Massachusetts Bay Transportation Authority.

Real-time information systems have been used in transit agencies around the world to better inform passengers of their estimated wait. In 2012, the Massachusetts Bay Transportation Authority (MBTA) rolled out new real-time countdown information across its heavy rail system. These signs display the estimated arrival for the next two trains in each direction. This paper examines whether the introduction of real-time arrival signage leads to reduced expectations of wait time, improved satisfaction with the MBTA, and increased ridership. In-station surveys were conducted before and after real-time information was introduced to gauge changes in satisfaction and passenger wait time expectations. These expectations were compared against headways collected from automated train tracking data. Ridership changes were measured using MBTA provided automated fare collection data. Survey results reveal that after the introduction of the countdown signs, people reduce their overestimation of wait time by 50 percent. Satisfaction with the MBTA did not significantly change as a result of the real-time signage. People reported feeling more relaxed with real-time signage if the next train arrival occurred within a scheduled headway, but less relaxed for headways much greater than scheduled. Minor improvements in ridership were detected in stations with the real-time information after controlling for other factors, but these results are preliminary. This study suggests that real-time arrival signage is a positive addition to heavy rail systems to increase passenger comfort and improve perceptions of system performance in a relatively cost-effective manner using existing technologies.

Railway traffic is sensitive to perturbations and disruptions, resulting in delays. To limit the effect and propagation of delays, real-time traffic control has been proposed, suggesting control actions based on current information on railway traffic state, the prediction of its future evolution, and mathematical programming for solving potential track conflicts. A growing literature is available on railway traffic control, but a comprehensive knowledge of effects of such automated systems on real operations is still blurry and limited, due to the very scarce implementation of these systems in practice. The authors analyze in depth how the state-of-the-art railway traffic control system ROMA performs when interfaced in a closed-loop control setup with the realistic (simulated) traffic environment EGTRAIN (Environment for the design and simulation of Railway Networks). The authors use a rolling horizon scheme, i.e. optimal plans are periodically computed based on current traffic information and implemented in the field, and study different combinations of parameters, setup and information availability onto the suggested control actions. Results obtained for the Dutch railway corridor Utrecht-Den Bosch show that the closed-loop setup outperforms an open-loop approach when uncertain, potentially erroneous, and limited information on train entrance delays and dwell times is used. A closed-loop setup with frequent rescheduling improves quality of the solution, at the cost of higher computation times. The authors also verified that large prediction horizons improve the solution, outperforming the dynamic and myopic First-Come-First-Served dispatching rule.


The adoption of information and communication technology (ICT) has made it possible to experience high levels of visibility, control and connectivity across the entire supply chain. However, in road transport logistics, wireless ICT applications like cellular networks, Wi-Fi, UMTS, 4G and WiMax have not entirely solved reliability and connectivity problems due to difficulties associated with limited range, scalability and security. This paper examines the feasibility of using a vehicular network technology, dedicated short range communication (DSRC), in a multimodal logistics environment as means of providing enhanced visibility and connectivity using a secure access architecture. The secure access architecture is necessary to provide a high degree of security to the detailed visibility involving road haulage feeding port operations using a centralised port service.


The growing complexity of logistics and its importance as a major economic activity has raised the profile of information and communication technology (ICT) as means to improve the levels of visibility, responsiveness and efficiency in supply chains relying in multimodal transport operations. With the use of wireless vehicular networks, Intelligent Transport Systems (ITS) have the potential to shape the future of multimodal logistics. In the absence of sophisticated ICT tools, the potential role and contribution of ITS and in particular wireless vehicular networks play in logistics is investigated in a multimodal case of a port terminal handling bulk material transported by sea, which is unloaded into haulage vehicles. Event flow mapping and network modelling analysis are used to determine the feasibility of ITS to support real-time data traffic related to the exchange of messages, which are representative of the flow of events taking place in multimodal logistics and which can be associated to high-impact capabilities with economic repercussions such as track and trace.
Cucala, A. P., et al. (2012). **ATO ecodriving design to minimise energy consumption in Metro de Bilbao.**

This paper addresses the use of automatic train operation systems (ATO) in minimizing energy consumption in the Bilbao Underground (Metro de Bilbao), Bilbao, Spain. Rail transit train driving commands and speed commands have both been improved, to take the energy efficiency of train operations into account.

Curtis, G. (2008). **SmartSander Enhancement for Commuter Rail, Transportation Research Board: 34p.**

This Innovations Deserving Exploratory Analysis (IDEA) project developed an automated improved train sanding system to ameliorate fall adhesion performance issues faced by commuter rail operators. Low wheel-rail adhesion is a major issue, particularly in the fall when there are leaves on the track. The system, SmartSander, uses a combination of driver's brake demand, train speed and wheel-slide activity to deliver a variable quantity of sand to the railhead appropriate to efficient stopping of the train and protecting track circuits from the insulating effects of sand. The cost-benefit of SmartSander has been proved in the UK. In terms of deceleration performance, SmartSander allows engineers to brake confidently during periods of low adhesion and achieve deceleration rates up to 2 mph/s.


This paper on the pantograph damage assessment system (PANDA) is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors remind readers that pantograph failures due to complex interactions between the overhead line (OHL) and pantograph structure cause significant problems to the railway industry worldwide. Then they describe the development, design and test results of the Pantograph Damage Assessment System (PANDA), which is now deployed on routinely operating trains in the United Kingdom. The system uses two subcomponents: the Digital Processing Module (DPM), which is directly clamped on the live 25kV pantograph structure, and the Receiving Signal and Relay Unit (RSRU) which is installed in a secure location inside the carriage. A pantograph mounted unit is interfaced with the accelerometers that are attached in vicinity of the carbon strip. The DPM uses Bluetooth communication to report any unexpected events to the RSRU. Any high alarm events are instantaneously transferred to the train to warn the operator and the control center about a potentially harmful event that requires immediate attention. The 'hot spots' caused by the overhead line are mapped and trended to allow successful implementation of predictive maintenance of the OHL. The authors conclude that the PANDA monitoring system reduces maintenance costs for both the pantograph and for the overhead line electrical equipment.


The new train operator on the High Speed Line South between Amsterdam Central Station and Brussels will introduce a special tariff system including an obligatory reservation. However, not all locations where tickets are sold will be able to provide a reservation ticket, making it necessary to provide reservation tickets on the platform using dedicated ticket reservation posts. The effects of these reservation posts on passenger flows on the platform have been investigated using the microscopic pedestrian simulation tool NOMAD as well as the use of the reservation posts. Simulations have been performed for three platforms in three stations (Amsterdam, Rotterdam and the airport station.
This paper presents the assessment methodology and shows simulation results for Schiphol station. The conclusions are drawn based on the simulation results for all stations. Various scenarios have been compared with different passenger demands using the ticket reservation posts and different service times. Also, the optimal amount and location of ticket reservation posts have been investigated. A number of assessment criteria have been calculated using the simulation results (total load of reservation posts, queue lengths per reservation post, number of passengers missing the train, average waiting time per passenger at a reservation post and average service time per passenger at a reservation post), resulting in an objective and quantitative comparison of the scenarios and custom made conclusions and recommendations. The case study also shows the added value of the microscopic pedestrian simulation tool NOMAD in comparing scenarios in a quantitative way.


This paper presents alternative design approaches and challenges related to methods for the conservation of electrical energy for Transportation Systems. The propulsion designs of traditional transportation systems did not originally include energy conservation as part of their basic design philosophy. These propulsion systems were not designed to conserve electrical power consumption by recapturing the energy stored in the train's moving mass. Therefore the energy consumed from the electric utility during accelerations and stored in the moving mass of the trains in the form of kinetic energy was simply dissipated as heat by either friction or electrical resistance braking during decelerations. The current generation of propulsion systems are being designed with the capability to re-capture the train's kinetic energy and convert it back into electrical energy. This recovered electrical energy can then be made available for use by the train's auxiliary electrical systems, other trains, stored for later reuse, or transferred back into the electric utility power feeds. The end result of this reuse of energy is reduced electric utility costs, and reduced brake system maintenance costs as well as a decrease in the amount of harmful chemicals released into the environment in the form of brake dust.


This article describes Copenhagen's driverless Metro, which has been created in order to move large numbers of people a relatively short distance from the city center to various urban areas. In lieu of drivers, the system employs stewards who ensure that ticketing is arranged for properly and that customers are on the right train. Funding for the system was supplied by the Municipality of
Copenhagen and the Government of Denmark for the initial stages of the project, to be reimbursed as the system begins to turn a profit. The driverless component uses automated train control (ATC) with an integrated automatic train protection (ATP) system. If the automation fails, the train can still be manually operated from the central control center. While there has been some reluctance in the local population regarding the system, the majority believes the system to be safe.


This paper will describe how it is often necessary to resort to monitoring of certain structural parameters when studying the long-term behavior of structures. This paper discusses two such applications. A first prototype was used to monitor strains in a concrete fly-over with carbon fiber reinforced polymer (CFRP) reinforcements. The second prototype was used recently to monitor the vibrations in a continuous fashion during four weeks of speed tests on a new section of the European High Speed Train network. This paper gives an overview of these experiences and lessons learned concerning power supply and possible electromagnetic interference in harsh construction site conditions. In addition, the paper describes the intention to build a new completely autonomous third prototype for thermal strain monitoring. Furthermore, the most important results of both test cases are discussed, including the effectiveness off the CFRP-reinforcement and the natural frequencies of a massive concrete fly-over.


This paper describes how on board digital train event recorders have been developed in recent years. These devices allow one to collect very detailed data about train movements and signal status. The new Italian ATC SCMT on board subsystem is combined with the DIS (Driver Information System) that collects both kinetic behavior and all signal and balises messages. Unfortunately, this large amount of data is normally stored but not used except for failure and maintenance management. At the same time the use of micro simulation tools has been extended to large scale problems. A known problem exists in the calibration and validation of these models. In this paper a new tool is presented. This software allows one to analyze real life collected data, to perform very detailed analysis of train movements, pointing out speed depending on position and signal aspects, acceleration, braking curves and dwell time graphically and by means of parameters. Train behavior can also be connected to punctuality, to find out differences between on time and late running. This tool may be very useful for: large scale model validation, definition of the stochastic behavior of the system (travel time, dwell time, initial delay), calibration of braking and acceleration curves for various train types, acceleration percentage depending on different conditions. In other words, the software allows one to set up a link between real data and micro simulation models. The tool has been tested in the north-eastern part of Italy. In this case study, a significant precision increase in the stochastic simulation results has been reached.


Deak, G., et al. (2013). "IoTs (Internet of Things) and DIPL (Device-free Passive Localisation) in a disaster management scenario." *Simulation Modelling Practice and Theory* 35(0): 86-96.
This paper presents an overview of the potential obstacles and challenges related to research topics such as IoT, DiPL WSNs (Wireless Sensor Networks) in IoT and disaster management using WSNs. This review will analyse key aspects of deploying a DiPL WSN in IoT scenario for disaster management. In an IoT scenario the DiPL WSN is only collecting raw data that is forwarded to the Internet using a Compressed Sensing (CS) IoT framework or other solutions including data compression. Compressed Sensing (CS) refers to a method used to reduce the number of samples collected in an IoT WSN. Thus it is possible to create stand-alone applications that require fewer resources. There is no need to process the data in the WSN as this can be done in the Data Analysis Network, after the data is reconstructed. This will enable a reduced volume of data transmitted and lower power consumption for battery-operated nodes. The detection of people in a disaster scenario who are simply moving and not in the possession of a ‘tracking device’ is revolutionary. The aim here is to build upon our patent-pended technology in order to deliver a robust field-trial ready human detection system for disaster situations.


This article describes how much attention in the rail supply community has been focused on U.S. railroads' drive to implement positive train control (PTC) by the end of the 2015 calendar year. But PTC isn't grabbing much of the attention switch machine suppliers use these days to stay abreast of rail industry trends. Instead, they're focusing more on ensuring that tried-and-true machines remain in tune with North American railroads' needs, dependability and affordability, while simultaneously trying to develop new machinery or features. Customers are always looking for equipment that is cost effective, reliable and easy to maintain. However, they also are increasingly interest in machines that incorporate next-generation "smart" systems, such as self-diagnostic capabilities. Pairing proven equipment with advanced features such as light emitting diode (LED) diagnostics, modular designs and components that are simultaneously lighter and more robust will all play a role in reducing maintenance costs, avoiding system down time and boosting operational efficiency. C&S Railroad officials might be distracted at times with the complexities and capital demands of implementing PTC, but they still consider switch products as a vital part of their operational needs. Because they're a rail industry supply staple, switch machines typically sell steadily in good and bad times and demand was largely unaffected by the recent market downturn. However, some suppliers registered significant sales growth in 2010 after a long period of relatively flat sales. Customers are shifting their purchases toward products that reduce failures and, ultimately, train delays.


With the opening of the Las Vegas Monorail, the first installation of an open standards based radio train control system is in operation. The architecture of the Las Vegas Monorail train control system will be presented, and the numerous benefits of this type of system as compared to conventional track circuit or inductive loop based control systems will be examined with an emphasis on flexibility, and cost reduction. Using the IEEE 802.3 open standard for LAN based communication, and the IEEE 802.11 standard for the wayside to carborne link, the installation in Las Vegas has proven the viability and benefits of basing a train control system on open standards. An analysis of the success of the first six months of operation will be presented. By specifying an IEEE 802.3 standard interface between the train control subsystems and the communication system and using the Internet Protocol as the basis
for all messaging, the layered architecture of the train control system eliminates its dependence upon a specific radio technology. The benefits of this concept will be examined. The IEEE 802.11 radios in use today provide a significantly expanded communication bandwidth, as compared to previous generation APM control systems. The benefits this added bandwidth brings to train control applications will be examined. In addition, an analysis will be made of the available unused bandwidth in the train control network for other applications such as carborne and remote wayside CCTV, enhanced diagnostics, and passenger announcement applications. Additional APM projects under development, which are using this technology will be discussed, with an analysis of their differences from the Las Vegas monorail.


With the rapid development of urbanization in China, the number and size of underground space development projects are increasing quickly. At the same time, more and more accidents are causing underground construction to increasingly become a focus of social attention. Therefore, this research presents a real-time safety early warning system to prevent accidents and improve safety management in underground construction, based on the "internet of things" (IoT) technology. The proposed system seamlessly integrates a fiber Bragg grating (FBG) sensor system and a RFID (radio frequency identification)-based labor tracking system. This system has been validated and verified through a real-world application at the cross passage construction site in the Yangtze Riverbed Metro Tunnel project in Wuhan, China. The system's application results show that it can effectively promote underground construction safety management efficiency, specifically in the real time detection, monitoring and early warning of safety risks.


This paper on the efficient design of automatic train operation (ATO) speed profiles is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors describe two possibilities for increasing energy efficiency and decreasing energy costs in electrical railway systems. The first system considered is the redesign of the ATO (Automatic Train Operation) speed profiles of metro lines. The author notes that speed guidelines currently in use were originally selected based on time and comfort criteria, not necessarily for their energy efficiency. The second system evaluated is the implementation of an on board energy storage device. The regenerated energy of electrical brakes in metropolitan railways is not used if there is no other train starting up at the same time, and it is wasted with heating resistors. On-board energy storage devices, despite their additional mass, could be used to take advantage of regenerative energy. The authors propose a method in which these two are combined, resulting in speed profiles that are even more efficient with the implementation of the method. They also describe a simulator that can be used to simulate all possible speed commands. This simulator has been developed and validated with measurements in Line 10 of the Madrid Underground (Spain). With only the speed profiles being redesigned, a 20% energy savings could be achieved; with the combination method that includes the on-board storage device, up to 47.5% energy savings may be realized.

This paper describes how traffic regulation systems of metro lines equipped with Automatic Train Operation (ATO) use a set of pre-programmed speed commands selecting coasting points and brake deceleration. Different speed commands provide different travel times between stations and the regulation system on-line selects and sends to the train one of these commands. Nowadays, speed commands are designed based on time and comfort criteria. In this paper a new approach of speed commands design, which takes into account not only present operational criteria but also energetic ones, is proposed in order to obtain energy efficient ATO commands. Firstly, the travel time and energy consumption of every command is calculated using a simulator that combines all the possible discrete values of the ATO configuration parameters. A set of systematic rules has been defined to include the consumption, operative and comfort criteria in the selection of the speed commands applying decision theory techniques. A software tool has been implemented for a computer-aided design of the speed commands. This tool includes a thorough simulation module of the train movement (ATO, motor and train dynamics), an automatic generator of every possible command and a graphical assistant for the speed commands selection according to the mentioned rules. The methodology described in this paper has been used to redesign the current ATO commands (4 for each station) of Line 1 of Madrid Underground. The results are presented in this paper. According to the simulation results, about 10% of energy savings are expected to be achieved with these new speed commands.


Trains equipped with automatic train operation (ATO) systems are operated between stations according to the speed commands they receive from balises. These commands define a particular speed profile and running time, with associated energy usage (consumption). The design of speed profiles usually takes into account running times and comfort criteria, but not energy consumption criteria. In this article, a computer-aided procedure for the selection of optimal speed profiles, including energy consumption, which does not have an effect on running times, is presented. To this end, the equations and algorithms that define the train motion and ATO control have been modelled and implemented in a very detailed simulator. This simulator includes four independent modules (ATO, motor, train dynamics, and energy consumption), an automatic generator of every possible profile and a graphical assistant for the selection of speed commands in accordance with decision theory techniques. The results have been compared with measured data in order to adjust and validate the simulator. The implementation of this new procedure in the Madrid underground has led to a 13 per cent of energy saving. As a result, the decision has been taken to redesign all the ATO speed profiles on this underground.


The athletes of the XXth Olympic Winter Games 2006 will certainly borrow the VAL of Torino. The inauguration of this new system of Italian transport will take place before the opening of the Olympic Winter Games 2006. The first 8.3 km section will be exploited with a new type of vehicle “the new VAL208”, these train-sets are made up of four carriages with a total length of 52m, an innovation
compared to the other VAL systems operated in France. Torino's first underground metro line is based on the VAL (automated light vehicle) system adopted in Lille, Toulouse and Rennes. It starts in the centre of Torino at the current main railway station Porta Nuova, crossing the city centre via Porta Susa railway station and then travelling west to Collegno along Corso Francia. The new vehicle VAL208, produced in the manufacturing unit STS (Siemens System Transportation) in Prague will be of a new design and will benefit of the French experience feedback to be improved. This is the Italian ministry which will authorize the putting into service, for that it asked, via the ministry of French Transport, the intervention of INRETS (National Institute of Research on Transport and their Safety) which followed the system VAL of Lille and its evolutions to Toulouse and Rennes, since the beginning of the 1980s. This article, after a short description of the new line and its specificities, will be focused on the contents of the Safety Case, produced for the opening of the line. The method employed, in order to guarantee already a level of safety equivalent to the other VAL lines in operating, will be developed and commented on. A more precise point will be carried out on the procedures of operating and maintenance specific to the operating with 52 meters vehicles. The conclusion of this article could be a starting point in order to show that the “of mutual acceptance” term also called “cross acceptance” is not an illusion.


Before a train departs a yard, the cars and locomotives undergo inspection, including safety appliance inspection. Safety appliances are handholds, ladders and other objects that serve as the interface between humans and rail cars during transportation. Currently, inspections are carried out by carmen, railroad personnel who are trained in detecting defects in railcars. These inspections are primarily visual and most take place while the inspectors either walk or travel alongside the train in some type of vehicle. Current regulations require that cars be inspected each time a train departs even if they have recently passed previous inspections. A cost model for current safety appliance inspection methods is developed and discussed in this paper. The model considers failure costs, which result from defective safety appliances, and the cost of ensuring defective appliances are caught by inspections, known as improvement costs. Regarding improvement costs, there exists a potential to increase both the effectiveness and efficiency of safety appliance inspections by utilizing machine vision technology to partially automate the car inspection process. Machine vision consists of capturing digital video and using algorithms capable of detecting and analyzing the particular objects or patterns of interest. These systems can objectively inspect railcars without tiring or becoming distracted and can also focus on certain parts of the railcar not easily seen by an inspector on the ground. Benefits of the addition of machine vision to the inspection process are evident in the inspection cost model. Machine vision is being developed for several inspection tasks in the railroad industry and the Association of American Railroads is sponsoring research at the University of Illinois to develop a system for safety appliance inspection. The use of machine vision algorithms makes it possible to recognize the safety appliances on railcars and to identify and report defective appliances. With nearly 1.3 million railroad freight cars in circulation, the development of an algorithm robust enough to detect safety appliance violations on all car types under a variety of environmental conditions is nontrivial. A machine vision system consists of the image acquisition system, algorithms, and the preliminary portable field setup, all of which are discussed in this paper.

Nowadays, automated systems and sensors are being developed to improve reliability, safety and offer new exploitation modes in guided transports. In maritime and airway domains, many intelligent systems are used for simultaneous location and exchange of information. However, in guided transports domain, no system is nowadays able to ensure the both functionalities. This paper presents a new system called CODIBDT (communication, detection and identification of broken-down trains) allowing multi-user access and combining the two main functionalities, location and high data rate communication, using a cooperative collision avoidance radar transponder inside targets (train, metro, etc.). The proposed system is made of a couple of microwave transmitting and receiving equipments fixed on each train, one ahead and other behind. The sensor uses a matched digital correlation receiver in order to detect the position, compute the distance towards the preceding vehicle and get its status and identification. This radar exploits two frequencies, 2.2 GHz for transmitting and 2.4 GHz for receiving. The distance to the targets is measured, in real time, with a resolution of 3 m in a range of 800 m in tunnel and 500 m in open space using a transmitted power about 600 mW. To allow multi-user access and to combine the two main functionalities, two original multiplexing methods called SSS2 (sequential spreading spectrum technique) and CPM (code position modulation) are performed. This study is focused on the comparison between the two methods in terms of bit error rate, degree of complexity and data rate.


This article describes some of the transportation projects undertaken in the city of Turin, Italy, in preparation for the Winter Olympics games in February 2006. The author notes that the Olympics was seized as the ideal opportunity to modernize public transport, in particular with the arrival of a metro (an automated, driverless train). Once the right to host the Olympics was obtained, the Italian government released the necessary subsidies and Turin brought its urban transportation plan up to date. The projects included a 12 km underground railway connection that linked the town's different stations to each other; the metro that linked the western suburbs to the southern suburbs; a rapid tramway that uses Alstrom's Cityway trams with integral low floor; separate bus lanes to facilitate movement in congested traffic; and the construction of parking areas on the outskirts of Turin. The author comments on some of the oddities in the Turin priorities and the hurdles that must be overcome as Turin incorporates public transport into a car-loving city. One sidebar provides details about the construction sites in Turin and how the transportation projects will continue after the Winter Olympics have come and gone.


This paper describes how Fully Automatic Operation (FAO) is rapidly becoming the system of choice for Mass Rapid Transit Systems. The technology is mature and there is now over 20 years experience in this technology. Existing systems would also benefit by being automated. The challenges of converting an existing manned system to FAO are more challenging than a green field installation. The MTR Corporation of Hong Kong is currently operating one line which is FAO and has a plan to convert the remaining lines. This is a system that transports 2.6M per day and trains that carry up to 2,700 passengers. This paper shares the planning strategy and business case for this conversion – the Hong Kong story.

With the development of driverless metro systems, the demand for high data rate train-to-wayside wireless transmission is increasing drastically in order to satisfy operational needs such as maintenance, video surveillance of the inside of the trains and passenger information. Thus, the association of new transmission techniques such as new video coding techniques, multi antennas at transmission and reception sides and recent precoders provides technically and economically efficient solutions to improve existing systems. This paper presents and evaluates two novel strategies to enhance train-to-wayside wireless video transmissions in tunnels using realistic channel models obtained with ray tracing previously experimentally validated. Multiple Description Coding (MDC) or Region Of Interest (ROI) coding, using the new Flexible Macroblock Ordering (FMO) technique, is combined with appropriate Multiple Input Multiple Output (MIMO) schemes, namely, spatial multiplexing (SM), orthogonal spatial multiplexing (OSM) and precoded orthogonal spatial multiplexing (P-OSM) depending if full channel state information at transmitter side (CSI-T) is available or not. For each strategy, both video encoding process and MIMO algorithm are combined in an efficient way to provide the best video quality at the receiver with no increase of the number of radio access points along the infrastructure.


The San Francisco Bay Area Rapid Transit District (BART) is a regional and metropolitan rapid rail transit system that utilizes automated train control system, automated fare collection system, and fiber optic networking system. The integration and inter-operation of data processing and control systems with its physical facilities are essential for its safe and reliable operation. Furthermore, the compatibility between new and existing elements are essential when modifying or extending the existing system. In order to better serve the Bay Area's transportation need and sustain its quality of life, BART is currently in a new era of expansion and renovation. Major projects and programs include BART to Silicon Valley (SVRT - Silicon Valley Rapid Transit), Warm Spring Extension, West Dublin Station, Oakland International Airport Connector, and System-wide Seismic Enhancement. BART is also working on the planning of many other programs in both the short term and long term. The BART Extension proposes a 16-mile extension of BART service from southern Fremont into Santa Clara County. Entire proposed BART alignment will be dedicated railway with seven new stations. BART trains would operate on average headways of six minutes, based on estimated 2025 service levels. About 120 new revenue vehicles are projected to operate the BART extension. It was in such context BART developed the comprehensive and all-discipline BART Facilities Standards (BFS) that capable of serving the needs.


This paper introduces the Neihu rapid transit system, which was contracted to Bombardier in June 2003. The Neihu Line, in the City of Taipei, Taiwan, is an extension of the existing Muzha Line. The Neihu line rapid transit system includes the following system-wide elements: (1) 202 new rubber-tired vehicles, to be configured in married pairs and operated as 4-vehicle trainsets; (2) for both the Neihu and Muzha lines - a communications-based automatic train control (ATC) system, the Bombardier* CITYFLO* 650 ATC technology (formerly known as Flexiblok* ATC); (3) power supply and distribution system; (4) platform screen doors; (5) communication system; (6) Neihu depot workshop equipment; (7) a new main control center at the Neihu depot and a new redundant control center at the Muzha depot; and (8) the retrofit of the existing 102 Muzha line vehicles. A key feature of the seamless


Today, detailed railway timetables in Sweden are published up to a year in advance, despite being based on volatile facts. The authors describe a new railway planning concept for Banverket, the Swedish National Rail Administration, which aims to reduce the workload and increase the timetable quality, thus making railway traffic more cost-effective and attractive. The concept distinguishes between deliverables and production plans. The former are settled early and involve a selection of arrival and departure times that Banverket promises to deliver to the operators. The latter are fixed later and only when sufficient information is available.


This paper on automated system testing of an automatic train protection system is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors note that automated testing has the advantage that the tests can be carried out much more frequently and with more numerous test cases. For low level unit testing, there are several good tools available, such as Aunit. For system testing, however, the test framework normally has to be specifically tailored for each project, since it has to deal with external interfaces, e.g., man-machine-interfaces, and sensor and control interfaces. The authors present an automated system testing framework for an SIL 4 safety critical train protection system. This system is able to serve both in a pure software setup, where most of the development is done, and in a hardware set-up, which is as close as possible to the environment where the product shall operate. The proposed testing framework can also extract its test cases from readable Test Specification documents and produce high quality Test Protocol documents. The authors discuss the use of this system for the development of STMs (Specific Transmission Modules) for Sweden, Norway and Finland. The STMs carry out train protection on national equipped lines that are not equipped with the ERTMS (European Rail Transport Management System). A total of approximately 1300 test scenarios are executed by the automated testing framework.

In Japan, over 60% of traffic accident fatalities are the result of vehicle collisions with pedestrians/bicyclists and intersection collisions. These accident types are difficult to prevent using vehicle based technology alone. In order to help reduce such accidents in the real world, technology with the potential for relatively easy actualization and wide deployment is important as well as the system performance. We have to consider making use existing equipment and equipment that is available to almost everyone. This paper describes safety support systems which are actualized or being actualized in Japan for those kinds of accident types.


This paper describes how the safety of life applications have high importance in today’s traffic as current statistics show. In particular active safety applications are at the center of research activities, focusing on vehicle to vehicle communications as it is easier and cheaper to deploy as well as more effective in most situations. This approach has also to be followed for railway traffic. However, different vehicle types have different characteristics and therefore different requirements to their communication systems and the communication networks in particular. The paper identified the need for an adapted Medium Access Control (MAC) protocol, called the Cell-based Orientation-aware MANET Broadcast (COMB) protocol that fulfills the requirements of the train specific scenario and overcomes the drawbacks of all existing approaches. COMB is based on localization aware cross layer dimensioned CDMA cells, and uses the SOTDMA protocol as an intra cell scheme, while the inter cell scheme relies on direction and speed awareness. Therefore, it can cope with the trains’ speed and their need for a robust communication.


This article describes a new technology that is undergoing testing for inspecting defects in railcar wheels—while the cars are moving. The new method, known as the Automated Cracked Wheel Detection (ACWD) system, uses specially designed ultrasonic probes and detection algorithms to spot shattered rim cracks and tread cracks in wheels along one side of the train as it moves at four to five miles per hour. The article describes the types of cars that have been tested, and the results of visual versus the new method in finding cracks or other flaws.


This paper analyzes methods and models for ITS applications in freight transport. A new interpretation is provided, which collects and groups studies into five macro-categories, according to the spatial context in which the supply chain works. The analysis is based on the approaches adopted by different authors: statistical surveys, “what if” and “what to” analyses and project proposals.

New rail vehicles are routinely purchased with state-of-the-art traveler information systems. These systems vastly improve the ridership experience and reduce train operator workload and distractions by automatically providing automated audible and visual announcements to travelers on board. Upgrading an existing older fleet with new equipment may be difficult as these vehicles may have limited ability to support installation of the new equipment. This paper will address in detail the challenges of updating an older fleet with new equipment. This paper will first discuss passengers’ expectations of interacting with the state-of-the-art traveler information system installed on an agency’s fleet of newer buses and/or rail vehicles. Inequities may be perceived when these expectations transfer to older vehicles without new systems. Next, the authors will present an overview of system functionality followed by a summary of typical design challenges faced installing new traveler information systems in an existing fleet. This will be followed by a discussion of design methodologies that address these challenges. Finally, system implementation issues including training, community outreach, and system cutover will be discussed.


Compared to automobiles on roads, trains have less degrees of freedom as they are bound to railroads. Thus, it should be more straightforward to let them drive autonomously compared to automobiles. Several autonomous trains and subways already exist; however they operate on closed tracks. Typical examples are airport trains, also known as people movers. This paper sketches the conceptual, technical and legal challenges towards autonomously driving trains on existing railroads that are freely accessible and thus require reliable obstacle recognition. The authors try to generalize the experiences made so far in several large-scale research projects that aim at automating small, secondary railways. The authors summarize the results of a prototypical autonomous train system that we called autoBAHN.

Gely, L., et al. (2010). *A Multi Scalable Model Based On a Connexity Graph Representation.*

This paper on a multi-scalable model for simulating railroad infrastructure is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors posit that, when considering problems such as online rescheduling of trains, experience shows a pitfall in the communication between the different elements that compose them, namely simulation software (in charge of projection, conflict detection, validation) and optimization tools (in charge of scheduling and decision making). An exhaustive description of the whole network is usually counter-productive in optimization problems; the description must be accurate, but should rely on a less precise representation. Therefore, the authors propose a model that uses a new description of the infrastructure that permits one to scroll between different description levels. These operations can be automated via dynamic aggregation and disaggregation methods. They allow one to manage heterogeneous descriptions and cooperation between various tools using different description levels. This model is based on the connexity graph representation of the infrastructure resources. The authors focus on how to generate corresponding mathematical models based on resource occupancy and will show how the aggregation of resources leads to the aggregation of properties (such as capacity) that can be translated into mathematical constrains in the optimization problem. The authors conclude that this model can be applied to any traffic management problem involving resource allocation.
This paper describes how reliable driverless operation requires specific features implemented at system and subsystem levels of the train control system. Communications-Based Train Control (CBTC) is now proven as the best choice for driverless systems because of the inherent high levels of safety and reliability with a low life cycle cost. This paper proposes a systematic approach that may be used to determine the most efficient way to fulfill the requirements specific to each customer faced with driverless operation (green field or redesign signaling). It also defines “must have” requirements (functionality) to obtain the desired performance and cost. The paper also addresses issues related to the operability, maintainability, and availability of different types of driverless CBTC systems implementations, and the advantages and disadvantages of each solution.


This paper closely looks at the subject of the conversion of a conventional metro line into a fully automated operation without interrupting or disturbing the service. The introduction presents the Line 1 Automation project as one of the principal aspects of Paris metro’s network modernization plan that was announced by the Régie Autonome des Transports Parisiens (RATP). Next, the paper gives an overview of the present line 1 and illustrates the decision key elements for choosing it as a target of a fully automatic operation. The following section describes the development of the line 1 model and shows the results made so far. Finally, the paper explains the conclusions of the present work and the outlooks of the line 1 automation project.


ERTMS is the standard railway control-command and signaling system which aims to ensure railway interoperability throughout Europe while enhancing safety and competitiveness. ERTMS is composed of two main subsystems which include GSM-R, a radio system for enabling communication between the train and the traffic management center and ETCS, an automatic train protection system (ATP) to replace the existing national ATP systems. The ERTMS specifications are defined by means of standard documents which set out the requirements ensuring interoperability. These documents evolve regularly to give rise to successive versions. The ERTMS/ETCS standard defines different levels and operation modes according to various trackside and onboard setups and some operational conditions. Given the complexity and the high criticality of railway operation, verification and validation (V&V) are crucial tasks in railway application development. In this paper, after setting the background and the motivations, a mechanizable formalization of a subset of ERTMS/ETCS specifications relative to ETCS modes and transitions is developed. The present work aims to offer a readily available model for formal V&V. Using formal techniques to check SRS is highly recommended to tackle the complexity of the defined requirements and prevent specification errors. Model-checking technique, which is targeted here, offers exhaustive analysis of the system behavior based on its model and is highly automated, since it is supported by software tools. Based on the last available version of SRS specifications, a progressive process is undertaken to get a formal model which makes explicit the various modes characterized by their respective active functions, as well as the numerous combinations of conditions for switching between modes. The various steps guiding the translation of the SRS literal specifications into a formal model are explained. As will be shown through different examples, the obtained model is a convenient basis to check safety, interoperability and liveness properties.

This paper describes how there is an increased demand for better and safer mass transport systems nowadays. The supervision and control of these systems is made through an architecture known as Automatic Train Controller (ATC). The use of processors in ATC provides new challenges in safety analysis. A typical railway system has a Speed-Distance Profile Generator that determines the maximum allowable speed in each track circuit. Dangerous situations are verified through the relative positioning and speeds between trains, switching machine positioning and other restrictions from operational commands generated by the ATC. Independent Safety Auditors should consider the failure modes of hardware and software and the safety analysis should consider alternative techniques to complete the complex task of evaluating how safe is the use of the processor and its associated software. Therefore, the use of simulation can improve and increase safety analysis, searching for fault states that could not be found in a static analysis. The main goal of this paper is to describe the development of a tool that simulates the behavior of trains’ movement in a subway system, with boolean expressions. The set of boolean expressions coordinates all the movements in a subway line and the simulation provides the possibility to find out lack of safety, considering different combinations in those boolean expressions. Another important goal is to simulate equipment faults in order to investigate problems not visible in a static analysis or even in a practical field test. Preliminary results have shown that the use of a simulator to execute boolean expressions offers a great variety of tests, allowing the detection of unsafe situations, complementing software tests validation in a final release. Through simulation, it is possible to observe the behavior of simulated objects in specific internal points which improves the completeness in safety analysis.


Determination of fleet size of locomotives and of a policy to deadhead them are tactical issues that influence the level of customer service in a rail network. This paper considers a railroad system in which a priori freight train schedule does not exist. A simulation-based approach is proposed for tactical locomotive fleet sizing. The study shows that the throughput increases with the number of locomotives up to a certain level; after that the congestion caused by the movements of large number of locomotives in the capacity-constrained rail network offsets the potential benefit of a large fleet.


Smart Objects and Internet of Things are two ideas that describe the future. The interconnection of objects can make them intelligent or expand their intelligence. This is achieved by a network that connects all the objects in the world. A network where most of the data traffic comes from objects instead of people. Cities, houses, cars or any other objects that come to life, respond, work and make their owner’s life easier. This is part of that future. But first, there are many basic problems that must be solved. In this paper we propose solutions for many of these problems: the interconnection of
ubiquitous, heterogeneous objects and the generation of applications allow inexperienced people to interconnect them. For that purpose, we present three possible solutions: a Domain Specific Language capable of abstracting the application generation problem; a graphic editor that simplifies the creation of that DSL; and an IoT platform (Midgar) able to interconnect different objects between them. Through Midgar, you can register objects and create interconnection between ubiquitous and heterogeneous objects through a graphic editor that generates a model defined by the DSL. From this model, Midgar generates the interconnection defined by the user with the graphical editor.


The enormous potential of combined transport (rail-road) makes rail the main alternative to the transport of freight by road in the Europe. Unfortunately, the European railway network is strongly fragmented, having different bottleneck points. This paper presents research that centers on the transhipment tasks in the Port Bou terminal. This terminal is a bottleneck point because of the different track gauges of the Spanish and French railways. In order to optimize the use of gantry cranes and the means available for train-train transhipment, a linear programming model that allows for the automation of container transhipment plans is proposed. An analytic decision support application is used to develop the model. As a result of this research it can be concluded that the problem can be solved through linear programming and the model proposed could be transferred both to other transhipment terminals and to cargo terminals in general.


North American rail terminals need productivity improvements to handle increasing rail volumes and improve terminal performance. This paper examines the benefits of double cycling in wide-span gantry terminals that use automated transfer management systems. The authors demonstrate that the use of double cycling rather than the currently practiced single cycling in these terminals can reduce the number of cycles required to turn a train by almost 50% in most cases and reduce train turn time by almost 40%. This change can provide significant productivity improvements in rail terminals, increasing both efficiency and competitiveness.


The Union Internationale des Chemins de Fer (UIC) has awarded ELOG AB (ELOG) to develop a fully functional Common Communications Interface with a web service based Metadata Management System and two industry Reference Files (hereetofore called TAF-TSI Common Components System)
which conform to the requirements of the Telematics Applications for Freight Technical Specification for Interoperability as listed in point 1(b) of Annex II to Directive 2001/16/ECn adopted by the Member States on 23 December 2005 and published as Commission Regulation (EC) N° 62/2006 on 18 January 2006. The TAF TSI Common Components System will be used by Railway Undertakings, Infrastructure Managers and other stakeholders to which Commission Regulation (EC) N° 62/2006 applies, also including stakeholders outside the EU electing to use these components voluntarily. The development of the Common Components System and Common Interface will be developed, supported and maintained by ELOG with starting date February 2009. Estimated project end date will be 31 months from start date with a 5 years maintenance period. First reference version of Common Components and Common Interface will be delivered end of 2009.


The train carried ATP (Automatic Train Protection) system is the main aspect of the ATC (Automatic Train Control) system. While acquiring MA (Moving Authority) information from track side ATP, a train carried ATP analyzes and outputs the speed restriction in real time. When the train speed approaches the speed restriction, ATP will alarm the driver when the train is over speed. ATP will then brake the train in an emergency. ATP plays such a vital role that it must be fully tested before put into service. A new testing method based on Infinity-Case Methodology and Virtual Instrumentation is proposed to meet test requirements under various conditions. Simulation and field tests imply that the test system is efficient, easy to use and can meet all the test requirements.


What has been learned from hosting over three million internet sessions on trains – one of the world’s largest hotspot? In 2004 the first fleet-wide commercial deployments of passenger internet was made by Swedish Railway’s and Great North Easter Railways (UK). With millions of user sessions on the train internet access service, there has been a great success, showing the highest uptake numbers for any onboard service. What is the experience gained from this massive experience? What are the user preferences and how should internet services be designed to provide a positive business case for train operators? What are the technical requirements and how can technology be handled over time? What do user surveys indicate regarding other requirements and how should train operators reason when introducing a new service today? The paper aims to describe Icomera’s unique experience with examples of both successes and failures.


The need for intermodality is stressed by policy makers to avoid congestion on roads and improve the environmental performance of transportation. Shifting transport flows from unimodal road transportation to intermodal transportation in port hinterland transit does also involve the potential advantage of cost reductions. The aim of intermodality is to facilitate transportation that is competitive on the transport market by combining comparative advantages of different modes. RAILPORT SCANDINAVIA is the Port of Gothenburg’s business concept to formalize and structure the interoperability concerning intermodal railway transports for distribution and consolidation of unit load goods to and from the Port of Gothenburg. One part of the project concerns if and how Auto-ID technology can be utilized to create added business value for the involved supply chain parties between the port and inland terminals.

Computer-based controls of transportation systems, industrial plants, sundry machinery, and consumer items became ubiquitous in the last quarter of the twentieth century. The microprocessor -- the heart of the microcomputer, microcontroller, programmable logic controller, and indeed today's workstations, servers, and even mainframes -- is the enabling technology behind these digital control systems. The behavior of computer-based controls is determined by the combination of kernel, operating system, and application software that the controlling computers execute. Today's multi-gigahertz and -gigabyte computer-hardware technology has seen a concomitant growth in the size and complexity of software development environments, i.e., in specification tools and languages, compilers and programming languages, and semi-automated tests. The quantitative aspects - size, speed, complexity - of the contemporary versions of these technologies have given rise to the general impression that hardware software architectures and software-development methodologies have changed fundamentally, i.e., qualitatively, from those of the 1960s. This is not the case, even for the vast majority of computer-based control applications in transportation, aerospace, and factory automation. To paraphrase a famous line in a famous film, the methodologies are the same, only more so. The notions safe software, along with those of secure software and trusted software, concern the real-world function, purpose, or 'meaning' of computer programs. Though not the stuff of daily headlines (but certainly the stuff of occasional, sensational ones), the correctness of software - it does what it's supposed to do - has been the subject of great effort from Computing Science's inception. This paper elaborates the issue of software-correctness, as it manifests itself in safety-critical (vital) transit applications; and describes emerging Best Practices in this area, including the safety-critical project life-cycle and an approach to safety certification. The paper also addresses cultural and economic influences that affect the education and training (a distinction with a difference) of the Software Engineering labor force, and that affect transit properties and their contractors, and provides an example risk assessment of the NYCT Canarsie Line safety-critical Communication Based Train Control (CBTC) transit system.


There are approximately 240,000 highway–rail grade crossings in the United States. High crash frequencies at these locations have led to continued research in safety modeling. Existing crash models for highway–rail grade crossings can be classified into two categories: models for predicting accident frequency and models of the severity of driver injuries. The majority of these studies have focused on the first category. Few studies have focused on the severity of injuries to motor vehicle drivers at highway–rail grade crossings. The objective of this study was to determine the contributing factors that influence the severity of driver injuries in accidents at highway–rail grade crossings. Probit models showed that the following factors were significant: whether the crash occurred during the peak hour, weather, visibility, vehicle type, vehicle speed, annual average daily traffic, train speed, driver age and gender, area type, and type of highway pavement. A marginal effects analysis was also conducted to quantitatively interpret the marginal effects of the contributing factors on each severity level for the highway driver.
Hartwig, K., et al. (2006). Requirements for Safety Relevant Positioning Applications in Rail Traffic—a demonstrator for a train borne navigation platform called "DemoOrt ″. National Research Council Canada: 7th World Congress on Railway Research WCRR, Montréal, Canada.


Both coordinated-actuated signal control systems and signal priority control systems have been widely deployed for the last few decades. However, these two control systems are often conflicting with each due to different control objectives. This paper aims to address the conflicting issues between actuated-coordination and multi-modal priority control. Enabled by vehicle-to-infrastructure (v2i) communication in Connected Vehicle Systems, priority eligible vehicles, such as emergency vehicles, transit buses, commercial trucks, and pedestrians are able to send request for priority messages to a traffic signal controller when approaching a signalized intersection. It is likely that multiple vehicles and pedestrians will send requests such that there may be multiple active requests at the same time. A request-based mixed-integer linear program (MILP) is formulated that explicitly accommodate multiple priority requests from different modes of vehicles and pedestrians while simultaneously considering coordination and vehicle actuation. Signal coordination is achieved by integrating virtual coordination requests for priority in the formulation. A penalty is added to the objective function when the signal coordination is not fulfilled. This “soft” signal coordination allows the signal plan to adjust itself to serve multiple priority requests that may be from different modes. The priority-optimal signal timing is responsive to real-time actuations of non-priority demand by allowing phases to extend and gap out using traditional vehicle actuation logic. The proposed control method is compared with state-of-practice transit signal priority (TSP) both under the optimized signal timing plans using microscopic traffic simulation. The simulation experiments show that the proposed control model is able to reduce average bus delay, average pedestrian delay, and average passenger car delay, especially for highly congested condition with a high frequency of transit vehicle priority requests.


The Federal Railroad Administration (FRA) tasked the John A. Volpe National Transportation Systems Center (Volpe Center) to conduct a reliability analysis of the four-quadrant gate/vehicle detection equipment installed on the future high-speed rail (HSR) corridor between Chicago and St Louis. A total of 69 highway-rail grade crossings on a 121-mile (195 km) segment of the 280-mile corridor were equipped with four-quadrant gates and inductive loop vehicle detection technology. This segment, between Mazonia and Springfield Illinois, will eventually carry passenger trains at speeds up to 110 mph (177 km/h) at many of the highway-rail grade crossings. The analysis was based on maintenance records obtained from the Union Pacific Railroad, the owner and operator of the highway-rail grade crossings. The results were used to assess the impact of the equipment reliability on the proposed HSR timetable. The Volpe Center study showed that the total average delay to the five scheduled daily high-speed passenger round-trips was an estimated 38.5 minutes, or approximately 4 minutes per train. Overall, extensive analysis of the trouble ticket data showed that the four-quadrant gate and vehicle detection equipment had a minimal direct impact on the frequency and duration of grade crossing malfunctions.

Sky Harbor International Airport has considered a transit system to connect its key facilities in the long term planning of the airport since the development of its newest terminal in the late 1980’s. After careful transportation planning and design, the Airport is now constructing the PHX Sky Train, an automated people mover system that goes beyond just connecting key airport facilities. The Sky Train will also: enhance the airport's long term ability to grow; provide a vital transit link to the region; utilize transit oriented design principles that enhance growth opportunities and livability for the community; reduce local roadway congestion; and use sustainable design and construction methods. The development of this robust transit system requires several unique design features and the undertaking of a complex facility construction program. The Sky Train is a predominantly elevated, five-mile long automated people mover system that will run through and connect key existing and future airport facilities with strategically located stations — Terminals, parking areas, ground transportation centers, Metro Light Rail and Rental Car Center. This paper will focus on the features of the Sky Train planning and design that enhance the airport and surrounding community along with an update on how the ongoing construction is meeting the challenges of building this complex system through a busy international airport.


The Wavetronix Matrix Radar was adapted for use at four-quadrant gate railroad crossings for the purpose of influencing exit gate behavior upon the detection of vehicles, as an alternative to buried inductive loops. Two radar devices were utilized, operating collaboratively, in order to realize a fully redundant system. Performance variables including vehicle size and location, vehicle occlusion, and radar positioning were evaluated, along with sensitivity to rain, snow, and other environmental conditions. Recommendations for utilization of the radars in conjunction with popular crossing warning system controllers are provided. Also included is a means for detecting vehicles that are stopped, stored, or deliberately placed in the crossing island, and rapidly communicating that information across cellular, positive train control (PTC), incremental train control system (ITCS), and advanced civil speed enforcement system (ACSES), and other data networks.


The transition from M2M towards an IoT is mainly characterized by moving away from closed silo deployments to openness, multipurpose technologies, and innovation. This transition is triggered by a set of megatrends and global game changers that present new challenges and opportunities. The transition is characterized by the following: moving away from isolated solutions to an open environment; the use of IP and web technologies; the Internet; multimodal sensing and actuation; and knowledge-creation technologies. Together, these forces create capabilities and drivers that form the basis of the evolution from M2M to IoT.
In this chapter, we present an overview of technology fundamentals—building blocks—that form the basis of M2M and IoT. Here, we cover devices and gateways, local and wide area networking, data management, business processes, cloud and analytics technologies. Devices form the basis of the Internet of Things and provide functions for sensing and actuating in the physical world. Local and wide area networking provides these with the necessary infrastructure to connect to services, using Wireless Sensor Networks to form multi-hop architectures with gateway sensor nodes that provides WAN connectivity towards the backhaul network. Data management handles essential functions such as data acquisition, validation and storage, and makes sure that critical information is available at the right point in a timely manner, and in the right form. Business processes refers to the series of steps to perform management, operational and supporting activities for achieving specific mission objectives.

XaaS is used as a general term to describe the functions provided as a service by cloud infrastructures, such as computational capacity, software, networking and storage. Analytics are used to extract additional value from data generated by devices and enable new opportunities by using data from devices for multiple purposes, most of which will not be imagined at the time of deployment. Knowledge Management Frameworks provides functions that provide the ability to understand data-generated information and use existing experience within a certain decision-making context. Local and wide area networking provides the necessary infrastructure to connect devices to services, using Wireless Sensor Networks to form multi-hop architectures with gateway sensor nodes that provides WAN connectivity towards the backhaul network. Data management provides essential functions such as acquisition, validation and storage of data and makes sure that critical information is available at the right point in a timely manner, and in the right form. Business processes refers to the series of steps to perform management, operational and supporting activities for achieving specific mission objectives.


The UK Department of Transport is procuring up to 2,000 new trains and cars for the Intercity Express Programme (IEP). This article describes this procurement initiative, which was formerly known as the High Speed Train 2 (HST2) project. This is the largest train procurement project ever commissioned in the UK. The procurement process is unique in that bidders must provide both trains and financing, alone or in a consortium. Manufacturers and financiers currently are forging partnerships in anticipation of the IEP. The Department of Transport is procuring the trains on behalf of train operators and will presumably expect the train operators to enter into the supply contracts towards the end of the process.


This article discusses the ways in which the quest for improved performance and a more cost-effective railway is changing the understanding of railway signalling - train control. The history of signalling going back to the incorporation of the Institution of Railway Signal Engineers in 1912 is presented, along with the evolution of the technology - from mechanical signalling to software-based automatic control.
systems, from basic telegraphy to sophisticated communications networks. Information technology, automation, reliability, resilience, security, flexibility and environmental friendliness all have their place in this era of change - they are all issues that the modern signal engineer must explore in order to meet the more complex demands of the future railway.


It has been fourteen years since RATP (Autonomous Operator of Parisian Transports) launched driverless trains on Line 14 of the Paris metro, and since that time driverless metro lines have been deployed in several countries, with unattended operation accounting for around two-thirds of all new metro projects. RATP is now converting an old line with manually-driven trains (Line 1) to driverless operation, and this article presents the details of the conversion, including testing, operations and future projects.

Hulse, J. D. and F. Bourgoin (2007). Integration of Automation into Urban Rail Transit. This paper describes how the coming decade will bring many changes to public transit and significant increases in ridership demand and the additional demand for value-added services, which are coupled with ever increasing energy costs are anticipated. The end result will be an intense focus on services. One of the means to help transit management deal with these often conflicting requirements is to increase the reliance on automation and technology. Communication Based Train Control (CBTC), allowing increasing levels of automation, provides examples of how we can help transit management respond to 21st century demands, but these are also examples that are difficult to achieve in practice. How do we overcome the gap? This paper discusses the means and methods used to better define system requirements, integrate new technology into the organization, design for system efficiency, safety and reliability, and develop a work force capable of maintaining high levels of safety and reliability. Bombardier Transportation is the global leader in the development, design and supply of automated transportation systems for urban and airport applications. Since the debut of the world’s first automated people mover (APM) system at Tampa International Airport in 1971 and through the parallel development of the Advanced Rapid Transit (ART) technology in the 1970’s, as well as the first radio CBTC system in service, Bombardier has remained at the forefront of the introduction and development of full automation through CBTC. This paper presents an overview of the process that has been developed over the years, to successfully integrate a modern CBTC automated train control system into the latest rail transit vehicle technology used for the Yongin Rapid Transit System in South Korea. The paper also provides an end-to-end view of the requirements, design, development, testing and delivery of the system.


One potential solution for reducing horn noise from a locomotive is a stationary horn mounted at the crossing. This “wayside horn” is sounded in place of the locomotive horn when a train approaches and is positioned to direct the sound precisely down the intersecting roadways rather than along the track. A wayside horn can therefore operate at a lower sound level than a locomotive horn and produce less area sound exposure. The objective of this project was to evaluate a wayside horn produced by Railroad Controls Limited. The authors conducted the evaluation through observation of a test installation in Rocky Mount before and after wayside horn installation. Before wayside horn installation, the site had a typical array of safety devices (gates, lights, signs, and marking). The site was a nearly ideal crossing of a road with one through lane in each direction of a single track with low train volumes.
and speeds in a moderate density suburban area. The authors examined the reliability of the system and also measured sound in the area, motorist behavior, motorist opinion, area resident opinion, and train engineer opinion. Based on the results from previous studies and the results from this test, the study team concluded that the wayside horn offers significant sound relief to residents and others in the area around a crossing. The team also concluded that the wayside horn has led to slight, if any, shifts in driver behavior and opinion. Finally, the study team concluded that the wayside horn appears to be reliable and acceptable to train engineers. The team recommends that the North Carolina Department of Transportation, other relevant agencies, and railroads continue to allow wayside horns.


This paper suggests the safety evaluation software tool for a train control system. The evaluation tool has the form of expanding the existing automated software test tool and the evaluation items required by standards are performed in the form of a dynamic test using the results of safety activities derived from the software development cycle as the input. The paper includes key evaluation items required by international standards and uses them during the development lifecycle of the software. The function to validate whether the safety is maintained or not continuously by using the results of safety activities performed at the software design stage as the input into the testing tools was added.


The paper contains an overview of unique identification issues and of the various radio frequency identification techniques that are available now or will become available in the short term. The paper also compares RFID with traditional ID technologies. It shows application possibilities and gives examples of current implementations. Each application has its own requirements that translate into specific RFID-techniques, -options and -parameters. Techniques include frequency range, tag energy supply and tag writing capabilities. The data to be stored in the tag and transferred to the reader must be selected as one of the options. Parameters influence reliability and confidentiality, among other things. Information interchange issues of identifier-based operations in supply-chains are discussed as well, while the last part of the paper presents a framework for choosing an auto-ID technique in a supply chain.


Phoenix, the nation's 5th most populous city, is undertaking a $1-billion people-mover project to shuttle Sky Harbor International Airport employees and visitors in air-conditioned comfort. The initial $625-million, 1.92-mile-long segment of the elevated PHX Sky Train will connect METRO's light-rail station at 44th and Washington streets with the Airport's 4,630-space economy parking lot east and 88-gate Terminal 4, which serves 80% of Sky Harbor's passengers. The project is being underwritten by pay-as-you-go project financing through airline fees, passenger surcharges, and airport revenue, with some funds coming from 20-year general aviation bonds.

Inro, T. and E. Bastiaensen "Deployment Scenarios for Advanced Driver Assistance Systems."


This project was an implementation of a pilot system produced by Bentley Systems, Incorporated (Bentley) on behalf of the New York City Transit Authority (NYCT) and sponsored by the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Transportation (NYDOT). The objective of this pilot project was to demonstrate that the safety and reliability of the New York City Transit transportation system can be improved by automating the correlation and analysis of disparate track related data. Through the use of the supplied technology NYCT is able to use synthesize traditionally disparate data sets into focused and actionable information. Bentley's Corridor Infrastructure Management (CIM) system was used to fuse multiple types of track related data into a single system and enabled the visualization of information with track charts and geographic maps. Furthermore, the CIM enables the identification of existing and anticipated problems along with indications of cause and effect relationships. Through continuing usage of the pilot system, NYCT has concluded the capabilities of the pilot system enable NYCT to visualize the actual track network. This includes knowing the type of track (Type I, Type II, Type IIM, etc. (e.g., ballasted, guarded curve)) as well as the environmental conditions in the tunnel (Dry vs. Wet). Most importantly NYCT can see for the first time the combined data from multiple inspections by displaying the defects from these inspections on the map or track chart. Clusters and areas prone to certain types of wear are immediately apparent. Planning maintenance work with this type of tool promotes more efficiency. A maintenance manager can sort the defects within a stretch of track, identify his work gang and material needs and schedule the work between point A and point B, with all this information on display and at their fingertips. In the past she or he would have to compile the information from the database by hand and mentally plan the job without the visual display. When doing the work by hand, a manager or supervisor would not look at more data then was minimally necessary. They would not see the whole line or even an extra mile or so down the track to take into account the bigger picture or a more effective solution. Multiply this with the fact that many work gangs receive assignments daily and the task of planning work effectively and efficiently suffers.


The introduction of the Autonomous Decentralized Transport Operation Control System (ATOS) to conventional lines in the greater Tokyo area is underway at JR East. Starting with the Chuo Line in 1996, ATOS is a large-scale train operation control system that has been introduced to 19 lines in the greater Tokyo area in order. Due to the fact that 15 years have passed since its introduction to the Chuo Line, JR East is going to launch a full-scale system update of ATOS in fiscal 2011. Hardware and software structures will be downsized and streamlined in the update to optimize the total system, improve functionality and remove outdated devices. All this will be done while adopting the newest technologies. To reduce the costs of renovation, system modifications will also be made easier to carry out.

The purpose of this Innovations Deserving Exploratory Analysis (IDEA) project was to develop an economical on-board wheel monitoring system for railroad applications that will improve railroad safety by reducing complete component failure. The Autonomous Rolling Stock System (ARMS) will provide warnings to train operators as well as railroad car owners before the component failure occurs such that preventive maintenance can be performed on a scheduled basis. There is currently a patent pending on this system. The ARMS unit is a small electronics package which attaches directly on the outer hub of a train car wheel. It forms its own network and communicates important data and trends to a central data collection unit on the train for transmission to a central database external to the train.


Vehicular communication systems facilitate communication devices for exchange of information among vehicles and between vehicles and roadside equipment. These systems are used to provide a myriad of services ranging from traffic safety application to convenience applications for drivers and passengers. In this paper, we focus on the design of communication protocols for vehicular access networks where vehicles access a wired backbone network by means of a multi-hop data delivery service. Key challenges in designing protocols for vehicular access networks include quick adaptability to frequent changes in the network topology due to vehicular mobility and delay awareness in data delivery. To address these challenges, we propose a cross-layer position-based delay-aware communication protocol called PROMPT. It adopts a source routing mechanism that relies on positions independent of vehicle movement rather than on specific vehicle addresses. Vehicles monitor information exchange in their reception range to obtain data flow statistics, which are then used in estimating the delay and selecting best available paths. Through a detailed simulation study using ns-2, we empirically show that PROMPT outperforms existing routing protocols proposed for vehicular networks in terms of end-to-end packet delay, packet loss rate, and fairness of service.


Recently, vehicular communication systems have attracted much attention, fueled largely by the growing interest in Intelligent Transportation Systems (ITS). These systems are aimed at addressing critical issues like passenger safety and traffic congestion, by integrating information and communication technologies into transportation infrastructure and vehicles. They are built on top of self organizing networks, known as a Vehicular Ad hoc Networks (VANET), composed of mobile vehicles connected by wireless links. While the solutions based on the traditional layered communication system architectures such as OSI model are readily applicable, they often fail to address the fundamental problems in ad hoc networks, such as dynamic changes in the network topology. Furthermore, many ITS applications impose stringent QoS requirements, which are not met by existing ad hoc networking solutions. The paradigm of cross-layer design has been introduced as an alternative to pure layered design to develop communication protocols. Cross-layer design allows information to be exchanged and shared across layer boundaries in order to enable efficient and robust protocols. There has been several research efforts that validated the importance of cross-layer design in vehicular networks. In this article, a survey of recent work on cross-layer communication solutions for VANETs is presented. Major approaches to cross-layer protocol design is introduced, followed by
an overview of corresponding cross-layer protocols. Finally, open research problems in developing efficient cross-layer protocols for next generation transportation systems are discussed.


As the Chinese transport system began to develop rapidly, researchers became highly concerned about the reform of wagon flow organization. The traditional modeling and optimization method of wagon flow organization based on concentrated decision-making doesn’t sufficiently support the exploration to the decision process and method of wagon flow organization with the innovation for railway transport mode currently. In this paper, the authors study the decision-making method of wagon flow organization, which is based on distributed autonomous decision-making in a manner of competing resources according to different wagon flows property in the process of organization. Each distribution agent competes and cooperates with the other according to competing ability in order to make more profit, the system arrived the state of global optimization in the process of conflict and coordination. Furthermore, a multi-agent model on wagon flow organization is presented. The modeling method is tested on experimental computation.


This article examines the possibilities for driverless operation of high-speed trains in Spain. The author, a rolling stock technical director for Renfe, suggests that unattended train operation in high-speed environments could be possible in the future, but that changes would have to be adopted first. The author describes the signaling systems that support the use of automatic train protection as the European Rail Traffic Management System (ERTMS), the driving modes of the Spanish high-speed rail, and aspects of high-speed environments compared to those of driverless systems. He also suggests there is a psychological effects on passengers of driverless operation of high-speed rail.


The ability of second generation train detection technologies to accurately measure train speed is evaluated. Train speed data were collected using video detection and Doppler radar at two locations in Nebraska, U.S. Then, these train speed measurements were fused using a discrete Kalman filter model and the speed data from Doppler radar, video detection and Kalman filter were compared using two measures of effectiveness (MOEs): RMSE and MAPE. The results show that both video and radar provide accurate train speed measurements and that a Kalman filter can reduce the noise in the speed measurements over that found in either sensor.


Positive Train Control (PTC) systems ensure train safety by enforcing observance of signal aspects and maximum authorized speed, temporary speed restrictions and stops for interlocking signals displaying a stop aspect. To achieve this level of safety through an automated system, certain worst case assumptions must be made regarding train performance and track conditions that are not known
to the system. There is also error that is inherent in train location information available to the PTC system which must be accounted for. For these reasons, trains will perform differently in the presence of a PTC system than they would if these operating conditions were left to be enforced by the engineer through adherence to rules and instructions. These differences in train performance will have an impact on train operations in the future under various PTC implementations. There are also design and implementation decisions that can affect and potentially alleviate some of these performance impacts. Until these various PTC implementations are in operation the only way to truly know the extent of these impacts and the potential benefit of various design decisions is through simulation. This paper will discuss the simulation of train operations under a system without PTC installed and under the same system with PTC installed. Specifically this paper will focus on the Advanced Civil Speed Enforcement System (ACSES) which has been installed on the North East Corridor and is currently in use by Amtrak.


Train scheduling is one of the most important and complex elements in the planning process for railway operations. However, this task is still done manually at the Taiwan High Speed Rail Company. The plan to add four stations and more than 100 additional daily trains in the near future necessitates the improvement of the quality and efficiency of the company’s train scheduling process. This research developed a novel two-stage hybrid method that efficiently automated and optimized the scheduling process for high-speed trains. The first stage applied a genetic algorithm to solve train sequencing problems. The resultant sequence was then sent to the second stage to determine the optimal timetable with linear programming techniques. Results from the linear programming model were sent as feedback to the first stage to determine the overall performance of the timetable by using the fitness function in the genetic algorithm. The timetable gradually evolved toward an optimal solution based on this iterative process. Experimental results demonstrated that this hybrid method not only improved the efficiency of the solution substantially but also provided better timetables compared with the current practice. The proposed method can help high-speed rail companies automate the scheduling process and improve the solution’s performance with efficiency.


Recent advances in wireless communications, especially the process called Wi-Fi, or Wireless Fidelity and Mobile IP, have made Internet connectivity possible in mobile environments. The “California Trains Connected project” aims to assist the Capital Corridor Joint Powers Authority and the California Department of Transportation to evaluate technology and business options and to assemble a decision framework and performance specifications for wireless Internet specifically operating in the three Intercity Rail service corridors subsidized by the State of California. Wireless Internet service will allow customers to conduct business or connect to websites for leisure, personal, or entertainment purposes. The cornerstone of the research is to define, specify and experiment innovative services offered both to passengers and train operators of a running train. Wireless internet access will also permit the train operators to utilize the Internet to improve ticket collection, public safety and security and implement other operational efficiencies. It is expected that such services will improve ridership on intercity trains and relieve congestion on interstate freeways.

This paper investigates an algorithm that optimizes the total energy consumption of multiple train operation that consider a DC feeding circuit. Our mathematical formulation includes several characteristics of trains which depend on feeding voltage. It makes it possible to give detailed consideration to an energy-saving operation. It is especially important for us to be able to discuss the influence of squeezing control of regenerating current and feeding loss. The paper constructed the optimizing algorithm based on the gradient method applicable to large-scale problems for future works. Several numerical examples are demonstrated to verify the reliability and validity of the proposed method. Every optimization result is obtained within a minute.

This paper describes how the ever growing demand for automation is among the fundamental forces driving technology change in the rail transit industry. Communications based train control (CBTC) is an example of train control automation that utilizes high-resolution train location determination, independent of track circuits; continuous high capacity, bi-directional train-to-wayside data communications; and trainborne and wayside processors capable of implementing vital functions. This automation helps overcome some limitations of traditional train protection systems such as poor resolution of locating trains, flexibility of recovery from failure conditions. Supervisory Control and Data Acquisition (SCADA) is another example of mechanical, electrical and plumbing automation. The SCADA provides centralized control, monitoring and supervision of elevators, escalators, pumps, lightings and supporting communication subsystems. As the demand for automation of vital and non-vital systems grow, the challenge of interoperability of these systems in the rail system environment increases due to the need for these technologies to function as an integrated system. This paper addresses and examines the demand drivers for automation across the rail transit industry first and then it examines current technologies that address some of these demands, such as CBTC, and SCADA. The paper further examines future technologies that may be able to address several expanding requirements for automation in an integrated manner. These include power, emergency procedures, communication sub-systems, SCADA, operational management and the latest generation of CBTC systems. It also examines innovative practices that can alleviate the burdens caused by the existence of several stand-alone automated systems in a rail system. Finally, the paper addresses issues, considerations and pros and cons of each system as a stand-alone and in an integrated environment in the context of security, and operations management.

In this paper, a new Controlled Vehicular Internet Access protocol with QoS support (CVIA-QoS) is introduced. CVIA-QoS employs fixed gateways along the road which perform periodic admission control and scheduling decisions for the packet traffic in their service area. The CVIA-QoS protocol is based on Controlled Vehicular Internet Access (CVIA) protocol that was designed only for the best-effort traffic. The most important contribution of the CVIA-QoS protocol is providing delay bounded throughput guarantees for soft real-time traffic, which is an important challenge especially for a mobile multihop network. After the demands of the soft real-time traffic is met, CVIA-QoS supports the best-effort traffic with the remaining bandwidth. Simulation results confirm that in CVIA-QoS protocol, the real-time throughput is not affected from the best-effort load and its delay is much smaller than CVIA.
delay when both the real-time and best-effort load exist in the channel. It has been observed that, unlike, CVIA-QoS, IEEE 802.11e with multi-hopping suffers from lower throughput and high number of real-time packet drops.


While some like the sound of a train’s whistle in the distance, those living closer to the tracks are looking for relief from the noise in the form of automated horn systems that can warn motorists without being excessively loud. This article describes federal regulations for locomotive engineers regarding how far from crossings they must sound their whistles, how automated horns work in tandem with crossing gates, and studies of the effectiveness of the automated horns. Wayside horn systems provide 20 seconds of warning and are focused only at crossing areas so they limit sound pollution. The author reports that wayside horn systems are active in Illinois, Kansas, Nebraska, Texas, and California. At a cost of $300,000, they are significantly less expensive than installing four quadrant gates at two crossings.


Simulation models of urban rail operations are valuable tools for analysis of the operations of complex rail transit systems. A framework is presented for the application of rail simulation that includes calibration, validation, evaluation methodology, and interpretation of results. Methods that can be used at each step to facilitate the application are discussed. In particular, approaches are presented for calibration of model parameters and inputs, such as dynamic arrival and alighting rates at stations. Application of simulation tools can be greatly enhanced by the use of train circuit occupancy data collected by automated control systems. A new rail simulation model, SimMetro, specifically designed for service performance analysis taking into account the major sources of uncertainty in operations, is also presented. A case study is used to illustrate the applicability of the proposed framework in testing alternative real-time control strategies.


This paper describes how the computer aided real time dispatching assistance of train runs is a hard and complex problem. Although several approaches for dispatching and train surveillance exists – often limited to very specific aspects and situations of computer aided train operation – an integrated
and flexible system covering train location, delay detection, computer aided (automated) conflict resolution and dispatching decision propagation is not available. The project DISKON is a development project initiated and assigned by DEUTSCHE BAHN AG that targets such a system. The proof of concept for this integrated approach has been made in 2007, when the system was tested several weeks at the Integrated Railway Laboratory (IEL) of the University of Dresden. In 2007 and 2008 the evaluation continued under real time conditions within operation control centers. Besides different modules and components for functionalities like train position detection, train run forecast, track assimilation and prognosis of arrival and departure times one scientific core of the DISKON system is a microscopic conflict solving component on blocking time level, enriched by another macroscopic component evaluating links of connection trains. The solving algorithm extends the ASDIS/L-system developed at the RWTH Aachen. It follows an asynchronous approach, considering conflicts chronologically and depending on priority values of the involved trains. The base algorithm was elementarily revised and enhanced by conflict situation detection and a derived conflict solving strategy builder. The result set of the strategy builder controls the parameter and the behavior of the base algorithm. A rough architecture of dispatching systems is introduced in this paper, system requirement, environmental condition and behavior are identified and a differentiated system evaluation is also presented.


The paper analyses the deployment of Intelligent Transport Systems (ITS) in Finland related to international trends as well as national and international policies. The paper includes an inventory of primary obstacles in ITS deployment and present models for efficient utilization of ITS. It is recommended to constantly seek for global success opportunities by large-scale pilots together with companion countries. The public sector should provide strategic leadership to the development and create prerequisites for ITS markets. Real-time network operation is a key task of the transport administrations. ITS actions should especially focus in large scale deployment of effective and efficient solutions. Such solutions include incident management, public transport services, eLogistics, urban mobility and traffic management, outsourced automated enforcement, road use charging, maritime traffic management, vessel traffic monitoring and control, train control, and utilization of satellite positioning. Finally, the paper recommends the roles and tasks for the Ministry of Transport and Communications Finland and its administrations.


Future high-speed trains are the main focus of the DLR research project Next Generation Train. One central point of the research activities is the development of mechatronic track guidance for the two-axle intermediate wagons with steerable, individually powered, independently rotating wheels. The traction motors hereby fulfil two functions; they concurrently are traction drives and steering actuators. In this paper, the influence of the track properties – line layout and track irregularities – on the performance requirements for the guidance actuator is investigated using multi-body models in SIMPACK®. In order to compromise on the design conflict between low wheel wear and low steering torque, the control parameters of the mechatronic track guidance are optimised using the DLR in-house software MOPS. Besides the track irregularities especially the increasing inclination at transition curves defines high actuator requirements due to gyroscopic effects at high speed. After introducing a limiter for the actuating variables into the control system, a good performance is achieved.

Radio is the new communication technology that can appropriately service the APM market. Radio is wireless which means it’s inconspicuous and unobtrusive, yet ever-present and accessible. It is also a proven and secure communication medium. How is radio utilized in a train control system? Radio is used to transmit data between the wayside applications controlling the trains and the trains themselves. This data exchange must be persistent in order to ensure smooth and regulated train operation. There is one problem though — several radios are required to provide signal coverage over the entire guideway. How is persistent data communication achieved? As a train moves through the system, handovers must occur between the onboard radio and those deployed adjacent to the track. This is accomplished through proper radio spacing and careful adjustment of the roaming and joining threshold parameters of the onboard radio. Seamless handovers, without data loss, has been proven at speeds of up to 130km/h. The Alcatel SelTrac train control system, as deployed on the Las Vegas Monorail system, makes use of open standard frequency hopping radios in the unlicensed 2.4GHz band. Las Vegas is an RF rich environment with a lot of interference in this public band. Dealing with this interference has been a challenge but convincingly overcome. Several techniques were applied including disregarding, avoiding, and contending with interference. Alcatel’s arsenal to mitigate against interference includes, optimization of radio settings to disregard certain interference, correct antenna selection and positioning to avoid interference, and use of radios with frequency hopping and collision avoidance mechanisms to contend with interference. These techniques will be elaborated upon in the final paper. The combination of high speed trains, high speed radio handovers and high levels of interference has nevertheless resulted in insignificant latencies and has had an inconsiderable effect on data throughput. This has only been possible through the correct selection of equipment and a well architected system design. A radio environment opens the door to the breaching of security through intrusion and emulation. Security violations are subverted through the use of open standard authentication techniques involving dynamic key management. These techniques will be explained in the final paper. The skepticism over the use of radio for APM CBTC is no longer legitimate as evidence of it’s viability becomes apparent. It is proven and secure.


During the last decades, the evolution of wireless technologies has allowed researches to design communication systems where vehicles participate in the communication networks. Vehicular Ad-Hoc Network is an important component of Intelligent Transportation System, which has a future potential in terms of a rich set of applications that it can provide to its commuters. Various approaches has been proposed in recent years for the design of intelligent VANET but most of the proposed works are limited to provide a complete road information to vehicles. For this reason, to develop a sophisticated framework which should disseminate up-to-the minute information about existing or impending traffic-related events has gained recent attention. The proposed framework exploit concepts data mining, machine learning and agent technology to model intelligent vehicular system contributes safer and more efficient roads by providing timely information and decision making capability to vehicle driver. Our work shows the techniques and methods resulting from the field of agent mining applied to many aspects including intelligent traffic control, dynamic routing, congestion management, decision support, modeling and simulation. The current research related to design a shell to control and monitor vehicles by sending intelligent traffic report and warning messages. Simulation results shows communication among agents in a collaborative environment.

CBTC is now the technology chosen by many Rail and Transit operators worldwide. Customer applications are demanding. Some systems are for new lines; some are for revamping of existing lines; and some are driverless, while some remain manned. As operators target efficient train operations, they also take the opportunity of the change to CBTC technology to ask for higher performances and enhanced value. In this change to CBTC, Operators are looking to industry to use its System Engineering know-how & experience to achieve successful project implementation. This paper presents a number of ways that to deal with the conflicting constraints of on-time delivery, delivering enhanced performance and meeting varied operating environments. For CBTC systems, the many trackside and trainborne interfaces are of paramount importance to the safety and performance of the system. A key industrial success factor is the management of the safety function during adaptation to the new standardized Telecommunication interfaces. This is illustrated with examples of recent radio-based train control systems for high speed or main lines that are now in revenue service. A second key factor is the flexibility of the architecture and modularity of the solution. This allows adaptation to varying customer requirements without changes to the system. The paper presents two examples. The first example is using a standard radio but with a choice of propagation medium: Free Propagation, Leaky Feeder or Wave Guide solutions. This choice of medium allows an optimum match to operator radio environment constraints. The second example given is the use of novel configurations to facilitate migration to CBTC in difficult transit environments where there is little time to do the work and where equipment needs to be fitted to existing trains. Finally, to meet the needs of a wide range of CBTC applications, Alstom is implementing a product line approach. The approach allows adaptation to varied customer operating environments in a controlled way. It avoids missing out on customer requirements that would perturb implementation of the system while maximizing carry-over between projects. The implementation of a product line approach for CBTC System engineering activities reduces development time, risks and project cost. This approach is presented with some examples from on-going CBTC projects in the areas of driverless mass transit and light rail. The conclusion stresses how a product line approach must also integrate good system engineering management to ensure on-time delivery as well as technological innovation to give the needed flexibility in meeting operating constraints. A number of project examples are given and illustrated, firstly to stress the main points, but secondly to also give a perspective on what is being achieved in this area at present.


In a railroad system, train pathing is concerned with the assignment of trains to links and tracks, and train timetabling allocates time slots to trains. These important tasks were traditionally done manually, but there is an increasing move toward automated software based on mathematical models and algorithms. Most published models in the literature either focus on train timetabling only, or are too complicated to solve when facing large instances. In this paper, the authors present an optimization heuristic that includes both train pathing and train timetabling, and has the ability to solve real-sized instances. This heuristic allows the operation time of trains to depend on the assigned track, and also lets the minimum headway between the trains depend on the trains’ relative status. It generates an initial solution with a simple rule, and then uses a four-step process to derive the solution iteratively. Each iteration starts by altering the order the trains travel between stations, then it assigns the services to the tracks in the stations with a binary integer program, determines the order they pass through the stations with a linear program, and uses another linear program to produce a timetable. After these four steps, the heuristic accepts or rejects the new solution according to a Threshold Accepting rule. By decomposing the original complex problem into four parts, and by attacking each part with simpler neighborhood-search processes or mathematical programs, the heuristic is able to solve realistic instances. When tested with two real-world examples, one from a 159.3 km, 29-station railroad that
offers 44 daily services, and another from a 345 km, eight-station high-speed rail with 128 services, the heuristic obtained timetables are at least as good as real schedules.


GO Transit has been aggressively developing the ability to communicate to customers about incidents and service disruptions over the past few years. In these days of “know anything, anywhere, anytime” customers have very high and increasing expectations about being kept informed about the status of their transit service. A number of commuter rail systems are introducing straight GPS technology for service status information; however this will not fulfill the customer’s needs when information is most needed such as when there is a service disruption. Technically, it is possible to provide a public feed from an existing GPS system that is being used to monitor rail service. This information is being delivered to the public at various commuter rail systems through the rail systems’ website, and to waiting passenger through “next arrival” dynamic signs at stations. A frequent commuter would find the tracking of real time information to be useful as a quick verification that service is operating as scheduled. Some websites go to the extent of highlighting delayed trains in colour, making it even easier to capture a service problem. However, in a severe service disruption the information that this system provides is insufficient. This is particularly true in commuter rail operations on shared corridors, when the outcome of an incident is very unpredictable. Providing customers with the information that they most value on service disruptions requires a focus on qualitative information that cannot be delivered by an automated train location-based system. This involves human intervention and an integrated approach to capturing operational information, composing content, and distributing the messages using a variety of channels. Developing an automated tool to support this is essential in the commitment to deliver service status communication and achieve customer service excellence.


Lehner, A., et al. (2009). Reliable Vehicle-Autarkic Collision Detection for Rail-Bound Transportation. This paper presents the concept for reliable vehicle-autarkic collision detection developed for a Rail Collision Avoidance System (RCAS) that is based on direct train-to-train communication. Similar to existing systems in air and maritime transport, the RCAS approach allows vehicle-autarkic detection of imminent collisions. Designed as a safety overlay system, it shall warn and advise train drivers in such situations. Broadcasted messages shall allow each railway vehicle to assess the traffic situation in its vicinity under all operational conditions. Apart from an onboard localization unit, which relies on satellite navigation signals, the system architecture does not require any other infrastructure.


Cross Border Information Technology (CroBIT) will deliver the IT-part to improve the European rail freight traffic. CroBIT is a 5th Framework Programme research and demonstration project under the
supervision of the European Commission. CroBIT is able to connect all freight railways along any transport corridor. Participants deliver their information into the CroBIT-System. In return, the participants get added value information from others, about their wagons and consignments. CroBIT combines information about consignments, wagons and trains. Train movements are followed by each railways internal operational systems. Each train consists of a locomotive and wagons. Wagons include consignments. CroBIT has been demonstrated in two ways: demonstration with real-world transports in Portugal and with virtual data and transports between Italy and Finland. Demonstration was completed in Spring 2005. Rail cargo operators stand to gain the most by using CroBIT. Also the policy and socio-economic impacts are positive. CroBIT will be a joint effort of pioneering railway and IT service companies that will maintain and operate the system on the basis of common agreement. The commercialization of CroBIT, if successful, will eventually lead to a market-oriented service company RISE (Rail Information Service Europe). The earnings of RISE will be based on added value information services.


Test is one of the key methodologies to guarantee the functionality correctness and safety of the railway signal system used in the operation line. The present test generation methods for the railway signal system in China are manual, which take too much time and are inefficient, so the automated test approach plays a more and more important role in the testing domain. This paper proposes an automated approach to generate a full set of the test cases and sequences. The all paths covered optimal algorithm (APCO) and the sequence priority algorithm (SPS) for automatically generating test cases and test sequences based on the CPN model are presented. Taking the scenario of Radio Blocking Center (RBC) handover as an example, the presented method is employed to generate the test cases and test sequences of this scenario. The results indicate that the test generation approaches fully achieved the goal of automation. Furthermore, the repeatability rate of the generated test
sequences was reduced by 75% with the algorithm proposed in this paper compared with the available depth first search algorithm (DFS), and the test cases covered all the related criterions in CTCS-3 Train Control System Function Requirements Specification (FRS).


Czech Railways is using its services in the Prague suburbs to test how Automaticke Vedeni Vlaku (AVV) automatic train operation equipment and European Train Control System (ETCS) Level 2-provided automatic train protection functions can be integrated. Testing using passenger-carrying dual-fitted trains using AVV began in February 2011 on Czech Railways' 22 km Poricany-Kolin section east of Prague. Automatic driving is possible using AVV in terms of acceleration, cruise control, and braking. AVV can compare actual speed with speed requested by the driver, as well as apply traction or braking for speed control to a 1 km/h precision, within the envelope permitted by the current braking curve. The authors provide an overview of AVV, its data inputs, its safety and economic benefits, AVV system coordination, and the Prague-area pilot project.


This paper demonstrates a framework of context awareness public transit transfer information service (CPTIS) model for intermodal connectivity and transfer facilities related to objects including bus stops, access points to train stations, vehicles, and other points of interest. This study has been conducted under a national intelligent transportation system (ITS) project which develops test and evaluation methodologies for facility and information design in the test-bed center. The results from this approach yield the proposed system applicable to the personalized service on demand for public transport users along the technologies and infrastructure in ubiquitous society, where a variety of service contents and business models has been considered to be a better quality service for providing CPTIS in the near future.


The unique features of Communication Based Train Control (CBTC) systems with Moving Block (MB) capability makes them uniquely suited for application ‘on top’ of existing Mass Transit or Metro systems, which permits an increase capacity in these systems. This paper defines and describes the features of modern CBTC Moving Block systems such as the Bombardier® CITYFLO® 450 or CITYFLO 650 solutions that make them suited for ‘overlay’ application ‘on top’ of the existing systems and gives an example of such an application in a main European Metro. Note: ®Trademark (s) of Bombardier Inc. or its subsidiaries.


Intelligent transportation system (ITS) was via the work with ITS World Congress in Stockholm 2009 established as an issue in the Swedish rail sector, even if the Swedish rail sector has been working with intelligent transport systems for a long time without calling it ITS. Right after the ITS World Congress in Stockholm 2009 the Swedish Rail Administration (since April 1 2010 a part of the Swedish
Transport Administration) started to interview rail sector actors (train operating companies passenger and freight, infrastructure management, train management, logistics companies, public transport companies, freight transport buyers), about their needs and demands from a business perspective regarding data/information/IT-solutions, i.e. ITS, provided by the Swedish Rail Administration. During 2010 the work has continued with analyzing the current and planned situation within the Swedish Transport Administration. The actors needs have then been compared with the current and planned situation at the Swedish Transport Administration to find the gaps to be filled. In June 2011 the action plan was decided. It will be presented to the rail actors late August 2011. The paper describes the work that has been done to establish the action plan, examples of actual work within the action plan that has been done so far or work that is planned to be done.


This paper serves both as a point of continuity - looking at what has happened in the driverless transit industry since the last conference in Singapore in 2003 – and as a point of reference - looking forward at what is in the pipeline. Suffice it to say, our industry is healthy and robust, despite continuing challenges with the world economy, world peace, air carriers and their re-definition, terrorism concerns and the corresponding need for increased security, and the like. This paper specifically surveys and lists driverless transit systems in the airport and urban sectors that have been opened since 2003 and those that are currently under construction. There are many more that are in the planning or procurement phase, or are being refurbished, that are not addressed in detail in this paper.


The development of the Internet of Things (IOT) needs to be driven by the applied requirements, so this paper attempts to achieve test application by studying in a system mode in the logistics industry. The system uses the technology of combining the Internet of Things in the development in attempt to achieve the real-time tracking for the state of the goods in the omni-distance rail logistics, and to achieve a "transparent" transport. In addition, it attempts to achieve an effective docking between the road and the rail, to achieve a "door to door" transport, which can effectively improve the competitiveness of rail logistics.


Scientific and technological policy has become a key activity in contemporary societies. In this context we present different projections about the evolution of science and technology in the area of robotics and advanced automation, which in turn shapes the new possibilities and risks emerging in this area in the future. This goes hand-in-hand with an analysis of the interaction of such trajectories with the social context from which they emanate. This interaction reinforces the need for establishing the probable sequence of technological innovation; analysing the impacts on economy and society; and providing qualified information for decision-making, both in policy and business. In this article, we present the results of the prospective research carried out in the field of robotics and advanced automation, paying special attention to the transformation trends of organizations, and the integration of robots in daily life and leisure, and underscoring potential repercussions which may deserve more attention and further research.


This article describes how the digital revolution is coming to freight rail. The article details how major railroads are installing digital communications, global positioning receivers, sensors and computerized controls on their trains and tracks. These new systems can gather intelligence on locations, size and speeds of trains and make automated decisions about whether or not the trains should stop or go. The article describes how these digital cameras and microphones on the tracks are working on monitoring train conditions to determine when equipment needs to enter a shop for maintenance. Some of these high-tech tools are already in limited use and others are still being tested. Freight-rail executives hope to put together the best solutions available and to transform one of the earliest network businesses, the railroad, into an integrated digital network that carries more trains and more freight at faster speeds and lower cost within the next 10 to 15 years. The article describes how technology will soon be able to produce a railroad that doesn’t derail, collide, break down or fall off schedule and the result will be faster and cheaper freight transportation.

Tram wheels need to be checked regularly, so when the wear reaches certain limits, the treads either have to be reprofiled to the correct shape or the wheels have to be replaced. This paper presents the autonomous wheel condition monitoring system for trams, whose employment has been the source of significant savings on wheel reprofiling and has reduced the noise level generated by trams. The measurement data is processed by a computer at the track side and transferred by wireless link to a database in a control room. Diagnostic and reporting software on the control room computer provides an interface for the display of the measured data analysis. If a wheel flat is detected, an alarm message is displayed advising the severity of the wheel defect and the recommended course of action. Exceedence reports are generated when the wheel flat exceeding the threshold value is detected. These reports give records of all wheel impacts and their position within the train. They include a graphical output showing the train, highlighting wheel defects. The experience collected using the system proves that keeping the limiting wheel dimensions without tolerance limits has eliminated tram derailments due to the wrong wheel geometry. Using the system makes it possible to forecast precisely the wheel tread as a function of its mileage between repairs, with the possibility of updating the information. The regular measurements allow forecasting of wheel tread needs, which is very important with the long lead times for them. The detailed information about the wheel profiles makes the material saving reprofiling on the wheel lathe possible. All wheel monitoring data is stored in the database which gives the possibility of extensive diagnostic analyses and reporting.

This paper on the use of (Global System for Mobile communications (GSM) technology to support automatic location-finding for train crews in the Netherlands is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors first report some statistics on the passenger brand of NSR (Dutch Railways): the service on a daily basis deploys approximately 1,000 drivers and 1,300 guards to run approximately 5000 trains. The current deployment is in line with the crew schedule as laid down in the transport management system and usually manually updated when necessary. In the event of major disruptions, however, problems may occur as a result of which the disruption management organization loses sight of the current personnel deployment. This can lead to errors in crew rescheduling and possibly to the cancellation of trains because crew have not been organized in a timely fashion. The authors report on an investigation conducted to address this problem. The research and development project was undertaken by NSR and the engineering firm Movares to develop a method for the automated detection of train crew on trains. The project developed a system that combined GSM technology and train monitoring (via the infrastructure) that automatically detects which train crew members are located in which train. In the spring of 2009, the system underwent testing that determined that it is possible on the basis of cell ID data and train position data to detect, in real time and with a reliability of 99%, which train crew members are where. The authors conclude with a brief set of recommendations for future work on this system.


In this article, two models for estimating the energy saving potential on a mass rapid transit system are described. The first model is very useful for analysing the energy and the second one aims at estimating consumptions of a mass rapid transit system in a period of time. The latter was applied first to a generic line with six stations and then to line A of Rome metro network. Results of both applications show that headways of 120–150 s are ideal for energy saving as they allow transfers between braking and accelerating trains.


Unattended train operation (UTO) refers to a transportation system in which guided vehicles are run fully automatically without any operating staff on-board. This article provides an overview of the UTO concept, highlighting both the benefits and the current needs that must be met in order to expand the concept to more systems. The International Union of Public Transport forecasts that by 2020, 75% of all new metro lines and 40% of existing lines will have UTO capability. UTO can optimize the running time of trains with the shortest possible headway, resulting in shorter journey and waiting times. Since human error is one of the major causes of rail accidents, a properly designed UTO also introduces a much higher level of reliability and safety into train operation by removing the human risk factor. Because UTO can lower operational costs, the investment to add UTO capability can be paid back within 10 years. Current UTO capability can be improved through the better harmonization of systems, safety demonstration of complex computerized systems, and overcoming the fear of the unknown.

A simulation model of a train-to-train collision has been developed using explicit/dynamic finite element analysis (FEA). The ABAQUS/Explicit dynamic finite element code was used. In comparison to other vehicle collision studies, this study is the first in which the interactions of colliding passenger rail equipment have been modeled using detailed FEA. Such simulation models provide several benefits. It increases the capability for vehicle crush modeling to include vehicle-to-vehicle interactions. It also provides a platform for studying the effect of trailing vehicles on lead vehicle crush behaviour. Finally, it provides insight into the modes of deformation and crush forces that were observed in the test. This model has proven to be a useful tool for evaluating the structural effects of a collision and improving the design of cab car end structures so that they can better withstand the extreme forces associated with a collision. The approach used by the Volpe Center included review of the high-speed film, development of Excel-based data and graphics files for direct comparisons to model results, and review of selected data sets to ensure that appropriate comparisons were selected. The finite element model of the two trains was then developed, starting with models that had been previously developed in prior programs for crush analysis of each of the two lead vehicles, the cab car and the standing locomotive. Volpe Center made a significant number of modifications to each of these models and developed new sub-models, defining truck-to-body connections for the cab car and defining the behaviour of the colliding couplers. Volpe Center used lumped mass elements to model trailing vehicles.

Martinez, I., et al. (2007). Statistical Dwell Time Model for Metro Lines. This paper describes how traffic simulation models in metro lines are widely used in predictive control algorithms for traffic regulation and robustness analysis of timetables. The simulation results are highly dependent on the uncertainty modeling. The two main parameters in the simulation models are running times and dwell times. In lines operated with Automatic Train Operation (ATO) systems, running times are more deterministic than random (consequence of control actions), while dwell times show a higher stochastic behavior due to the influence of passengers and drivers. Typically, simulation models do not include a realistic modeling of dwell time uncertainty, and the confidence on results is affected. This paper focused on the stochastic component of dwell times in order to obtain a realistic model suitable for traffic simulation of metro lines. For this purpose, several statistical studies have been developed considering peak and off-peak hours, incidences, relations with other operation variables, etc. Models have been obtained and validated using data of different days and Metro de Madrid lines.

Martins, J. P. and E. Morga (2010). Case Studies in Planning Crew Members. This paper on planning and managing the work of railroad crew members is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors describe CREWS, a software product that can be used for planning and managing the work of railroad staff. They report some results of a long-term study of the application of both Artificial Intelligence and Operations Research techniques to the planning and managing of railroad staff, including drivers, guards, and station personnel. The paper includes case studies emerging from the application of CREWS, in both railway and subway companies. The authors conclude that CREWS is a strong and mature product that provides decision-support in the task of planning the daily work of more than 20,000 staff members across Europe. CREWS-based systems are in routine use in the Dutch Railways, the Norwegian State Railways, the Finnish Railways, the Danish State Railways, the Suburban trains of Copenhagen, and the London Underground. The authors conclude with a section describing the various benefits that the CREWS software can provide, including eliminating repetitive and tedious work on the part of planners, generating alternative solutions, cost-savings, and a simulation mode.
This special supplement for mass transit discusses the current state of projects and features some of the more promising newer technologies. Despite receiving a failing grade in the 2005 Report Card for America's Infrastructure Between 1993 and 2002 by the American Society of Civil Engineers, transit has increased faster than any other mode of transportation. Federal investments are declining, but local ballot initiatives are experience support from voters in 42 of 53 recent initiatives. Other types of systems are being looked at such as automated people movers or automated light rail, which operate without drivers, keeping costs down. Projects around the country include a new East Side Access project in the NYC metro area that will provide a direct LIRR commuter rail link at Manhattan's Grand Central Station. The Chicago Transit Authority is conducting studies for possible improvements and expansion. Communications-based train control technology is being installed in the New York City Transit Authority system. Elsewhere, the Roosevelt Avenue/74th St. complex is being renovated by the New York City Transit Authority, and New Jersey is expanding its commuter rail line.

This paper first presents an historical review of railway signal systems, describing how signal equipment evolved with the development of electronic technologies. It then describes innovative systems, such as the Autonomous Decentralized Transport Operation Control System (ATOS), the Computerized Safety, Maintenance and Operation Systems of Shinkansen (COSMOS), and digital automatic train control (D-ATC. Despite these advancements, signal control was still relying on outdated wiring technologies, ultimately leading to disruptions and system failures. The paper concludes with a discussion on the development of a new network signal control system using optical cables.

This paper explores the evolving industrial control paradigm of product intelligence. The approach seeks to give a customer greater control over the processing of an order – by integrating technologies which allow for greater tracking of the order and methodologies which allow the customer [via the order] to dynamically influence the way the order is produced, stored or transported. The paper examines developments from four distinct perspectives: conceptual developments, theoretical issues, practical deployment and business opportunities. In each area, existing work is reviewed and open challenges for research are identified. The paper concludes by identifying four key obstacles to be overcome in order to successfully deploy product intelligence in an industrial application.

This paper presents the detection performance of a dual microwave radar vehicle detection system installed at a railroad grade crossing with quad gates. The system included two identical microwave radar units located at opposing quadrants of the crossing, each unit covering approximately the same detection area. The objective of the dual radar installation was to increase system reliability by providing redundancy in the detection. The performance of each radar unit alone, and then the
performance of the two units combined, were assessed in terms of false calls, missed calls, stuck-on calls, and dropped calls. The system was first evaluated based on the “best” initial setup by the distributor. Then, some modifications were made using the results from the initial setup, and the system was evaluated again based on the modified setup. The analysis included data from 12 days, with more than 40,000 vehicles and close to 1250 train activities. The most frequent type of error in the initial setup was false calls (0.54%), mostly generated by bicycles and pedestrians in the crossing. False calls increased to 0.96% in the modified setup, mostly due to activations generated when the gates were moving. Individual radar outputs showed a total of 27 missed calls in the initial setup (0.07%) and 34 missed calls in the modified setup (0.09%). However, the number of missed calls dropped to zero when the outputs from the two radar units were combined, illustrating the benefits of having dual units.

MEGHDADI, V. "Vehicular Ad-Hoc Networks (VANET) applied to Intelligent Transportation Systems (ITS)."


In response to requirements in the Rail Safety Improvement Act of 2008, BNSF Railway is developing and implementing an electronic train management system to prevent train-to-train collisions, overspeed derailments, incursions into work zones, and movements through improperly aligned switches. The author describes the testing and application of research findings and the progress to date.


Train delays are the time between scheduled and actual arrival of the train. They have a great influence on the timetable and technological processes related to the train traffic. A model for calculating train delays can be used in the process of railway operations and timetable planning, and operational management. The model for train delays is based on the soft computing techniques. Neural Networks model and Adaptive Network-based Fuzzy Inference System model are trained and verified by the data collected from train dispatcher’s and infrastructure manager’s database. Model is tested on Rakovica station in Serbian Railways.


The development of V-to-X systems in North America is described with a focus on the services and applications that may appear, particularly in the United States. The scope of this article is therefore broad, and while it involves engineering the emphasis is on transportation applications from V-to-X; this dictates consideration of societal and institutional considerations. Different types of over-the-air interfaces are covered, followed by a description of the evolution of the Vehicle Infrastructure Integration program into IntelliDriveSM, and subsequently to the more generic term, connected vehicle next, vehicle-to-infrastructure and vehicle-to-vehicle components are covered. The vehicle-to-vehicle section describes an analysis that suggests that the USDOT path toward mandating Dedicated Short...
Range Communications transceivers on vehicles may be well-founded. Anticipated institutional arrangements in addition to research and deployment ideas for the vehicle and infrastructure are then covered in a section entitled “the short horizon”. Finally, the future of V-to-X in North America is discussed from “the long horizon” view.


This paper looks at how signal management and transportation management in Japanese railway systems are used advanced technologies to achieve higher functionality and safety. The paper describes a new digital automatic train control (ATC) signal system; the Intelligent Multimode Transit System (IMTS), which is an automated bus system that uses radio transmission to control the headways between buses; the Advanced Train Administration and Communication System (ATACS). It discusses the importance of establishing evaluation methods that can assess the functionality, safety, and reliability of these systems. The paper also discusses the need for ensuring that the new technologies and systems conform to international standards, with the goal that these standards become recognized as international standards in the future.


As a complex system with substantial assets in the form of its resources the railway transport should be capable of managing them rationally. It is therefore very important to insist on efficient managing of resources in this field in order to be able to intervene in real time in all the situations that direct business operation contradictory to market principles. One of the mechanisms that supports such a concept of relations within the railway traffic system lies certainly in the business resources management by the application of the elements of intelligent transport systems and the expert system from the area of railway traffic using information technology which has been presented in this paper.


Individual railroad track maintenance standards and the Federal Railroad Administration (FRA) Track Safety Standards require periodic inspection of railway infrastructure to ensure safe and efficient operation. This inspection is a critical, but labor-intensive task that results in large annual operating expenditures and has limitations in speed, quality, objectivity, and scope. To improve the cost-effectiveness of the current inspection process, machine vision technology can be developed and used as a robust supplement to manual inspections. This paper focuses on the development and performance of machine vision algorithms designed to recognize turnout components, as well as the performance of algorithms designed to recognize and detect defects in other track components. In order to prioritize which components are the most critical for the safe operation of trains, a risk-based analysis of the FRA Accident Database was performed. Additionally, an overview of current technologies for track and turnout component condition assessment is presented. The machine vision system consists of a video acquisition system for recording digital images of track and customized algorithms to identify defects and symptomatic conditions within the images. A prototype machine vision system has been developed for automated inspection of rail anchors and cut spikes, as well as tie recognition. Experimental test results from the system have shown good reliability for recognizing ties, anchors, and cut spikes. This machine vision system, in conjunction with defect analysis and
trending of historical data, will enhance the ability for longer-term predictive assessment of the health of the track system and its components.


The Switzerland railway companies operate one of the world's most complex railway networks. There is a highly ambitious timetable, the so-called "Taktfahrplan," with regular intervals and extremely dense traffic at the major rail network nodes. Almost all of the main lines are used for both passenger and freight trains. Train operations are controlled by a centralized and fully autonomous system based on the given schedule and a train identifier for each train. Most interlockings are controlled remotely from the central control system. The new Lotschberg Base Tunnel, which is partially single-track, is equipped with its own operations control system, called AF (automatic function). This article provides an overview of the AF system, which solves operational conflicts automatically or with the intervention of the dispatcher, according to situation.


After several years of planning and design work related to a landside APM system, the City of Phoenix officially began construction of the Sky Harbor International Airport PHX Sky Train™ project facilities in April 2009 and awarded the train system supplier contract in June 2009. The first stage of the PHX Sky Train™ system will replace the existing bus connection between the Metro Light Rail station at 44th Street and Washington, the East Economy Parking structure and Terminal 4. Future stages will connect to existing and planned terminals to the west, a planned ground transportation center and the new Rental Car Center. Under an accelerated schedule, the first stage of the PHX Sky Train™ is scheduled to begin carrying passengers by the spring of 2013. Central to the planning process for PHX Sky Train™ was the City's goal to provide a state of the art transportation system that would link all of the airport facilities to regional transit to help reduce traffic congestion within the terminal core. The PHX Sky Train™ project is timely in accomplishing this goal given that the first segment of the METRO light rail system that links downtown Phoenix, the airport and Tempe began operation in December 2008. Upon completion of the entire system, the PHX Sky Train™ system length will be about 8km (5 miles) with up to seven stations. The system will serve a total daily ridership of 96,000 passengers and a total annual ridership of 35 million passengers and will operate 24 hours a day with peak headways of less than three minutes. This paper focuses on the unique challenges and opportunities related to the PHX Sky Train™ system planning and procurement activities, as well as provides an overview of the progress of the system implementation and construction activities.


This paper describes how New York City Transit (NYCT) has initiated a program to install communications-based train control (CBTC) technology, utilizing continuous, two-way digital RF communications between intelligent trains and a wayside network of vital zone computers. The industry generally acknowledges that suppliers of such complex software based projects must use a disciplined Systems Engineering approach to be successful. A similar approach is also required on the customer’s side and in applying CBTC to the Canarsie Line, NYCT initiated steps to use a Systems Engineering approach to the design, procurement and management of the pilot CBTC project. Some of the positive steps implemented include a project risk assessment of changes to the supplier’s existing system and getting feedback on the design from other properties prior to the procurement. A major step was the
writing of system requirements in as clear a manner as possible, getting agreement on these with the supplier, and then freezing the requirements approximately one year after the contract award. Other steps in the Systems Engineering process include the use of prototyping with real trains and track, the use of working groups for each technical subject and formal First Article Inspections of hardware for all subsystems. This paper describes the Systems Engineering approach that was used for the Canarsie Line project and discusses the main benefits of this type of approach to technically and logistically complex projects. Key benefits include the reduced risk of schedule slippage and better likelihood of fully meeting the users’ needs. The transition of a team or organization to this way of delivering a project is never easy, but it is highly recommended and it mirrors the discipline that suppliers need to successfully manage project within schedule and budget.


New York City Transit (NYCT) has initiated a system wide program to install communications-based train control (CBTC) technology, utilizing continuous, two-way digital RF communications between intelligent trains and a wayside network of vital zone computers. The contract for re-signaling the Canarsie Line was awarded in December 1999. At the time of writing the project is on the verge of placing the first section into revenue service. Over the next several months subsequent sections will be cut in until the complete line is under CBTC control. Shortly thereafter, additional functions will be added in a second release of software and the fully functional CBTC will be operating in passenger service. The attractions of CBTC technology are significant; enhanced safety, greater operational flexibility, increased throughput, improved reliability and availability, and reduced life cycle costs. The challenges of implementing CBTC technology on an operational transit system as complex as the New York City Subway is much better understood that at the outset of the program.


This paper presents eight research projects developed during an intensive rail programme. The projects are as follows: Comparative Assessment of the Impacts of Rail Deregulation on Rail Transport Performance; Overcoming the intermodal transport barriers; Standing seats for high-capacity trains; Logistics principals for efficient rail systems; Access charge systems in European countries; Efficient energy use for sustainable rail transport; Analysis of Rail Yard and Terminal Performances; and Urban freight movement by rail. For each project a short description is provided covering the project key components, including the aims, objectives, methodology, results and the conclusions.


This paper on implementing the safety-case process in practice is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors introduce the European project called “INESS – Integrated European Signalling System” which is designed to define and develop specifications for a new generation of interoperable interlocking systems. These systems must be suitable to be integrated into the European Rail Traffic Management System (ERTMS), with the objective of making the migration to ERTMS more cost-effective. The authors focus on the sub-project, undertaken by the Technical University of Braunschweig, that deals with the safety case process. This sub-project is designed to reduce time and money for the development of the safety case in industry, i.e. operators.
as well as suppliers, by avoiding unnecessary or redundant procedures. Topics covered include a
definition of the safety case, the transparency of the safety argument, improvement by automation, and
workflow issues. The authors conclude that the sub-project has the potential to save at least 15% and
up to 50% of European Committee for Electrotechnical Standardization (CENELEC) related costs.

Muller, J.-P., et al. (2014). "The 24/7 railway: creating capacity by minimising the impact of

The authors' research aims to identify ways to maximize track infrastructure capacity and improve the
efficiency of track positions, while also improving railway worker safety and reducing delays due to
engineering works. The key to current railway track maintenance systems is the person in charge of
possessions (PICOP), who is responsible for laying down detonators to warn of approaching trains,
managing the contractors performing track possession, and ensuring the safety of workers as trains
pass through the possession. The authors assert that the key to providing a more sustainable solution
is to exploit communication technology advances from military systems and combine these with 3D
imaging so that both the train driver and the PICOP have the best possible information to ensure safety.
The article describes innovative technologies, including robotic systems, and highlights similar issues
that have been seen in space exploration and in the coal mining industry.


Barcelona metro's new lines (9 and 10), when completed, will be the longest driverless metro operation
in Europe, and the tunnel will be excavated up to 90m below ground. In order to combat the technical
challenges that these factors present, innovative construction and design solutions are necessary in
order to maintain excellent passenger experience. Various aspects of the metro are illuminated here,
such as using high-speed lifts, keeping safety at the forefront, utilizing lighting to avoid claustrophobia,
and making use of effective signage. From the point of view of operational efficiency and passenger
experience, this metro's success thus far is something that should be of interest to other cities planning
to build deep underground metro stations.


This paper describes how the Metropolitan Transportation Authority - New York City Transit (NYCT) is
one of the largest subway fleet operators and it runs one of the most extensive and complex public
transportation systems in the world. Each day, more than five million people ride the NYCT subways
and about two billion, annually. The R160 New Technology trains are the latest addition to NYCT's
fleet. The fleet is equipped with several hi-tech customer amenities, including state-of-the-art air
conditioning, three-phase ac propulsion, a regenerative braking system that returns power to the third
rail, LonWorks-based trainline communications, automated passenger announcements and, most
noticeable from the rider's perspective, a real-time electronic strip map known as the Flexible
Information and Notice Display or, simply, the FIND. The FIND is a hybrid electronic display that
incorporates a video screen (LCD Unit) and an adjoining LED strip scrolling station names as the train
progresses along the route, and route maps that can be changed if a train switches routes. The
outstanding feature about the FIND is that, if the train switches routes (anywhere on the B Division),
the conductor can reprogram the FIND to show updated station and route information, unlike the
current trains on the R142 (2, 3, 4, 5, 6) and R143 (L) which require replacement of an overlay map
placed over light bulbs. FIND displays route information and animated media messages received from
a FIND-Controller (FIND-C for short) by using an LED unit and an LCD unit. The FIND LED display
shows "This Stop" in a flashing box which transitions to the "Next Stop". The display also includes the subsequent nine stops (beyond the Next Stop), and five additional "further stops", which vary along the line. The "Last Stop" is displayed at all times. Below the name of each station, the display indicates the number of stops to the station, transfers to other lines, if any, and whether the station is handicap accessible. The Automatic Announcement System in the train and the FIND display are synchronized to provide consistent and unambiguous information to the riders.


Transportation plays an important role in building supply chains; several emerging theories and practices of supply chain management rely heavily on transportation. In recent years, information and communication technologies (ICT) have been favourably employed in engineering, operations and business sectors. However, applications and opportunities of ICT are still evolving; with reference to ICT, today's norm is obsolete tomorrow. Rail transport too is becoming increasingly dependent on ICT, not only for commercial purposes such as asset management, passenger ticketing and information broadcasting etc., but also for mission/safety–critical functions, particularly in infrastructure development in the era of high speed and automated railways. A critical issue is that railway infrastructure is capital intensive and has a long gestation period. The initial effort and cost of developing ICT for safety/mission critical railway applications are high and detailed planning is necessary to study requirements and product specifications. The ever-evolving ICT standards contribute to high cost over–runs and long lead time. Whilst the rail industry has embraced the technology of the day, several ICT advancements remain unexplored by railways; financial and technical mishaps tend to make one cautious. This paper analyses automated rail operational technology in–depth and the role of ICT in a broader overview of enhancing transportation capacity.


The emergence of Intelligent Transport Systems (ITS) has been recognized with many initiatives during the last 20 years. In Europe, the "ITS Action Plan" identifies a number of applications as key elements contributing to the efficient co-ordination of the overall transport chain. The context and experience surrounding the recent widespread development of technological tools and ICT platforms to support the emergence of ITS are notable for the way in which they permeate the transport and logistics chain. But a key question remains: to what extent is the public transport sector able to exploit the wider benefits of ITS? This paper provides a comparative analysis of ITS policy between Europe and Australia. With a focus on the applications and methods adopted in the use of ITS in the public transport sector in Australia the paper critiques their effectiveness in enhancing passenger experience, operator effectiveness and the likely effect on patronage. The relatively low incidence of the use of ITS in the
public transport system in Australia, as compared to Europe, is discussed in the context of technology trends/pathways and impediments to deployment in the public transport sector.


In this paper, we present the findings of a case study on the development of a radio frequency identification (RFID) prototype system that is integrated with mobile commerce (m-commerce) in a container depot. A system architecture capable of integrating mobile commerce and RFID applications is proposed. The system architecture is examined and explained in the context of the case study. The aims of the system are to (i) keep track of the locations of stackers and containers, (ii) provide greater visibility of the operations data, and (iii) improve the control processes. The case study illustrates the benefits and advantages of using an RFID system, particularly its support of m-commerce activities in the container depot, and describes some of the most important problems and issues. Finally, several research issues and directions of RFID applications in container depots are presented and discussed.


Abstract This chapter presents a mathematical framework for modeling connected vehicles, an emerging transportation paradigm where vehicles are able to communicate with each other and the roadside. In this framework, highways and vehicles are perceived as a field by a subject driver whose driving strategy is to navigate through the field along its valley. With Field Theory as a basis, strategies of integrating the effects introduced by connected vehicles are discussed. Directions of applications of Field Theory are highlighted. In addition, two concrete examples are provided to further illustrate application details.


Within the present industrial society, some of the greatest challenges of humanity are related to achieving a sustainable industrial metabolism, which integrates technical activity and ecological systems. Electric traction drive systems using induction motors fed by variable voltage variable frequency (VVVF) inverters have provided high performance for urban electric trains. Moreover, power converter technology based on advanced techniques in control electronics and efficient anti-slip systems allows optimum traction characteristics and minimum energy consumption. For underground electric trains, however, it is also important to assess the environmental impact of braking. From the viewpoint of exergy and environment, the braking regime, particularly electric braking, is a special aspect of non-autonomous vehicles using electric traction. As electric drive systems are used with VVVF inverters and traction induction motors, these machines with appropriate controls can realize both traction and electric braking regimes for electric traction vehicles. Concerns regarding mechanical braking are associated with unrecovered energy and material utilization. Also, for underground electric trains during mechanical braking, the abnormal but frequent situation involving the unequal charge of the traction induction motors is a concern. These aspects of underground electric trains are analyzed in this article so as to assist in improving performance.

As part of Stage 1A for the PHX Sky Train project at Phoenix Sky Harbor International Airport in Phoenix, Arizona, a three-quarter-mile-long above-grade and below-grade people-mover guideway is being constructed between existing airport Terminals 3 and 4. The design of the large-diameter drilled shafts supporting the elevated guideway is complicated by space constraints, due to the elevated guideway alignment being situated between an existing adjacent retaining wall and an existing high-pressure jet fuel line, both of which are to remain in service during construction. Finite element analyses were performed during design to estimate the deflection of the existing retaining wall during staged construction of the guideway drilled shafts. Monitoring of the wall during construction confirmed the geotechnical design analyses, indicating that the new drilled shafts did not cause any detrimental deflection of the existing retaining wall. For the depressed section of guideway passing below two adjacent aircraft taxiway bridges, top-down construction methods were designed to construct an additional end-span and new abutment for these bridges. A combined drilled-shaft soldier pile, tieback anchor, and taxiway anchor slab system was designed to resist the high loading conditions. The drilled shafts are to be used for both foundation support of the taxiway undercrossing bridge abutments, and as the earth-retention system for excavation support. Numerical analyses were performed to predict the short- and long-term behavior of the new abutment wall. Based on survey monitoring of the new abutment wall performed during construction, the recorded lateral movement of the wall is significantly below that calculated by numerical analyses.


Through this operational test, the Minnesota Department of Transportation (Mn/DOT) hopes to determine whether a newly developed low-cost active railroad crossing warning system functions as well as traditional active system at low-volume highway-railroad intersections; and to determine whether the low cost system’s addition of flashers on advance rail warning signs provides any additional benefits. Field tests have indicated the following: (1) MUTCD compliant warning to the public; (2) crossing warning times in the 30 second range regardless of train speed; (3) in-cab crew warning in the event of system malfunctions; (4) the ability to properly detect train switching movements; (5) the ability to detect unequipped trains or cars in the crossings; and (6) the ability to record and report system performance data. There have been three preliminary evaluations conducted during the system development that all indicate the system performed without failure, the warning times were acceptable, the system accurately tracked daily train movements, and the system maintained communications. An independent evaluation is underway. If successful, this newly developed low-cost system offers the opportunity to install active warning systems at 20% the cost of traditional systems. Such a development would significantly increase the number of crossings equipped with active systems. By leveraging emerging technologies, rail crossing safety may soon be provided at a cost previously thought unthinkable.


Stricter requirements on the quality of industrial plant operation together with environmental limits and decreasing energy consumption bring more complex automation systems. The intelligent control techniques, which are based on approaches from diverse disciplines including statistics, artificial intelligence or signal processing, have been widely used during the last years and their benefits have
been proved. They cannot be developed and tested without simulation models and access to online and historical data. This article proposes a platform for the integration of simulations and industrial SCADA systems supporting complex data access and simulation code re-use. The idea of the presented framework is to connect simulations, data sources, optimizers, other calculations and SCADA systems into one integrated environment seamlessly. A technical level of the framework provides integration of stakeholders and a semantic level captures engineering knowledge in inter-mapped ontologies and configures the technical level, which is often called model-driven configuration. The semantic level utilizes a formal model implemented as set of ontologies. The major contribution of the article are the layered model of the integration architecture and formulation of the integration requirements in the industrial automation domain. The proposed solution has been implemented and tested on a software prototype level. It is demonstrated on two use-cases covering both design and integration of simulation models from the industrial perspective. The proposed architecture is intended to be as general as possible, however it has been tested on signal-oriented simulators only. It is the main limitation of this contribution and it should be addressed in upcoming work.


This paper is devoted to the analysis of the broad technological field of mechatronics, robotics and components for automation and control systems. Several sub-fields are considered: (i) components and instruments, involving sensors, actuators, embedded systems and communications; (ii) mechatronics concepts and technologies; (iii) robotics; (iv) human–machine systems, including technical issues and social implications; and (v) cost-oriented automation which is a multidisciplinary field involving theory, technologies and application as well as economical and social issues. First current key problems in this field are considered then, the accomplishment and trends are analysed. Finally, the forecast is presented to discuss issues relevant for future developments.


Our consortium has developed a public transit information system that provides railroad and bus transfer information, as well as shopping and sightseeing information, in order to promote use of public transportation and provide economic impetus to train station environs in areas where train stations serve as a focal point for local community interaction. The system is being tested at Senrichuo Station on the Kita-Osaka Kyuko and Osaka Monorail lines. It is a key terminal in the Osaka Prefecture region used by 120,000 passengers a day and considered a difficult station to locate for boarding. The test will serve to evaluate the system’s usefulness and aid in enhancing its applicability.


With the growth in both High Speed and Light Rail infrastructure projects worldwide there is a general requirement for accurate modelling of the interaction of the track with respect to any supporting bridge structures, and in particular, to ensure that any interaction between the track and the bridge as a result of temperature and train loading is within specified design limits. To accurately assess track-structure interaction effects nonlinear analyses are required to investigate thermal loading on the bridge deck, thermal loading on the rail if any rail expansion devices are fitted, and vertical and longitudinal braking and/or acceleration loads associated with the trainsets. For a complete rail track assessment, dynamic effects caused by the passage of trains that affect the structure itself must also be considered. The paper describes how rail track analysis for both high speed and general trainsets can be carried out.
according to the Union Internationale des Chemins de Fer (International Union of Railways) UIC774-3 Code of Practice with reference to the use of the LUSAS Rail Track Analysis software application. A comparison of 'simplified' and 'complete' UIC774-3 analysis methods is made showing that 'simplified' analysis results can lead to an over-estimate of the rail stresses when compared to 'complete' simultaneous analysis which considers the temperature and longitudinal and vertical train effects simultaneously. Automated modelling techniques and results and graphing capabilities are described and projects either built or under construction and on which the track-structure interaction software has been used to good effect are described.


Intelligent Transportation Systems (ITSs) make use of advanced detection, communications, and computing technology to improve the safety and efficiency of surface transportation networks. An ITS incorporates a variety of equipment and devices all working in mutual harmony. However, each piece of equipment or device has its own data format and protocol so they cannot exchange data with each other directly. In this paper, a platform of data exchange in an ITS is proposed that can receive data from several types of equipment external to automobiles, repackage the received data, and then dispatch the data to different devices inside the vehicles.


Signalized intersections that interface with light rail transit (LRT) pose a unique challenge to traffic operations and safety. Although progress toward mitigating light rail vehicle–motor vehicle crashes has been made, many agencies still face safety issues at these intersections. Few empirical studies of the effectiveness of the safety measures currently being used have been conducted. Safety measures have not been tested with drivers; rather, the measures have evolved over time through practice. The objectives of this research were to assess driver comprehension and to explore drivers’ perceptions and opinions of a variety of traffic control devices (TCDs) that were or that might be used at signalized intersections that interface with LRT. The research approach was to present simulated scenes to drivers with a variety of intersection scenarios and TCDs in a focus group setting. The results showed that drivers had preferences for TCDs at these intersections. Although existing TCDs are understood and generally liked, ongoing issues with safety suggest that improvements can still be made. The use of green arrow signal displays or supplemental pavement markings could improve driver situational awareness at some intersections. Enhancements to the existing "Manual on Uniform Traffic Control Devices" W10-7 (i.e., train icon) activated blank-out sign, such as adding the word “train” or alternating the train icon with the no left turn icon, could result in increased driver compliance. Finally, providing
an active warning device on the cross street, such as the W10-7 sign, could increase safety by making drivers and pedestrians more aware of the arrival of a train.


The success of an intelligent sensor environment is mainly determined by the extent to which it is adopted by users. In order to understand how the adoption process works and when it is likely to be successful, we developed a general adoption model and applied it to the four main categories. Based on four case studies, we developed and tested questionnaires that contribute as an instrument for evaluating existing sensor environments, or during the design phase. It turns out that each specific type of intelligent sensor environment has its own adoption issues.


Foot patrols are an integral part of track and corridor maintenance at most railroad organizations and are considered the last line of defense in defect detection. Foot patrols have been around as long as the railroads themselves and have always played a vital role in ensuring a safe infrastructure for train movements. While foot patrols are very important for detecting and controlling risks to railroad infrastructure, they can also pose serious safety risks to railroad staff. In this paper the authors put forward an alternative methodology to foot patrols that can mitigate the risk of injury to railroad patrolling staff. This methodology, Mechanized Track Inspection, has demonstrated that with the latest imaging and positioning technologies along with the design of system tools that have the specific needs of the end user in mind, railroad companies and railroad maintainers can continue meet the inspection requirements of foot patrols, but with significantly improved safety outcomes for staff and infrastructure. This paper presents a case study of one railroad organization in Australia that has successfully replaced foot patrols on its most heavily trafficked rail corridors with a Mechanized Track Inspection methodology.


Based on a comprehensive data set of German railway customers, the authors analyze consumers’ choices and particularly subsequent changes of two-part pricing contracts (loyalty cards). In a competing risks framework, they simultaneously estimate effects on three types of contractual events: cancellations, upgrades, and downgrades. Focusing on customer relationship management (CRM) practices, they find several factors affecting these events, some of which railway companies can influence to their advantage. Intuitively, installing auto-renewal procedures for loyalty cards decreases cancellation hazards. However, automated electronic mailings (e.g., reminders and account statements) and advertising (e.g., ticket offers) can be counterproductive and increase the risk of cancellation.


Dither generated by rolling contact of wheel and rail smoothes dry friction damping provided by the primary suspension dampers of freight wagons and it should be taken into account in numerical
simulations. But numerically the problem is non-smooth and this leads to long execution time during simulation, especially when the vehicle with friction dampers is modelled in the environment of an multi-body system simulation program, whose solver has to cope with many strong non-linearities. The other difficulty is the necessity of handling within the code a number of big volume files of recorded dither sampled with high frequency. To avoid these difficulties, a substitute model of two-dimensional dry friction exposed to dither is proposed that does not need application of dither during simulation, but it behaves as if dither were applied. Due to this property of the model, the excitation of the vehicle model by track irregularities may be supplied as low-frequency input, which allows fast execution and, the necessity of handling high-volume files of recorded dither is avoided. The substitute model is numerically effective. To identify parameters of the substitute model, a pre-processing employing a sample of the realistic dither is carried-out on a simple two-degrees-of-freedom system. The substitute model is anisotropic, describing anisotropic properties of the two-dimensional friction arising in the presence of one-dimensional dither. The model may be applied in other branches of engineering, for example, in mechatronics and robotics, where application of dither may improve the accuracy of positioning devices.


In order to improve railroad safety, Network Rail introduced the Sentinel system in 1999. This article describes the program and its successes over the past 8 years. The purpose of the system is to minimize the risk of untrained personnel carrying out safety critical work on railroads by establishing a national training, competence and identification database for railroad workers. Workers who have undergone training are issued a uniquely numbered track safety card which is presented to designated staff at work sites. An automated system is available if employers or on-site managers need to check the validity of cards. The system records 47 separate competences, which allows employees to verify that workers have had the right training for each job they undertake. Cards can be suspended due to unsafe work practices or drug and alcohol use. The system has been praised by both the railroad industry and labor unions.


The presented concept of Global Intelligent Transportation System (GITS) consists of two subsystems: Ground and Sea. An element of both subsystems is an unmanned Automated Vehicle (AV) that may be considered as a hybrid of conventional motor vehicle and rail electric vehicle. It is possible to say that it is a high speed truck or trolleybus. GITS is not a breakthrough but it is an evolutionary step relating to railroad systems that are nearly 200 years old and to motor vehicle systems that are nearly 100 years old. Using the achievements of contemporary control and communication systems, there is a good chance to make an automatic transportation system today that may be economically effective, environmentally friendly and safe. It is possible to say that GITS is a concept of Transport Internet.


The Federal Railroad Administration (FRA) Office of Research and Development initiated a research project to develop and evaluate innovative concepts for locomotive crew egress in the event of a crash that makes the normal means of egress unusable. Locomotive operating crews and rescue workers need improved means of cab egress and access in the event of an accident. Although present regulations and practices address this need in a limited way, further measures could provide substantial improvements in the survivability of crews. This program has focused on three innovative egress concepts that would be of particular use following a crash that toppled the locomotive or prevented use of the front and rear doors. These concepts are 1) roof-mounted escape hatch with hand/foot holds to facilitate reaching the hatch 2) easily removable door hinges and 3) windshield that is removable from the cab interior. A fourth concept, automated collision notification (ACN), determines that a crash has occurred and places a phone call to report the crash. The roof-mounted hatch system was fabricated as a working prototype and installed in a full-scale mockup of a toppled locomotive. Usability testing with experienced train crewmembers and emergency responders demonstrated the usability of the system under 90° and 45° toppled scenarios. The removable door hinges have been fabricated and installed in a crash test locomotive. A prototype hatch egress system is being installed in a demonstration locomotive. A prototype windshield system is ready for installation in a demonstration locomotive.


From 1992 to 2002, the Federal Railroad Administration (FRA) Office of Research and Development (ORD) sponsored a multi-dimensional study of horns as warning devices, conducted by the Volpe Center. The purpose of the study was to assess ways to provide adequate warning. The results were used as the basis for a final rule, established in June of 2005, for sounding audible warnings before a train arrives at a grade crossing. The study consisted of two components: (1) technology assessment and (2) human perception and recognition. The technology assessment addressed physical characteristics. It consisted of (1) measurement of the acoustic properties of three typical railroad horns and prototype automated horn systems (AHS), (2) measurement of the insertion loss and interior noise levels of several 1990 and 1991 motor vehicles, (3) laboratory studies to assess the effectiveness and detectability of horn signals, and (4) measurement of horn sound levels at multiple measurement locations. The human perception and recognition research addressed the effectiveness of those systems as warning devices and their impact on the daily activities of residents. It consisted of (1) use of video cameras at selected grade crossings to observe driver behavior after sounding of three-chime train horns and AHS mounted on the wayside and (2) surveys of residents along railroad corridors about the effects of those two horn systems on their daily activities. The wayside AHS was shown as a potential solution for providing an effective, detectable warning to motorists with acceptable community noise levels. AHS installed on the wayside can be directed down the roadway toward oncoming traffic to greatly reduce the amount of community exposure. The technology assessment showed the sound level of a wayside AHS that used a digital recording of a five-chime train horn was equal to or exceeded that of a train-mounted three-chime horn for drivers approaching a crossing. The
laboratory studies showed a five-chime train horn to be far more effective in warning motorists than a three-chime train horn or a single-tone AHS. The technology assessment also showed that wayside AHS lowered community noise levels. The human perception and recognition tests showed that wayside AHS significantly reduced violations at grade crossings and reduced the disruption of daily activities experienced by nearby residents. The digital five-chime AHS was developed as a result of the tests performed.

Redd, M., et al. (2009). *Operations and Maintenance at Atlanta Airport*. The Bombardier-supplied Automated People Mover (APM) at Hartsfield-Jackson Atlanta International Airport is one of the busiest and most complex systems of its kind in the world. Bombardier Transportation is operating and maintaining the system that operates underground with 20 hours of pinched loop service daily over 4.4 miles with an additional 30-minute 2-train shuttle at the end of normal loop service nightly. This paper provides details of how the Atlanta APM system is operated and maintained and how it has grown over the past 28 years to provide an essential transportation service around one of the world’s busiest airports.


In this article, the new Federal Railroad Administration (FRA) rules governing the use of locomotive horns is addressed. These rules, collectively establishing locomotive “Quiet Zones,” are intended to moderate the overall decibel level of locomotive horns in areas with higher populations. The main concern with the adoption of these rules was the synthesis of high safety standards for grade crossing with mitigating the excessive use of high-decibel warning horns. To create a Quiet Zone, the FRA calculates a Quiet Zone Risk Index (QZRI) and compares it to the Nationwide Significant Risk Threshold (NSRT). If the QZRI is found to be less than the NSRT, the new rules are not applicable; otherwise, four new requirements are put into place. These rules include: 1) the horn of the locomotive must be sounded within 15 to 20 seconds of the point of the grade crossing; 2) the horn may not be sounded further than a quarter mile from the grade crossing; 3) the minimum sound at 100 feet from the grade crossing is 96 dBA; and, 4) the maximum sound at 100 feet is not to exceed 110 dBA. The article then discusses alternatives to locomotive horn use that are known as Supplemental Safety Measures (SSM). Of these, the article discusses paired one-way streets which utilize full closure gates, median barriers with two-quadrant gates, four-quadrant gates, permanent crossing closures, and temporary crossing closures during the night hours. The article also discusses the use of wayside horns allowed for by the FRA Interim Train Horn Rule which states that these automated horns may be used in lieu of standard locomotive horns.


Ren, J., et al. (2010). *Vertical Load-Carrying Natural Frequency of Railway Continuous Steel Truss Bridges*. In this paper, the vertical load-carrying natural frequency of 3 x 64 m through stud welding railway steel truss bridge is calculated using the vehicle-bridge system model, and the rule with time and some influence factors to the continuous bridge vertical load-carrying natural frequencies are analyzed, when 20 high-speed passenger vehicles with the same parameters are travelling on the bridge. The results
show that when the vehicles are distributing on the whole bridge, the bridge vertical load-carrying natural frequency is periodically varied, and the periodic time is \( T = \frac{L}{v} \). Also, the bridge vertical load-carrying natural frequency is related to the unsprung mass and the stiffness of the unsprung of each wheel-set of the vehicle, the vehicle’s length, and the mass of the vehicle. But it is independent of the speed of the train. When the length of the train is shorter than the length of the bridge, the periodic changing stage of the vertical load-carrying natural frequency would never occur, and then the vehicle-bridge system would not incur vertical resonance.


Urban metro rail systems are subject to high and growing demand as the populations of major cities increase. A point may be reached where improving system management using advanced control is more attractive than expanding the network. Control schemes for strengthening system performance and therefore user satisfaction typically involve measuring certain system state variables such as the numbers of passengers aboard trains and waiting at stations. Given the high cost of installing the necessary sensors, an alternative methodology is proposed for online estimation of the two variables using a particle filter. Experiments performed on a dynamic simulator show that the variable values can be inferred by measuring only train dwell-times and passengers entering stations, data on which are generally accessible without major investment. The level of accuracy of the estimates generated by the methodology is high enough to enable a model-based controller implemented in a real metro system to achieve significant performance improvements.


This paper describes how the features of Communication Based Train Control (CBTC) systems with Moving Block (MB) capability make them uniquely suited for overlay on existing Mass Transit or Metro systems and this permits a passenger (line) capacity increase in these systems. This paper defines and describes the features of modern CBTC Moving Block systems such as the Bombardier* CITYFLO* 650 product line that can be overlaid on existing metro systems in order to improve passenger throughput.


This article describes how Swiss Federal Railway is once again pioneering the next step in the development of the European Train Control System (ETCS). A pilot installation of Level 1 Limited Supervision (LS) at Burgdorf has confirmed the practicality of limited supervision technology. Limited supervision is a key element in the Federal Office for Transport’s strategy to introduce ETCS across Switzerland’s entire standard gauge rail network by the year 2017. LS is seen as the essential requirement to create a real end-to-end ETCS network connecting both new and existing lines. LS offers an economic way to migrate from conventional signaling to ETCS, while preparing the network and rolling stock for further upgrading towards Level 2 and beyond.


The author explores two major themes: (1) that the design of systems can facilitate human error and (2) that the design of automation and human behavior can combine to affect human and system performance. One factor that ties these two themes together is cognition; system designers often ignore the cognitive aspects of the design and consequently fail to understand how the design will affect user actions, decisions, and responses. These issues are examined in the context of automated systems. The author follows the evolution of human-centered automation issues from the rarified atmosphere of aerospace to their emergence in society at large through the 2000 Florida presidential election and the 2001 terrorist attacks in New York. In conclusion, he points out that the question of whether the human operator or the automation should have ultimate authority is still unsettled. He also makes the final point that, when processes are automated on the basis of technological availability, cost, efficiency, and the other factors usually considered, the role of automation is optimized and the role of the operator is defined by default rather than by design, while a safer and perhaps more rational approach would be to define the operator's role first. This paper serves as background to a discussion on railroad operational safety.


Across the United States, freight train inspections, currently primarily visual, are being automated through new developments. Use of camera and light array systems manufactured by different firms for three-dimensional wagon end capture and reproduction, which should increase both efficiency and effectiveness of wagon inspections, are examined by the author. Inspections, including safety appliances and brakes, are discussed.


This article describes the role that machine-vision technology can play in detecting and monitoring freight railroad cars for structural or maintenance defects. Machine-vision technology has applications in the railway industry in detectors such as wheel profile measurement (WPM) systems and brake shoe measurement (BSM) systems. In addition, this technology compiles historical data that can be used for defect trending and preventive maintenance. The authors outline three machine-vision based systems that are currently being developed under the Association of American Railroads' Strategic Research Initiative Program. The first is the Automated Inspection of Safety Appliance System (ASAIS), which assesses the condition of a railcar's safety appliances, including the ladders, hand holds, and sill steps. The second program is called the Automated Inspection of Structural Components (AISC), which evaluates the condition of the railcar's underframe and related structural members. The third system, Fully Automated Train Scanning System (FATSS), images the entire railcar, top, sides, and bottom. The authors note that the ultimate goal of the industry's Technology Driven Train Inspection Program is to deploy a network of wayside inspection sites that would feed a centralized database that covers the North American rail network.

In the Summer of 2001 the San Francisco Municipal Transportation Agency (SFMTA) completed the detailed design for a new maintenance and operations facility in support of the new 5.6 mile Third Street Light Rail project. The SFMTA METRO East LRV Maintenance facility (MME) located on a 13-acre site at 25th and Illinois Streets in the Bayview area, was planned to support the operation of the Third Street Light Rail line and relieve the overcrowded conditions at the agency’s only light rail facility at Metro Green/Geneva. The project was planned to be a new, state-of-the-art storage yard, maintenance shop and operations/dispatch facility for a fleet of 80 light rail vehicles. Now, after many budgetary and funding hurdles, several starts and stops, multiple procurements, and seven years later the construction is nearing completion and service scheduled for this fall. This is an accomplishment that could have only been successful with a true partnership between the San Francisco Municipal Transportation Agency (SFMTA) and Stacy and Witbeck, Inc. (SWI) along with the invaluable support of the Federal Transit Administration, San Francisco County Transportation Authority, California Public Utilities Commission and other local agencies. The scope of work included: site demolition, pile driving, earthwork and dewatering, corrosion control, installing underground utilities, handling and disposal of excess hazardous waste material, landscaping and irrigation work, trackwork, installing fences/gates, installing concrete pavement, installing overhead catenary system, automated signal system, special signal interlocking system and special liftable overhead catenary system at freight train crossings, communication system, traction power substation, procurement and installation of shop equipment including a new wheel truing machine and a car hoist system, constructing two shop buildings and an on-site parking lot for non-revenue vehicles, installing mechanical and fire protection systems, electrical power and lighting systems, fire alarm system, security system, monorails, overhead bridge cranes, elevators, constructing access roads, traffic signals, art enrichment work, signs and graphics, and providing testing and training to agency operations staff.


The world’s first driverless train went into testing 50 years ago in New York City. Once placed into service, the almost-forgotten New York City Transit Authority (NYCTA), the 42nd Street Automatic Shuttle was a milestone in the technology of driverless automatic train technology. It was the visionary Chairman of the NYCTA Board of Directors, Charles L. Patterson, who galvanized his own Signal Department, along with two major signal manufacturers, and an air brake manufacturer to develop the 42nd Street Automatic Shuttle train. This technical paper will discuss the history of the trials and in-service operations of the three-car train used on the 42nd Street Grand Central to Times Square Shuttle, which was only operational for two years of passenger service. The technical operation and the technology used at the time will be discussed concerning the wayside, wayside backup system, and car-carried automatic train operation. The technology used on the 42nd Street Automatic Shuttle paved the way for today’s cab signaling, overspeed enforcement, and automatic train operation with automatic door operation. This paper will show the basic comparisons of the technology from the days of the 42nd Street Automatic shuttle to the evolution of modern technology with high frequency track circuits, microprocessor wayside and car-carried equipment in cab signal applications.


A customer-oriented and easy-to-use traveler information service as well as a reliable cross-operating service is one important base for the attractiveness of public transport. Especially in larger areas like
in the German Federal States of Berlin and Brandenburg, some disturbances in public transport will occur. Since public transport operators use ICTS-systems, real time information for trains, trams, and busses, is continuously increasingly available. VBB, the public transport authority of Germany’s capital region of Berlin-Brandenburg, provides real time information on the Internet and via mobile devices, and a cross-operating connection management from around 13 different ICTS systems covering 25 operators.

Rumsey, A. F. (2012). So Who Really Needs a “Fall-Back” Signaling System with Communications Based Train Control?

Communications Based Train Control (CBTC) technology has evolved over the last 25 years for both fully driverless operations, and for transit systems with drivers, to not only achieve a state of good repair (SGR) for the fixed assets but also to enable the maximum return on the investment into the rail transit infrastructure through optimized line capacity and passenger throughput and reduced operating/maintenance costs. While the operating and performance benefits of CBTC technology have been well established in revenue service operations around the world, there often remains a perception that CBTC systems need to be supplemented with a “fall-back” signaling system - also referred to as an “auxiliary wayside system” or in this paper as a “secondary train control system” - which can make the total capital costs for a CBTC system difficult to justify in many applications. Depending on the specific design, a secondary train control system can increase the capital costs of a CBTC project by at least 30% with corresponding increases to ongoing maintenance costs. This paper establishes logical, structured criteria to enable any transit agency to establish the appropriate level of secondary train control for a given CBTC application, and to assist in developing the business case and demonstrating the return on investment (ROI) for a CBTC infrastructure upgrade. The paper addresses issues of mixed mode operations and the detection and tracking of non-CBTC equipped trains. The paper also addresses the protection of failed or “non-communicating” trains, as well as the protection for maintenance vehicles and the role of the signaling system in broken rail detection. All of the above issues are interrelated in that they all impact, or are impacted by, the need or otherwise to incorporate some level of secondary train control to supplement the primary CBTC system.


Railway Highway grade crossing safety has always been a concern in the United States. This report presents an overview of drivers’ behavior at different active and passive warning sign systems present at railroad-highway grade crossings. The report summarizes past studies on controversies over use of STOP sign at grade crossings, a history of guidelines over the years in the Manual on Uniform Traffic Control Devices (MUTCD) and problems associated with passive signs, including the STOP sign and YIELD sign at grade crossings. A field study is conducted on nine grade crossings with selected warning devices to determine driver stopping behavior with various warning devices at passive grade crossings during day and night. Statistical analysis and comparisons are done for stopping of school buses, heavy trucks and other vehicles, poor sight distance versus good sight distance approaches at grade crossings, and grade crossings with parallel highway versus grade crossings without parallel highway. After conducting the field study it was found that the majority of drivers did not stop at the STOP signs at the grade crossings. Results from the comparison between stopping behavior of school bus, heavy truck and other vehicles showed that heavy trucks had a poorer compliance percentage
than all other vehicles (not including school buses). The number of school buses was too small to make any statistically reliable conclusion. Results from comparison between poor sight distance versus good sight distance approaches showed that a higher percentage of drivers actually stopped at poor sight distance approaches than good sight distance approaches. Comparison between grade crossings with parallel highway versus grade crossings without parallel highway showed that a higher percentage of drivers stopped at the grade crossings with no parallel highway than the grade crossings with parallel highway. Based on this limited study and review of previous studies the authors recommended that a STOP sign should not be used at grade crossings without a valid engineering study.


The authors address the problem of navigating a set of moving agents, e.g. automated guided vehicles, through a transportation network so as to bring each agent to its destination at a specified time. Each pair of agents is required to be separated by a minimal distance, generally agent-dependent, at all times. The speed range, initial position, required destination, and required time of arrival at destination for each agent are assumed provided. The movement of each agent is governed by a controlled differential equation (state equation). The problem consists in choosing for each agent a path and a control strategy so as to meet the constraints and reach the destination at the required time. This problem arises in various fields of transportation, including Air Traffic Management and train coordination, and in robotics. The main contribution of the paper is a model that allows to recast this problem as a decoupled collection of problems in classical optimal control and is easily generalized to the case when inertia cannot be neglected. Some qualitative insight into solution behavior is obtained using the Pontryagin Maximum Principle. Sample numerical solutions are computed using a numerical optimal control solver.

Sakowitz, C. and E. Wendler (2006). Optimising Train Priorities to Support the Regulation of Train Services with the Assistance of Active and Deductive Databases.

This paper describes how the maximization of revenues is a fundamental goal of any business-driven railway infrastructure company. In order to achieve this target in the context of traffic regulation, it must try to avoid delays and ensure scheduled connections. However, nominally equal delays to two different trains are not equal in value from an economic point of view in most cases. Moreover, some connections between trains might be more important in this sense than others. There are complex interdependencies and reciprocal effects in railway traffic. Considering these effects, a dispatcher must evaluate possible forms of conflict resolution and the waiting times these give rise to and select the best solution possible. This is not achievable where a time-critical conflict arises at short notice. Even closed mathematical optimization algorithms encounter limits in the case of larger railway networks due to the enormous number of constraints to be considered. This paper will therefore propose that the optimization process be separated from the train regulation process. Instead, economically evaluated train priorities for conflict situations are to be determined with the help of active, deductive and normative rules. Existing concepts of “smart” database management systems (DBMS) with integrated active and deductive database functionalities can be used for this application. An active DBMS allows the definition of reactions to be automatically initiated by the DBMS in response to the detection of given database-related events. A deductive DBMS allows new, deducible facts to be specified, administered and specially derived from explicitly introduced facts. Train priorities are generated and assigned in detachment from day-to-day operations for lightly and heavily disrupted railway traffic respectively. Long-term optimization of these priorities is effected by evaluating past operational data.
German Rail’s (DB) operations control center (OCC) project is one of the largest undertakings in all rail traffic automation in Europe. Dispatching and control of rail traffic is becoming increasingly integrated and automated, with these 2 functions being brought closer together in the OCCs. Besides enabling concentration of technical procedures, such as the integration of electronic interlockings, the OCCs also make it possible to centralize operational functions. In the future, the classical role distribution between dispatcher and train controller will be replaced by the modern concept of train router and local traffic controller. Applications of the OCCs are based on shared data entered once into a central database and made available to all applications. This procedure minimizes the need for data maintenance, supports use of standard language throughout all applications, and ensures that any required valid information is provided at the proper time. This article describes the installation by DB of OCCs in Hannover, Berlin, Leipzig, Frankfurt, Karlsruhe, Duisberg, and Munich, which will be supported by the Consortium BZ 2000, consisting of Alcatel, Siemens, and Vossloh Information Technologies. The complete BZ 2000 system is being introduced in basic, timetable, train dispatching, and direct control stages. The basic stage, which replaced the existing local computer-aided train monitoring units on the DB network and the dispatching centers on the network of the former German State Railway, covers the entire DB network and enables monitoring of most rail traffic.

Sambo, P. (2012). "To find cost effective routes that are able to meet the fuel/time constraints using the Intelligent Transportation Systems in VANETS."


Tomorrow’s train traffic systems must be able to handle more frequent traffic, higher speeds and different companies operating on the same infrastructure. Improving train traffic control can be a cost-efficient way to improve punctuality and increase utilization of rail infrastructure. The main objective of this paper is to describe a new control strategy, and a prototype system derived from basic research. By shifting the control paradigm to a high-level control strategy, many of today’s problems can be avoided. The main goal for the traffic controllers will be to ensure that there always exists a valid plan for the train traffic. This plan can be executed by an automated system.


Monitoring the structural health of railcars is important to ensure safe and efficient railroad operation. The structural integrity of freight cars depends on the health of certain structural components within their underframes. These components serve two principal functions: supporting the car body and lading and transmitting longitudinal buff and draft forces. Although railcars are engineered to withstand large static, dynamic and cyclical loads, they can still develop a variety of structural defects. As a result, Federal Railroad Administration (FRA) regulations and individual railroad mechanical department practices require periodic inspection of railcars to detect mechanical and structural damage or defects. These inspections are primarily a manual process that relies on the acuity, knowledge and endurance of qualified inspection personnel. Enhancements to the process are possible through machine vision...
technology, which uses computer algorithms to process digital image data of railcar underframes into diagnostic information. This paper describes research investigating the feasibility of an automated inspection system capable of detecting structural defects in freight car underframes and presents an inspection approach using machine vision techniques including multi-scale image segmentation. A preliminary image acquisition system has been developed, field trials conducted and algorithms developed that can analyze the images and identify certain underframe components, assessing aspects of their condition. The development of this technology, in conjunction with additional preventive maintenance systems, has the potential to provide more objective information on railcar structural condition, improved utilization of railcar inspection and repair resources, increased train and employee safety, and improvements to overall railroad network efficiency.


Railcar condition directly affects the safety, the efficiency, and the reliability of freight railroad operations. Current railcar inspection practices are intended to identify defects before failure, but these practices generally do not enable preventive maintenance because manual, visual inspection is inherently limited. As a result, automated wayside condition-monitoring technologies have been developed to monitor rolling stock condition and facilitate predictive maintenance strategies. Improving the effectiveness of monitoring of railcar conditions could substantially reduce in-service failures and derailments, operational waste, and variability in rail operations and could enhance network productivity, capacity, and reliability. An analysis of the effect of lean production methods on main-line railway operations was conducted to determine the potential impact of improved railcar inspection and maintenance practices made possible by new, automated wayside technologies. Dispatch simulation software was used to quantify the magnitude and the variability of train delay as a function of both traffic level and severity of service outage. The results indicated that the annual cost caused by main-line delay was substantial compared with the annual cost of track and equipment damages from main-line derailments caused by mechanical causes. This work provided an analytical framework to assess the potential cost savings available through improved preventive maintenance strategies.


Germany will soon have its first fully automated metro system, which is scheduled to open in Nuremberg in 2008. This article describes the major costs and benefits of this project. The overall project cost is EUR 612 million. A fortunate set of circumstances has made this project viable: the rail network is undergoing major expansion, which has coincided with the need for increased vehicle replacement acquisitions. Most of the significant expenses specific to the new system are related to automation. Although investment expenditures for the automated system are higher than for a conventional system, operating costs are lower. Automating train operations reduces the number of vehicles needed, energy consumption and personnel requirements. The automated system is also projected to enhance passenger service and improve passenger safety.
This study shows how the risk analysis platform at the Federal Office of Transport in Switzerland contains about 50 safety topics that are assigned to over 300 railway lines. Occurrence rates and damages have been estimated by experts during the last 5 years. In cooperation with the institute for traffic safety and automation engineering, a prototype for risk estimations is currently under development. The main difference to the former approach is the use of physical models for prediction of accidents and the use of history information’s for estimation of the damage size. For some topics (e.g., avalanches, ignoring of shunting signals) a Monte-Carlo-Simulation is used to estimate occurrence rates and accident parameter, for example, collision speed, number of involved passengers, danger goods etc. The main purpose of the prototype is the validation of the risk estimation method for the entire country of Switzerland. This study shows three representative examples of implemented risk topics including risk models. The simulation results basing on a subnetwork of 90 km will also be presented.


Communications-based train control (CBTC) addresses many of the demands facing the operators of today's metro systems. Siemens has been working with driverless train technology since applications in the early 1980s in Germany and France. CBTC technology applications depend on individual system needs. On Paris' Meteor line, for example, system operators may revert to driver operated trains if needed. Siemens has developed the Trainguard MT CBTC product range. In addition to being used on New York's Canarsie line driverless trial in 2006, Trainguard MT is being used in Paris, Budapest, Beijing, Guangzhou (China), Barcelona, and Algiers. It can be used on existing line migration and refurbishment, works with mixed fleet operations, and fulfills interoperability requirements, and works with different levels of automation. In terms of functionality and costs, it is highly scalable and flexible through its modular design. CBTC is a trend that will continue, especially in megacities, so a holistic approach is needed to meet both budget and profitability goals.


In order to offer a more attractive rail transit system to passengers and to enhance the economic efficiency of the operator demand-driven train operation is suggested. A spatial and temporal adaptation of capacity to demand is required because passenger demand fluctuates during the day and along the transit line. In this respect, automated transit systems are known to be able to operate according to demand. In this paper a comparison of traditionally operated urban transit systems and more flexible and demand-driven line haul APM systems is presented. The influence of the vehicle size is examined with respect to demand driven controllability of supply, traction energy consumption, fleet size and overall fleet capacity. An estimation of the potential reduction of traction energy and fleet capacity is described. In order to estimate the interaction between demand and supply an aggregated
transport demand model is used. With the help of this model an optimal demand-dependent control strategy for the train headway can be derived explicitly taking into consideration the spatiotemporal distribution of demand. This strategy considers the vehicle capacity, the minimum and maximum admissible train headway and the change in demand to a change in supply simultaneously. In spite of an increased number of trains per day (shorter train headways), the overall traction energy consumption can be decreased by about 20% with a demand-driven AGT operation compared to a fixed interval timetable.


To improve passenger safety and security, surveillance cameras are increasingly widely used in public transport systems, with thousands of cameras having been installed in trains and train stations worldwide. This article describes the recently developed Siemens' RailProtect system that promises to improve both the efficiency and effectiveness of transport video monitoring systems by using electronic recognition. RailProtect is able to analyze real time analog or digital video streams and identify situations such as abandoned luggage, overcrowding or intrusion by people or animals into restricted areas; it can also be used to detect and track people, animals, vehicles, or other objects. The RailProtect video software processes distributed real time video input, issuing alerts when specific events occur, and it logs the information, and supports the dispatching of personnel to deal with emergencies or security threats. In addition, the system architecture will support multiple concurrent applications typical within rail environments such as safety - train protection, security - remote video surveillance, automation - train control, maintenance - remote diagnostics, and information, entertainment and advertising.


The ALARP (A railway automatic track warning system based on distributed personal mobile terminals) project has the aim to study, design and implement an innovative more efficient Automated Track Warning Systems with the intent of overcome the limits of current state-of-the-art solutions. The ALARP system provides a solution which is low cost, non-invasive, easy to install and totally independent from the existing signaling. It is responsible of advising workers of a train approaching and has the functionality of localizing the workers inside the worksite and of guiding them to a safe area.


This paper presents an initiative concept to improve railway safety in Thailand. The prime objective is to develop an automated system that is capable of supporting the decision making process of all parties concerned in the railway daily operation. These include train driver, railway station manager/officer, the automatic road-crossing barrier, car drivers and the railway authority itself. The system being
developed is designed to have a capability to distribute information among the involved parties to give appropriate warnings to aid their decision making process. The prototyping project is currently underway and due to submit the final report in September 2010. As the Thai government is now launching a campaign “2010: The Year of Transport Safety”, the authority has short-listed the first 100 level-crossings to be equipped with the newly developed control system to lessen the rate of accidents to come.


This article describes staffing changes on four of six metro lines in Barcelona aimed at improving the quality of service for riders and increasing job satisfaction for employees. The Barcelona metro is halfway through a 10-year expansion program that will increase its size by 50 percent. The article describes how the program will modernize existing lines, how automation will play a large part in deploying metro staff, and increasing security. It describes negotiations with the six unions representing metro staff, and the importance of more and better contact between staff and riders. The article includes a sidebar on the system’s master plan, as well as a map of the system that includes lines in service and those under construction.


A working knowledge of vehicle vibration, sound quality and noise is provided in this book. The information can be applied to real-world problems resulting in solutions that will reduce vibration, improve sound quality and control noise in ground, rail, marine and aerospace vehicles. Fundamental principles, design approaches, testing techniques and analytical formulations are also described and illustrated. Individual components, as well as whole vehicle systems, are discussed. Computation and measurement tools are presented. The fundamentals of vibrations and basic acoustic concepts are presented first, along with how to analyze, test and control vibrations and noise, followed by a discussion of noise and vibrations emanating from powertrains, bodies and chassis. Finally, the topic of evaluating noise, vibration and sound quality is covered.


Issues regarding environment sustainability and energy saving have been receiving concerns in worldwide railway society though railway system have been recognized as a transport mode of less environmental impact. Energy saving via train operation and regulation would be a cost-effective way and becomes a requirement while performing train operation and regulation. Automatic Train Regulation (ATR) plays an important role of maintaining the service quality of metro. However, designing ATR is a large scale optimization problem with high nonlinearity, heavy constraints, and stochastic characteristics. Considering issues regarding energy saving in the ATR design further complicates the problem. A metro traffic model which accounts for energy consumption is investigated in this paper. Thereby, Dual Heuristic dynamic Programming (DHP) technique is employed to design an optimal ATR with energy saving for metro line. Simulation tests of the ATR design were carried out with field data. Results show that better traffic regulation with less energy consumption is attainable through coasting and dwell time control.


In the metropolitan cities of developed and developing countries, longer journeys are mostly performed by two or more modes. In the event of availability of suburban trains and public buses, commuters prefer to travel a longer stretch of their journeys by train, so as to avoid traffic congestion on roads, and the remaining part by buses to reach local areas if their final destination is not in close proximity to railway stations. Normally suburban trains have fixed corridors and buses have the flexibility to serve remote local areas. Thus design of feeder routes from railway stations to various destinations and the transfer time from trains to buses plays a very important role and can be controlled by transport planners. A considerable amount of research has been done on the independent design of a bus route network without considering the effect of train services. Researchers have made attempts using heuristics, simulation, expert systems, artificial intelligence, and optimization techniques for design of routes and schedules. So far, limited effort has been made in modeling coordinated operations. In this research, a new hybrid algorithm which exploits the benefits of genetic algorithms and a well tested heuristic algorithm for the study area is discussed. More convincing results in terms of feeder routes and coordinated schedules at the selected railway station are obtained by the proposed hybrid algorithm as compared to earlier approaches adopted by the writers for the same study area.


Bombardier’s eco4 suite of solutions, services, products and technologies addresses the most pressing concerns facing rail transit operators today. It offers the latest state-of-the-art environmental technology by combining the four “e” cornerstones of sustainable mobility: energy, efficiency, economy and ecology. By this, the research and development focused on integrating a wide spectrum of performance requirements and operational needs. Because the result of this research is a modular suite of solutions, it offers specific benefits for the individual train operators. Implementing our eco4 technologies can create an overall energy saving of up to 50 per cent. Solutions range from planning energy efficiency of new transportation systems and new aerodynamically enhanced train designs to optimizing the energy consumption of an existing fleet.


Inability to meet the key requirement of efficient mobility support is becoming a major impairment of wireless sensor network (WSN). Many critical WSN applications need not only reliability, but also the ability to adequately cope with the movement of nodes between different sub-networks. Despite the work of IETF’s 6lowPAN WG and work on the use of MIPv6 (and many of its variants) in WSNs, no practical mobility support solution exists for this type of networks. In this paper we start by assessing the use of MIPv6 in WSNs, considering soft and hard handoff, showing that, although feasible in small networks, MIPv6 complexity leads to long handoff time and high energy consumption. In order to solve these problems, we propose a proxy-based mobility approach which, by relieving resource-constrained sensor nodes from heavy mobility management tasks, drastically reduces time and energy expenditure.
during handoff. The evaluation of both MIPv6 and the proposed solution is done by implementation and simulation, with a varying number of nodes, sinks and mobility strategies.


This thematic research summary synthesizes results from projects dealing with intelligent transportation systems (ITS). Some of the sub-themes addressed in the paper include highway traffic control, air traffic control, maritime traffic control, rail freight volume, safety and emergency systems, satellite based technology, ITS system architecture, cross border cooperation, and electronic toll and fee collection.

Experiences from the Swedish hybrid locomotive (T43H) are presented. The locomotive has a series hybrid propulsion system with a comparatively small diesel engine and a large battery pack. Original layout was a traditional diesel-electric power train. Indications from switch operations show fuel savings of 37 to 50 % with the hybrid locomotive. The Swedish experiences are thus in parity with North American experiences showing savings between 30 and 80 %. The evaluation showed that hybrid locomotives in switch duty have significant advantages compared to conventional diesel locomotives in terms of reducing fuel consumption and improving environmental performance.

This article reports on the newest addition to the tram train market, the Citadis Dualis. The author visited the manufacturer, Alstom's, plant in Valenciennes, France to learn more about the new tram train and to hear about the company's plans to transform inter-urban transport over the next few years. The new tram trains feature low-floor LRVs, improved braking, and the use of magnet motors derived from the AGV automotrice à grande vitesse). The Citadis Dualis recovers 99% of the energy drawn from braking. The tram train is environmentally friendly, with 98% of the materials used in construction being recyclable, emissions per person are estimated to be four times less than a bus, while the train produces four times less noise than a conventional tram. The article outlines and emphasizes the flexibility of the product's design and components. The article also gives some examples of the anticipated use of the Citadis Dualis in Nantes, Lyon, and Paris, France.
This article describes the Turin, Italy, metro system, opened in 2006 as part of the infrastructure for the 2006 Winter Olympics. The author focuses on the various public transportation options available in Turin, a rapidly growing and often congested city, as well as the recently-introduced restrictive road congestion system that prevents cars from traveling on some of the city center's narrowest streets. The present metro system is 9.6 kilometers long and connects Fermi in Collegno, a town west of Turin, to the Porta Nuova mainline station in the heart of the city. The Turin Transport Group (GTT) is now overseeing construction of a 3.8 kilometer, six-station extension of the system, due to be completed in 2010. The author describes the rolling stock, an automated system that uses Siemens' driverless VAL vehicles that use rubber-tired wheels that run on steel tracks. The VAL computer software, called Carl Master, schedules and manages the maintenance activities of 100 internal operators and 40 external operators, as well as subcontractors working at Collegno. The system stores a detailed history of the 21,000 preventive and curative work orders carried out since the metro went into operation, covering approximately 350 procedures per month. The author maintains the this software is proving to be a huge factor in the metro's excellent reliability.

Sweden's Luossavaara Kiirunavaara Aktiebolag (LKAB), a government-owned mining company, opened its newest and deepest excavation level at its iron-ore mine in Kiruna in May 2013. It is using an automated railway to move extracted iron-ore, as is reported by the author, who visited the mine. After a life cycle cost analysis of five potential options for moving the iron-ore, a railway was chosen out of necessity of locating the compressor 1.2km away from the excavator due to potential stresses in the rock in the area. The interlocking and radio communications for the railway and issues movement authority to the train are managed by a centralized traffic control center located on the surface. As miners in Australia, Africa, China and South America are exploring how they might improve the efficiency of their operations, LKAB is likely to become an example to emulate in the near future.

The safety of railway system operations depends on several internal and external factors. The former include rail traffic rules, infrastructure, rolling stock reliability, organizational safety culture, and human factors. The railway systems in Europe, North America, and Australasia have seen significant technological developments for improved capacity and efficiency. Europe, for instance, is implementing the European Railway Traffic Management System (ERTMS). However, transition to a more automated traffic management system requires, among other things, changes to infrastructure, rolling stock, operational procedures, or all three. Concerning operational procedures, the literature shows that train drivers, signalers, and controllers have the greatest effect on the safety of a railway network. Therefore, the reliability and safety integrity of the railway network are largely dependent on human factors, in particular, the performance of human operators. This performance in turn is affected by a number of factors broadly known as performance-shaping factors (PSFs), with deficiencies in communication accounting for more than 90% of incidents for the conventional railway system. Therefore, this study investigated the influence of ERTMS and in particular the Global System for Mobile Communications–Railway (GSM-R) on operators' performance. The study analyzed 74
accident and incident reports of railway operations before and after GSM-R implementation from several European railway organizations. The results identified the communications-related factors that affected human performance in the conventional and upgraded railway system based on the existing railway–PSF taxonomy. Finally, the results showed the positive impact of GSM-R implementation on operators’ performance.


The new Monorail system in Las Vegas includes the application of a number of technical innovations. The foremost among them is the implementation of communication based train control. Fully composite car body construction, hydraulic vehicle suspension, automated fare collection, are also some of the additional innovative system elements constructed as part of this Design Build Operate Maintain (DBOM) project.


Beginning in 2006, public transportation users in Perth, Australia will be able to use a fully-integrated smartcard for that city’s 1,000-plus buses, 48 two-car train sets, and two ferries. SmartRider, a new automatic fare collection system, will allow users to reload their cards at designated shops and automated vending machines, as well as over the Internet, via debit card, and by phone. Satellite-based location equipment will ensure automatic calculation of fare zones for bus and ferry operations. The system is designed to take into account situations where a passenger goes through a gated railway station onto the platform, then remembers he or she left something in a the car, and exits within a certain period of time and without using the system. SmartRider is programmed to take no deductions in such a situation. About 500,000 SmartRider cards are anticipated to be in use when the system is fully operational.


Although backstepping control design approach has been widely utilised in many practical systems, little effort has been made in applying this useful method to train systems. The main purpose of this paper is to apply this popular control design technique to speed and position tracking control of high-speed trains. By integrating adaptive control with backstepping control, we develop a control scheme that is able to address not only the traction and braking dynamics ignored in most existing methods, but also the uncertain friction and aerodynamic drag forces arisen from uncertain resistance coefficients. As such, the resultant control algorithms are able to achieve high precision train position and speed tracking under varying operation railway conditions, as validated by theoretical analysis and numerical simulations.


Advanced control is a key technology for enhancing safe and reliable operation of high-speed trains. This paper presents an automated train control scheme for high-speed trains with combined
longitudinal aerodynamics and tracking/braking dynamics, with special emphasis on reliable position and velocity tracking in the face of traction/braking failures. The controller is synthesized using a so-called virtual-parameter-based backstepping adaptive control method, which exhibits several salient features: 1) The inherent coupling effects are taken into account as a result of combining both longitudinal and traction/braking dynamics; 2) fully parameter independent rather than partially parameter independent control algorithms are derived; and 3) closed-loop tracking stability of the overall system is ensured under unnoticeable time-varying traction/braking failures. The effectiveness of the developed control scheme is authenticated via a formative mathematical analysis based on Lyapunov stability theory and validated via numerical simulations.


Passenger rail travel is experiencing a renaissance in the United States, with both large and small cities planning new above-ground rail facilities. The Obama Administration’s commitment to intercity high speed rail has generated much media attention. In the Northeast, Amtrak plans to upgrade facilities between Boston and Washington that will allow trains to consistently reach 150 mph. In the Midwest, a special train traveled at 110 mph from Chicago, Illinois to Kalamazoo, Michigan, which is the fastest train speed in the United States outside the Northeast Corridor. Despite financial setbacks, a 200-mph bullet train is still in the works in California. It is hoped that high-speed trains will make rail a viable alternative to air and highways for long-distance travel. Modern streetcars and elevated rail lines are also being implemented to encourage local rail travel in several cities. Kansas City, Missouri, after several unsuccessful attempts, is close to approving a streetcar line in its downtown. The Kansas City line, like similar ones in other cities, features sleek cars and a short connector route. The goal is for these modern streetcars to attract new office, retail or residential development along the route. Honolulu, Hawaii is embarking on one of the first fully elevated commuter-oriented rail lines in the United States. Elevated rail was chosen to avoid taking up roadway lanes on the island, where space is limited and traffic is already congested. Despite these ambitious and optimistic plans, many of these proposed rail lines still face financial and political obstacles that may hamper their rapid implementation.


This paper presents a new kind of train control system for branch lines that are operated by radio-based operational train control systems. Most branch lines with such operating limitations cannot afford the cost of investment for modern signaling systems. The train control system presented herein represents a low cost solution which improves safety, increases ease of operation, and introduces an interesting level of automation without any costly line-side installations. It is based on data radio communication between the central computer, which is located in the dispatcher’s office and trains (each train is equipped with an on-board computer), cab signaling in the trains, and autonomous determination of train location using GPS and an odometer. Low cost has been achieved by using standard industrial computer hardware within the trains and by omitting any line-side installations, such as signals. Safety has been achieved by special operational sequences and by software redundancy. In Austria this system is in full operation on several lines (standard as well as narrow gauge) with a total length of approximately 90 km.

This article discusses the new technologies being developed to improve railroad maintenance of way (MOW) and to increase the speed of material handling processes. The author focuses on the provision of Multi-Purpose Machines (MTM) and Programmable Linear Unloading System (PLUS) train services. The MPM system allows crews to place materials such as ties and rail ahead of MOW gangs, and to clean up after natural disasters such as hurricanes, tornados, and floods. As railroads are demanding more and more automation to increase speed and improve safety to reduce costs and increase gains, providers continue to invest heavily in research and development. Additional systems described include a mobile, self contained material-handling package featuring a side-boom excavator equipped with a special undercarriage to operate quickly atop rail cars, an automated ballast distribution system, and loader/unloader situated atop rail cars and has Global System Positioning (GPS) capabilities to increase position and speed of an operation.


This article describes some examples of new-generation software and computers that can help plan and adjust train blocks before the cars enter the yard. Railroads are customizing off-the-shelf programs developed by a number of vendors to generate extensive data files about each car including its origin and destinations, special customer instructions and car characteristics and other data that help form patterns around which train blocks can be built. Among the goals is to increase the velocity of cars, that is, the time they spend carrying their loads. For BNSF, the new software has speeded velocity from 109 miles a day in January 2006 to 125 miles in May 2007 for merchandise cars. Another goal of industry is to decrease the amount of time that cars sit in yards. Typically they spend only 18 percent of their time moving in a train. Various railroads’ programs are described.


This article describes how Arizona’s Valley Metro Rail (VMR), which is building a 20-mile light rail system serving Phoenix, Mesa and Tempe, is coordinating the use of 64 consultants on the $1.3 billion project that is slated to open in December of 2008. Focus of the article is on the role that consultants are playing in this project, with Parsons Brinckerhoff (PB) as the primary consultant. PB divided the system into five four-mile line sections: each section will be designed by different consultants. The VMR project is considered to be the largest at-grade, in-street light rail system in the U.S. In addition, the line passes through 148 traffic signals, which required developing a priority system that did not unduly delay traffic but provided safe passage for the train. The article also describes how the light rail project will connect to Sky Harbor International Airport through an automated people mover (APM).


To evaluate the service quality of railway systems the punctuality of the train operation is one of the most meaningful criteria. The punctuality results from the reliability and availability of the technical system as well as from the operating program and a number of external preconditions. The punctuality requirements on the Transrapid as a fully automated transportation system with its own nonintersecting guideway trace are basically strict. After only two and a half years of commercial operation in Shanghai the Transrapid system has actually shown a very high punctuality based on a high availability of its technical subsystems considering the specific operation conditions. While reliability and availability of technical systems are defined by international standards there is, however, a wide range of different punctuality definitions. It is to say that this item is very important for the comparison of punctuality data.
of different transportation systems. After explaining the common expressions of reliability and availability the presentation describes the most useful definitions of punctuality for railway systems. Based on these commitments an overview of the punctuality and availability data of different international railway projects, especially airport connectors, in comparison with the Transrapid Shanghai is presented. Finally an outlook to the punctuality requirements of the German Transrapid project in Munich is given.


The purpose of this paper is to provide a research outlook on the concept of decentralized freight intelligence, i.e. autonomous freight making localized routing decisions. A review of research literature on decentralized intelligence in freight transport serves as the foundation of the analysis. The analysis reveals a scarcity of scientific evidence to suggest a successful introduction of decentralized freight intelligence. Among numerous conceptual findings, the analysis reveals a dearth of research on the clear and present challenges of introducing and adopting decentralized freight concepts in contemporary multi organizational open freight systems. For practitioners this paper provides useful input on future ICT development in the transport field. In particular, due to the lack of guidance on adoption of decentralized freight, a focus on non-networked benefits of information technology is to be recommended. Given the large number of projects, papers and various initiatives related to decentralized freight intelligence, this paper, to the authors’ best knowledge, provides a novel technology adoption perspective on decentralized freight intelligence research.


The provision of appropriate quality rail services has an important role in terms of railway infrastructure: quality of infrastructure maintenance, regulation of railway traffic, line capacity, speed, safety, train station organization, the allowable lines load and other infrastructure parameters. The analysis of experiences in transforming the railway systems points to the conclusion that there is no unique solution in terms of choice for institutional rail infrastructure management modes, although more than nineteen years have passed from the beginning of the implementation of the Directive 91/440/EEC. Depending on the approach to the process of restructuring the national railway company, adopted regulations and caution in its implementation, the existence or absence of a clearly defined transport strategy, the willingness to liberalize the transport market, there are several different ways for institutional management of railway infrastructure. A hybrid model for selection of modes of institutional rail infrastructure management was developed based on the theory of artificial intelligence, theory of fuzzy sets and theory of multicriteria optimization.


This report describes the results of a finite element-based analysis of the train-to-train impact test conducted at the Federal Railroad Administration’s Transportation Technology Center in Pueblo, CO, on January 31, 2002. The ABAQUS/Explicit dynamic finite element code was used to simulate the first 0.5 second (s) of the collision. The primary objective of this program was to extend the use of finite element-based models for simulating the crush of train structures to include vehicle-to-vehicle interactions. A subset of the data collected during the test was first selected as a basis for comparison with model predictions. A finite element model of the train was then developed. This model includes detailed representations of the end structures of the cab car and the locomotive, and coarser representations of the back of these vehicle bodies and the trucks of the cab car. Connections between the cab car body and trucks were modeled to allow for lift of the body during the collision. Trailing vehicles and vehicle-to-vehicle connections were modeled using lumped mass parameters. The results of the model were compared to the selected data. These comparisons indicate that the model captures many aspects of collision behavior, with a fair degree of accuracy, especially over the first 0.25 s of the collision.


In the 1980’s the U.S. Federal Transit Administration (FTA) (then known as the Urban Mass Transit Administration, UMTA) initiated a program to demonstrate the ability of automated guideway transit (AGT) systems to serve as downtown circulators. Three cities were chosen for demonstration grants to build these “Downtown People Movers.” Only two of the systems were eventually built. They are both still operating in Detroit, Michigan and Miami, Florida. The Detroit People Mover (DPM) was built as a 2.9 mile (4.7 km) single-track loop connecting thirteen stations in the downtown core of Detroit. A fleet of twelve cars, which usually run in pairs to improve dependability, went into service in July 1987. The system was designed and built by the Urban Transportation Development Corporation (UTDC) using an integrated AGT system technology that the UTDC called automated light rapid transit (ALRT). Similar systems using the ALRT technology were also installed about the same time in Toronto (Scarborough) and Vancouver. All of these systems used the original 41-foot (12.5-meter) long vehicles, known as Mark I cars. The ALRT technology has since been transferred to Bombardier which now markets a longer Mark II vehicle, replacing the Mark I. Vancouver expanded its fleet with Mark IIs and now runs a mix of 2-car Mark II trains with 4-car Mark I trains and most recently a system with Mark II vehicles has gone into operation at Kennedy Airport in New York City, NY, USA. The automatic train control (ATC) system provided with this technology is the SelTrac® system and has been provided by a subcontractor to UTDC/Bombardier, Alcatel. SelTrac® utilizes a moving block control, which more recently has come to be known as a communications based train control (CBTC). The DPM is run by the Detroit Transportation Corporation (DTC), which functions 24/7. Revenue service is provided from 7 am to midnight on weekdays and for reduced hours on weekends, while most guideway related repairs and maintenance occur overnight. The DTC has kept the system operating daily since it opened, except for disruptions that were beyond the DTC’s control. One of these was a building implosion that went awry in October, 1998, destroying several sections of the guideway. But the system is now nearly 20 years old and the high-tech subsystems were beginning to age. Repairs were needed more often and spares for the dated technology were increasingly more difficult and expensive to find. In addition, over the years funding cuts from past city administrations had forced the DTC into a severe deferred maintenance program.
SUN, Y.-s. and R.-h. XU (2011). "Estimation of Rail Transit Passenger Route Using Automated Fare Collected Data [J]." Traffic & Transportation 2: 023.

This article describes how a three-year program to install platform screen doors (PSDs) on Seoul (Korea) metro lines has been completed successfully, thanks to a technical cooperative agreement between the supplier and the metro operator, Seoul Metropolitan Rapid Transit (SMRT). PSDs are used to reduce ambient noise in the stations, to improve air freshness, and to save energy by improving the efficiency of air-conditioning in the platform areas, as well as their most important function, to prevent accidents. The author describes the pilot study that was undertaken, the approval and funding process, and the equipment and installation methods used. The central control system oversees the whole network. Local controls at each station manage the door functions and the interface with the signaling and automatic train operation (ATO), while collecting and analyzing PSD status information. The system uses a radio-frequency (RF) interface which allows the door systems to be overlaid without physical connections that could damage the integrity of the train control, interlocking, or safety features. Local operating modules allow the driver to open or close the PSDs in an emergency. The article concludes with a description of the modular assembly techniques and installation methods that were used with a minimum of disruption to regular train services.

This article discusses automatic generation of train timetables, with focus on the Sujic program and how it can be a valuable decision support tool in automated scheduling. The basic premise of Sujic is that the evaluation of planned timetables must be approached primarily from a passenger's perspective, with travel time and overcrowding being the two most important criteria that are being optimized. The article includes a detailed discussion on the Sujic concept, timetable evaluation, automatic generation, scheduling and rescheduling, four track railways, and boosting capacity.


Dedicated short-range communication (DSRC) has been used in prototyped vehicles to test vehicle-to-vehicle communication for collision avoidance. However, there is little study on how collision avoidance software should behave to best mitigate accident collisions. In this paper, we analyse the timing of events and how they influence software-based collision avoidance strategies. We have found that the warning strategies for collision avoidance are constrained by the timing of events such as DSRC communication latency, detection range, road condition, driver reaction and deceleration rate. With these events, we define two collision avoidance timings: critical time to avoid collision and preferred time to avoid collision, and they dictate the design of software-based collision avoidance systems.

This paper describes how many transit agencies are faced with highly visible issues that impact on service delivery and customer/stakeholder perception. The customer sees declining reliability and/or performance. Underlying the visible issues are often core issues of outdated management systems and workforce challenges. Agencies must address the areas under their control that can produce short term, visible improvements to support new/sustained funding and improve public perception. Getting the best possible performance from the vehicle fleet is often an easy way of improving the overall standard of service delivered to the customer. While many vehicle improvement programs focus on engineering reliability through overhauls, modifications, and changes in maintenance processes, experience shows that a successful improvement program will tackle both the technical and people issues. Only by addressing those issues surrounding leadership, behavior, values and knowledge can the foundations be laid for a sustainable improvement. Good data is the foundation for any improvement effort, but the quality of available data provides a challenge for every transit agency. One approach to addressing this is to use a Failure Review Group that includes representatives from Operations and Maintenance to ensure that an accurate account of every key event is recorded. Failure analysis tools utilize this data and help to drive to the root cause, enabling a prioritized action list to be developed. Actions can then be implemented based on their relative cost and impact to performance. As poor performance can arise from a number of sources, the Failure Review Group must look for a diverse range of causes, including maintenance processes, poor fault finding, components, environmental factors and operator error or misunderstanding. Only by tackling all of these diverse causes of poor performance can real improvements be generated. However, to make the improvement happen, a strong governance regime which instills a culture of searching for improvement, with appropriate senior management support, is crucial. Such approaches have been effectively followed in the UK by private train operators where high levels of performance and cost effective maintenance are critical to their business survival. This paper outlines these approaches and places them into a context that can be equally effective in improving system performance on any transit system.


The Grona Taget research, development and demonstration program – a joint initiative by the Swedish Railway Administration Banverket, KTH Royal Institute of Technology, Bombardier Transportation and other partners – started in 2005 and is scheduled to run until 2011. A unique and very fruitful cooperation between society, universities and industry to build up knowledge and resources to develop and specify the next generation of high speed trains for Nordic operation. The main objective of the program to achieve is reduced travel times, more attractiveness for passengers, achieve fewer operational costs and about 30 per cent less energy consumption compared to existing X2000 high speed fleet. The high speed train concept of the Grona Taget would cut the travel time between Stockholm and Gothenburg by 10 – 20 % with a operating top speed of 250 – 300 km/h. The program’s valuable results can be adapted to various markets with similar requirements around the world. In a time when rail operators are increasingly challenged by the pressures of volatile energy costs, operating efficiency and global climate change.


This paper describes how, Bill Gates once said that “The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency.” The concepts and principles
of driverless metro systems are well established, especially when applied to Automated People Movers and new build Metro Systems. Driverless operation can deliver significant operational and service benefits over conventionally operated lines. With the establishment of Driverless systems and the underlying enabling technologies the business case for converting an existing metro system to driverless operation is becoming increasingly feasible. To this extent many existing metro operators are either considering, planning or implementing driverless operation. When considering converting an existing metro operation from a conventionally staffed operation a number of factors need to be assessed by the operator in order to evaluate the feasibility of the endeavor. These include but are not limited to: the operational and service benefits required from the system; the safety risk and subsequent control measures; the public perception and acceptance of the system; systems integration and migration from the existing to new system. This paper assesses the principle factors that need to be addressed in the feasibility case for conversion of a heavy metro system to driverless operation. This paper is not setting out to provide an economic evaluation of such a scheme. However it is suggesting that it is possible to construct a feasibility case to convert an existing heavy metro system to driverless operation by considering the issues that have been discussed in this paper.


This paper describes how the European Rail Traffic Management System (ERTMS) is the concept by which Europe is moving towards the standardization of its rail signal control systems. Standardization focuses on interfaces necessary for interoperability between trainborne and trackside equipment. ERTMS represents a step change for many railways, the vast majority of which are signaled with color light signals and basic warning systems. ERTMS is specified in a number of different levels, and dependant on the implementation can introduce the benefits of cab signaling, automatic train protection and future moving block train separation. This paper examines the capabilities and limitations of an ETCS/ERTMS level 2 implementation as specified by the current Technical Specifications for Interoperability for use in high density network locations and the suitability of ETCS/ERTMS to support the integration of an Automatic Train Operation (ATO) overlay. A generic sample section has been developed to analyze the headway constraints within the current ERTMS solution. The conclusions from the study suggest that there are no fundamental constraints preventing a level 2 implementation supporting an operational headway of 24 Trains Per Hour with recovery margin. The use of ATO for a high density application will offer an improved headway performance but will require a level of development and enhancement to the ERTMS functionality and architecture to correctly implement some ATO functionality. A further potential constraint is the capacity of the GSM-R radio communication network. This limitation can be removed by the envisaged migration to packet mode (GPRS) data transmission.

Tsuchiya, R., et al. (2008). A Route Choice Support System for Use During Disrupted Train Operation. This paper presents a route choice support system designed to provide information for passengers when train operation is disrupted due to some accidents, disasters or other incidents. The authors note that a wide range of accurate information must be included, such as the possibility of train operation resuming, the predicted status of train operation after restart, possible detour routes, and the method of travel and time needed to reach the destination using the detour route. The support system is designed to help passengers determine whether they should wait for service to resume on the disrupted line or take a detour route to their destinations. The system consists of an optimal route computation engine and diversified man-machine interfaces, each of which is designed for a specific guidance application. Typical application of the system might include variable signs for many and
unspecified passengers at stations, support systems for station staffs engaged in passenger guidance, or personalized guidance systems using passengers' portable terminals. The system arrives at decisions after computing estimated travel times to specific stations in a regional railway network where some parts of the train services are disrupted. The authors describe field tests in which users use their mobile phones to access the system and learn their route options during a disruption in train services. Results of field tests show that approximately 65% of all users taking the advice arrive at their destination at the same time as, or earlier than, the time estimated by the system and approximately 80% of them evaluated the system as useful. The authors conclude that even though the information represents only possible scenarios and the degree of certainty is not 100%, this route choice support system can be accepted and effectively utilized by passengers.


This paper explores the potential of using automated fare card data to quantify the reliability of service as experienced by passengers of rail transit systems. The distribution of individual passenger journey times can be accurately estimated for those systems requiring both entry and exit fare card validation. With the use of this information, a set of service reliability measures is developed that can be used to routinely monitor performance, gain insights into the causes of unreliability, and serve as an input into the evaluation of transit service. An estimation methodology is proposed that classifies performance into typical and nonrecurring conditions, which allows analysts to estimate the level of unreliability attributable to incidents. The proposed measures are used to characterize the reliability of one line in the London Underground under typical and incident-affected conditions with the use of data from the Oyster smartcard system for the morning peak period. A validation of the methodology with the use of incident-log data confirms that a large proportion of the unreliability experienced by passengers can be attributed to incident-related disruptions. In addition, the study revealed that the perceived reliability component of the typical Underground trip exceeds its platform wait time component and equals about half of its on-train travel time as well as its station access and egress time components, suggesting that sizable improvements in overall service quality can be attained through reliability improvements.


Positive train control (PTC) and electronically-controlled pneumatic (ECP) braking are two technologies that, after almost two decades of development, are finally poised to change North American heavy-haul freight railroading's character dramatically. Existing brake cylinders and rigging are used in ECP-actuated braking, but the brake pipe functions only as a reservoir charging pipe. PTC is designed to protect track workers, enforce permanent and temporary speed restrictions, and prevent train collisions. The two technologies allow the opportunity for "intelligent" trains with intelligent control centers to be created, and pave the way for virtually unlimited opportunities for North American railways. Implementation challenges are discussed. An insert describes several North American PTC projects.


Supply chains are increasingly virtualised in response to market challenges and to opportunities offered by nowadays affordable new technologies. Virtual supply chain management does no longer require
physical proximity, which implies that control and coordination can take place in other locations and by other partners. This paper assesses how the Internet of Things concept can be used to enhance virtualisation of supply chains in the floricultural sector. Virtualisation is expected to have a big impact in this sector where currently still most products physically pass through auction houses on their fixed routes from (inter)national growers to (inter)national customers. The paper defines the concept of virtualisation and describes different perspectives on virtualisation in literature, i.e. the organisational, team, information technology, virtual reality and virtual things perspectives. Subsequently it develops a conceptual framework for analysis of virtualisation in supply chains. This framework is applied in the Dutch floriculture to investigate the existing situation and to define future challenges for virtualisation in this sector.


This research for developing global collaboration has its seeds in the Trains Connected Project, and builds up the partnership, objectives and business and technology considerations relating to the deployment of Wireless Fidelity (Wi-Fi) on trains. The goal of the project is to pursue Pilot Demonstrations to provide Wireless LAN, High speed Internet connectivity and Infocentric Services on trains and this started with an initial co-operation in California’s Capitol Corridor’s AMTRAK service subsidized by California Department of Transportation (Caltrans) managed by the Capitol Corridor Joint Powers Authority with similar efforts at SNCF in France and co-operation between French technology center of excellence INRETS, GLOCOL USA and the University of California at Berkeley. The focus of this paper is to evaluate the challenges, needs and important issues for Wireless LAN Security as Wi-Fi becomes more available to commuters in trains and rail environments, while improving passenger service and building on that experience to better understand the best ways to incorporate Wi-Fi, Wi-Max and Mobile IP capabilities into broader applications for train operations, safety and security.


The opening of the European market for freight and passenger services has initiated the need of new, cost efficient locomotives which fulfill the specific requirements of each country and comply with new European standards. The TRAXX locomotive platform was developed to address these new needs for freight throughout continental Europe. The technological challenges were mastered with a high level of component and system integration as well as with new developments. Important innovations were in the power conversion systems, in the design of the operator’s desk, in the development of automatic train protection systems based on ETCS and in advanced adhesion control schemes. Today, the TRAXX locomotives operate cross-border on long-haul routes throughout Europe allowing short turnaround times, low overall transportation cost and increased quality of service.


Typically, the costs for traction energy add up to 20% or more of the total train operating costs for electric locomotives in Europe. Therefore, there is a high incentive for the railways to reduce energy consumption and thus to improve operating margins. Energy savings of typically 10 to 30% are possible through both regeneration of braking power and an appropriate driving style. Also, it is important to improve the energy efficiency of the entire traction chain. New dual-powered locomotives which combine diesel and electric traction also lead to substantial energy savings compared to conventional vehicles.

The management of information has been associated with the movements of goods and passengers since the origination of the transportation business. Fast couriers were galloping flat out ahead of caravans and merchants in order to announce important people and prepare fair trades. Cables and telegraphs were being channeled across oceans or plains as soon as ships or trains were steaming out of harbors or railway stations. The process of information has improved more and more along one and a half century of joint technological progress and development of transportation and information technologies. Their fates are totally interrelated. Although NTI has fundamentally changed from hyper centralized processes toward delocalized processors and from rigid procedures to customized applications the needs remain the same: to inform passengers and traders and to support operators™ fleet, staff and maintenance management. Rail and Public Transport operations remain largely based today upon the principles imposed decades ago by existing technologies and when there were still no planes or cars to compete with trains or ships. The major challenge remains today to rethink the way trains and public transport are operated in terms of clients™ expectations and company management. NTI (driverless, train control, new signaling, etc.) had demonstrated that they can bring more safety and more reliability as well as more capacity to the operation of existing infrastructures. NTI had although proved to be able to accompany the social change within operating companies. There is still a lot to do for the best of clients and staff by attending the right needs. Some issues can be managed at any time along the life of a transportation system (just by improving systems along with technology evolution without impact on infrastructures). Others shall come right at concept design of new projects like opportunities to optimize quality and costs (capex + opex).


The optimal trajectory planning problem for train operations under constraints and fixed arrival time is considered. The varying line resistance, variable speed restrictions, and varying maximum traction force are included in the problem definition. The objective function is a trade-off between the energy consumption and the riding comfort. Two approaches are proposed to solve this optimal control problem. First, the authors propose to use the pseudospectral method, a state-of-the-art method for optimal control problems, which has not been used for train optimal control before. In the pseudospectral method, the optimal trajectory planning problem is recast into a multiple-phase optimal control problem, which is then transformed into a nonlinear programming problem. However, the calculation time for the pseudospectral method is too long for the real-time application in an automatic train operation system. To shorten the computation time, the optimal trajectory planning problem is reformulated as a mixed-integer linear programming (MILP) problem by approximating the nonlinear terms in the problem by piecewise affine functions. The MILP problem can be solved efficiently by existing solvers that guarantee to return the global optimum for the proposed MILP problem. Simulation results comparing the pseudospectral method, the new MILP approach, and a discrete dynamic programming approach show that the pseudospectral method has the best control performance, but that if the required computation time is also take into consideration, the MILP approach yields the best overall performance. More specifically, for the given case study the control performance of the pseudospectral approach is about 10% better than that of the MILP approach, and the computation time of the MILP approach is two to three orders of magnitude smaller than that of the pseudospectral method and the discrete dynamic programming approach.


This paper describes how the rescheduling train traffic in a busy and complex railway area is a challenging task, partly because of the high number of constraints to be taken into account, and partly because of the many variables involved. Currently this task is performed almost exclusively by human traffic operators. Previous attempts to provide an automated decision support system have been limited to identifying and solving train conflicts locally. Recently innovative dispatching support tools have been presented that are able to cope with large (real-time) timetable perturbations, such as train delays and their propagation. However, there is a lack of computational studies that underline their additional practical value. This paper compared two advanced support systems for real-time rescheduling of train operations that were developed for the German and Dutch railway networks. The research aim is to establish a benchmark for future co-operation and exchange of innovative solutions. A common test case from the Dutch railway network, the dispatching area between Utrecht and Den Bosch, and disturbed traffic conditions are studied to evaluate the two dispatching support tools in terms of delay minimization. Since these tools make use of different mathematical optimization techniques for the computation of running times and train sequences, a detailed comparison of the proposed rescheduling solutions is provided. The use of railway capacity is illustrated in order to enable an easy and fast detection of the conflicts between the trains running in the network and to get precise information about their resolution by the different rescheduling techniques.


This paper on the use of satellite engineering (SAT.engine) for modern train control systems is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The authors describe how during the worldwide introduction of modern train control system projects, such as the ETCS (European Train Control System), it turned out that the actual engineering processes cannot fulfill the increasing requirements of the new technology. This is because, in comparison to conventional train control systems, the amount, as well as the required quality, of planning data is substantially higher. Due to the lack of tools, too many tasks are done manually, which is inherently inefficient and error prone. The authors describe the development of the SAT.engine at Dresden University of Technology. SAT.engine provides an efficient method for a satellite-based track survey as well as further processing tools, e.g. those used for capturing relevant track elements, generating topological plans, producing video simulations for training purposes, and the verification and validation tasks necessary for planning data.


Today the Metro system in Stockholm consists of three lines, the Green, the Red and the Blue line, with a combined total of 108 km of double tracks and 100 stations. As the planning of the new signaling system for the Red line has progressed, the general interest in fully automated systems, unattended train operation (UTO) has increased. The new signaling system will be able to handle 36 trains per
hour. In a fully automated system without drivers, the existing fleet will be able to run more frequent but shorter, trains, especially during off peak hours.


Communications-based train control (CBTC) systems are being implemented worldwide in two forms: moving-block and logical-block. Choice of CBTC mode is usually determined by application or consumer preference. Train operators emphasize different values depending on needs. Operational context and use are even more important than implementation subtleties. Siemens offers CBTC products. Thales Rail Signalling Solutions also does in both moving-block and logical-block categories, including the SelTrac S40 and S30 systems. The author discusses Thales Rail Signalling Solutions ability to integrate system design into a single entity allows more fully coordinated function interaction.


Robust, reliable, and interoperable wireless communication devices or technologies are vital to the success of positive train control (PTC) systems. Accordingly, the railway industry has started adopting software-defined radios (SDRs) for packet-data transmission. SDR systems realize previously fixed components as reconfigurable software. Recognizing the potential uses of SDRs for PTC systems, this project developed a railway cognitive radio (Rail-CR) that implements artificial intelligence decision making capability in concert with an SDR to adapt to changing wireless conditions and learn from past experience. Objectives of the project included: developing a concept of operations for wireless data communication link adaptation based on use-case scenarios for packet radio systems; designing and implementing decision making architecture on an SDR; designing strategies for radio environment observations; defining operational objectives and performance metrics; and designing and exercising a test plan to demonstrate performance under varying conditions. The decision making architecture of the Rail-CR begins with observations of the wireless operating environment and performance metrics. An event, such as an increase in ambient noise or a jamming signal that degrades performance, defines when the cognitive engines (CEs) engage. The architecture enables adaptation to new situations and the capability to learn from past decisions. The Rail-CR was tested under a variety of interference conditions designed to simulate real-world experiences. Each test case compared the SDR with no cognition to cognitive operations. Results show that a radio operating with no cognition was unable to mitigate interference conditions causing either significantly high errors or a loss of connectivity. By changing SDR parameters, the CE was able to successfully address these issues.

Workman, D. and R. Kral (2011). *Flash Butt Wedge Repair of Rail Head Defects*. Transverse defects in the head of rail are the cause for many repair plug insertions and can lead to potential train stoppage if not repaired in a timely manner. In 2009, 76 train derailments were attributed to transverse head defects progressing to fracture in the rail. This phenomenon has been associated with the high axle loads found in mainly North American and heavy haul markets. Market trends are for increasing axle loads which may increase the occurrence of head defects. An efficient, high-performance repair for this defect has been sought for many years. For a truly effective repair, the loss of service time must be minimized to maintain cost effectiveness and the repair must perform as close to parent metal rail as possible. In early 2009 EWI and Holland entered into a joint development program to develop a repair for transverse defects in the rail head. Gas Metal Arc Welding, Resistance Brazing and flash butt welding with a wedge geometry piece were examined as methods for the repair. The flash butt welding process appeared most viable and is already associated with high-quality rail butt joints. The benefits of flash butt wedge welding include no rail cutting or removal, rapid on track repair time within 30-45 minutes, and the ability to modify the process using the computer-controlled flash butt welding system to accommodate different rail wear conditions. Additionally, cooling rates of the weld can be controlled such that the weld and heat-affected zone (HAZ) performance closely match the base metal. Special tooling and processing parameters were developed to use flash butt welding to place a wedge-shaped piece of matching rail material into a slot cut in the rail replacing the compromised area with matching rail material. Hardness testing, bend testing, and fatigue testing of joints produced with the final process all met American Railway Engineering and Maintenance-of-Way Association (AREMA) performance objectives. Residual stress measurements of the weld showed a tendency for residual compressive stress in the rail head, although the level of residual stress was low. Currently, the first-generation welder with automated flash-removal equipment is being deployed in the field. Results of the qualification/performance tests show these welds perform very similarly to flash butt welds currently in rail. The use of this process is expected to enable railroads to quickly repair head defects in a more efficient manner.

Wullems, C., et al. (2014). "In-vehicle railway level crossing warning systems: can intelligent transport systems deliver?".


Xun, J., et al. (2008). *Multi-Objective Optimization Method for the ATO System using Cellular Automata*. This paper describes how Automatic Train Operation (ATO) is one of the most important functions for an advanced train control system in high-speed railway systems. Research on optimization methods for ATO has been done before it is implemented in a train control system. From a theoretical point of view, it can be formulated as one of the functions of multi-objective Optimal Control Theory. This paper presents a new multi-objective optimization method for an ATO system using Cellular Automata (CA). A CA model for an ATO system is applied to simulate train operation. An optimal method for ATO is proposed. Compared with actual train operation results, the control algorithm can reduce energy consumption and ensure train operation safety such as higher accuracy of train stop. Therefore, it can improve the efficiency and safety of the train operation.

This paper presents the methodology for Mobile IP Trial Evaluation at California’s Capital Corridor Inter-City Rail project. The goal of the project is to pursue Pilot Demonstrations to provide Wireless LAN, High speed Internet connectivity and Info-centric Services on trains and this started with an initial co-operation in California’s Capitol Corridor’s AMTRAK service subsidized by California Department of Transportation (Caltrans) managed by the Capitol Corridor Joint Powers Authority with similar efforts at SNCF in France and co-operation between French technology center of excellence INRETS, GLOCOL USA and the University of California (Berkeley). The Trains Connected Partnership Project Work Group was set up to focus on emerging standards, technologies and evaluations which have received interest from various Rail Authorities. The focus is to understand the best ways to incorporate satellite communication, Wi-Fi, Wi-Max, Mobile IP and various promising technologies into broader applications such as passenger service, train operations, safety and security. This paper reports seamless roaming simulations over different systems using Mobile IP.


In train operations over 300 km/h, drivers are supposed to operate the handle for acceleration or deceleration quite often because of speed restrictions at the curves. In order to ensure on-schedule operation and lighten the burden imposed on drivers under high speed operation this paper developed the automatic train operation system for the Shinkansen train. This system automatically controls the speed to follow the target speed of operation as well as obey Automatic Train Control (ATC). The target speed is set by taking account of the ATC restriction, on-schedule running, and energy-efficient operation. The system was applied to running tests using a series E2 Shinkansen train from Morioka to Hachinohe, about 100 km, on Tohoku Shinkansen line. The test results tell that the accuracy of on-schedule operation is 4 s longer than the simulated running time, and the accuracy of following the target speed is within 2 km/h at the maximum speed of 320 km/h. The paper concludes that the system performance is satisfactory for the secure speed control and on-schedule operation.


First driverless line in Spain, the new metro line 9 under construction will soon become the backbone of the Barcelona’s public transport system. Early March 2003, GISA - Generalidat de Catalunya – awarded Siemens Transportation Systems and its consortium the contract for equipping the line 9 with CBTC for driverless train operation. The CBTC system will equip 50 steel-wheeled trains running on 42 km of line. The paper provides an overview of the driverless signaling project.


The objective of this research is to give a business perspective according to technology and usage studies for the service trials. The output will be an overall business model for deploying Wi-Fi on trains. The volume of interest, acceptable service price for end users (consumers, professionals, machines...)* will be compared to the timeframe and cost of such a system implementation, and “business” directions for service will be given to maximize value creation and customer valuation. The description of business models explains the cost structure and the revenue structure to expect according to the value chain. Since the value chain depends on the technological, regulatory, cultural and economical environments, comparing Californian, French and Japanese experiments could be useful to understand how the markets may experiment take-off and growth. The challenges to
implement such services and technologies in other countries are based on the experience obtained in all locations and experiment sites.


European rail operations are being changed by the European Rail Traffic Management System (ERTMS). Train drivers gain unprecedented support through ERTMS through on-board intelligent systems and track-to-train communications. Designed to facilitate European rail network interoperability, it is also designed to improve network performance, capacity, and safety. From human factors and other perspectives, the aviation and automotive industries’ automation concepts parallel ERTMS. Aviation and automotive industry automation has shown that there are a number of human factors issues to be considered in regard to train operations and driving in the United Kingdom. Systemwide intelligent agent interaction must be coordinated effectively if ERTMS strategic benefits are to be had. The authors discuss key human factor issues, including Mental Workload, communications, interface design, transitions and migration, and user information requirements. It is hoped that a structured, proactive research program will anticipate and define challenges to ERTMS before it is implemented on trains.


Communication-based train control (CBTC) is an automated control system for railways using data communications. CBTC systems have stringent communication latency requirements. For rail transit systems, wireless local area network (WLAN)-based CBTC is a popular approach due to the wide availability of commercial-off-the-shelf WLAN equipment. However, WLANs were not originally designed for high-speed environments with frequent handoffs, which may result in communication interrupt and long latency. In this paper, we propose a handoff scheme in CBTC systems based on WLANs with multiple-input-multiple-output (MIMO) technologies to improve the handoff latency performance. In particular, we consider channel estimation errors and the tradeoff between MIMO multiplexing gain and diversity gain in making handoff decisions. The handoff problem is formulated as a partially observable Markov decision process (POMDP), and the optimal handoff policy can be derived to minimize the handoff latency. Simulations results based on real field channel measurements are presented to show the effectiveness of the proposed scheme.


Railway system and track inspection has been the subject of significant research and implementation technology to monitor track conditions and provide timely and accurate information to government agencies, suppliers, and railroads. However, the implementation of new technology is lacking in the area of turnouts and their key components. Turnouts, a design "discontinuity" in the railroad track structure, represent a change in track geometry as well as in the stiffness of the track structure. High levels of force are generated as a vehicle negotiates the turnout, which results in rapid degradation of the turnout and causes train derailments. Derailments in turnouts represent more than 20 percent of track-caused accidents. While other areas of track structure use the visual and automated inspections required by the Federal Railroad Administration (FRA), turnouts still rely on walking inspections whose key provisions are qualitative rather than quantitative. The National Academy of Sciences (NAS) is sponsoring a project to look at international inspection tools and practices and their potential application...
for United States freight and passenger railways. While many of these technologies are still in the research, development, or early implementation stages, they represent significant potential for complementing today’s visual and manual inspection processes with automated technology in order to provide accurate information about turnout condition.


According to ambitious plans unveiled in 2013, a six-line driverless metro network is planned for Saudi Arabia’s capital city, Riyadh, by 2019, and construction on this flagship rail project for the Middle East is set to start in early 2014. This article takes a look at the project, from financing to design plans, to construction challenges (including those that accompany building in the desert).


There is an application need for seamless multimodal advanced traveler information systems. Currently, no comprehensive network modeling approach exists to deal with routing queries for different private and public transport modes taking into account multiple attributes, dynamic travel times and time tables in large-scale transport networks. The goal of this paper is to develop and test a generic multimodal transport network model for ATIS applications. First, we model multimodal transport networks from an abstract point of view and categorize networks into private and public modes. Then we use a generic method to construct a multimodal transport network representation by using transfer links which is inspired by the so-called supernetwork technique. Among all modes, pedestrian networks play an important role in modeling transfer connections. We test our model and algorithm based on a case study in the Eindhoven region. The results indicate that our model and algorithms provide a suitable basis for ATIS applications. One current limitation is that much time is required for data reading and compiling. This can be solved by implementing existing computational strategies to increase efficiency.

Zhao, X., et al. (2010). Modelling and Design of the Formal Approach for Generating Test Sequences of ETCS Level 2 Based on the CPN.

This paper on a formal approach for generating test sequences of ETCS Level 2 (European Train Control System Level 2, ETCS-2) is from the proceedings of the 12th International Conference on Computer System Design and Operation in Railways and Other Transit Systems, held in Beijing, China, in 2010. The ETCS is a safety-critical system (SCS). The authors propose a new Colored Petri Net (CPN) model-based formal approach for test cases and sequences generation to increase the test automation degree of the ETCS-2 system and subsystems. They describe the automated test approach, which includes an automatic test case generating algorithm and a type of automatic test sequence searching algorithm. The output of this approach is a set of well-formed XML (Extensible Markup Language) file that can be used to increase the automation degree of the test executing process. The authors also built and analyzed a partial model of an ETCS-2 On-Board subsystem using the CPN Tools as a case study. They conclude that their CPN-model based testing approach can be used to improve the automation of the testing procedure and the generated test cases can meet the relevant requirements.

