Safe, secure and efficient railway operations with IoT and analytics

Application note
Abstract

Railways are a key part of the sustainable transportation systems of the future, transporting goods and people efficiently and safely. But railways worldwide need a major upgrade in their infrastructure, including digital systems. On the passenger side, digital transformation will be key to providing tomorrow’s passengers with a safe, secure and connected experience. Operationally, it will dramatically transform maintenance, management and operational systems using digital technologies, such as IoT, analytics and, eventually, automation.

Nokia can help railways realize the full benefit of digital transformation and automation with an extensive suite of end-to-end solutions in areas including mission- and business-critical networking and connectivity, IoT platforms, and railway-specific analytics applications. This application note describes how the Nokia water events prediction, scene analytics and asset lifecycle optimization solutions can bring computer vision technologies and machine-learning techniques to help railways to ensure the safety, security and efficient maintenance and operation of their infrastructure.
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Introduction

Spurred by climate change and highway congestion, the world's governments are putting a renewed emphasis on railways with many of them setting ambitious targets. Paradoxically, in many markets for both freight and passenger, they are experiencing falling share of miles. Thus, they are under significant pressure to respond, not only to meet government targets, but also to comply with regulations around security, safety and the environment, as well as new demands from digitally-focused customers. Digital transformation is a critical piece in helping them to lower operational costs, improve safety and create an improved customer experience for their passengers.

To meet these targets, railway operators are facing the overhaul of aging infrastructure. In the area of freight, there is a level of urgency, as well as a golden opportunity to make a step change in railway technology. Emerging technologies include: train control systems, asset monitoring, video surveillance, predictive maintenance, intelligent rail infrastructure and operations, freight and passenger information systems, safety systems, and cybersecurity.

The railways have always put a high emphasis on safety and security. As they increase freight and passenger miles on existing infrastructure, they will need to implement automatic train control, such as ETCS, PTC, and CBTC, in order to support non-stop operations, decreasing time and tighter safety margins. Analytics, machine learning and AI systems will play a key role in enabling them to maintain and even raise safety standards under these more compressed schedules.

More efficient and cost-effective trackside, rolling stock and station maintenance can also be achieved using IoT paired with advanced analytics, prediction and machine-learning technologies. As railways increasingly employ digital technologies, they will also expand the attack surface, putting a much higher emphasis on cybersecurity.

Railways are facing many challenges, from other modes of transportation, budget constraints, aging infrastructure and pressure to do more with less. Digital technologies will play a key role in helping them to meet these challenges and help them to transform railways to one of our safest and most sustainable forms of transportation.

Water events prediction for railways

Railway lines are inherently vulnerable to natural hazards such as water, even more so as climate change increases the probability of extreme weather events. Flooding is the most dominant weather event causing harmful impacts to railway operations. Response to flooding is usually reactive due to a lack of targeted specificity for where and when flooding conditions are likely to occur. Compounding the problem are knowledge gaps regarding infrastructure most vulnerable to flooding. This is proving a liability as the climate changes and historic trends are exceeded year by year. To ensure sustainable network operations, protect infrastructure, optimize route strategies and control assets, operators need to understand the relationship between real-time conditions, historic trends, and infrastructure.

Nokia water events prediction leverages historic data sets to produce predictive analytics embedded within an advanced high-powered hydrologic model. This model identifies real time and forecasted flooding conditions for flash flooding and river flooding scenarios. It considers the unique operational context and infrastructure of client assets in determining and broadcasting flooding risk.
Figure 1. The Nokia flood alert model has been specifically designed for railroads.

<table>
<thead>
<tr>
<th>General flood alert models:</th>
<th>Nokia’s railroad specific flood model:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Uses precipitation input only</td>
<td>• Includes a multidimensional array of attributes to model flooding as a unique process</td>
</tr>
<tr>
<td>• Are not trained to understand industry impacts</td>
<td>• Leverages machine learning to train the model to understand rail specific flood conditions</td>
</tr>
<tr>
<td>• Do not model the routing of water</td>
<td>• Is available 24/7/365 and is configurable for client operations</td>
</tr>
<tr>
<td></td>
<td>• Is data driven rather than textual</td>
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On a continually updating basis, real-time weather data is loaded, and analytics are recalculated. Alerts exceeding defined thresholds (e.g., geography, time interval, or type) are pushed to the user interface and alerts are sent by email, text or other systems to operational staff who analyze the best course of action to mitigate risk to assets. An operational decision is determined and resulting action is taken, averting or minimizing the impact of flooding.

Operationalizing the Nokia flood alert model

<table>
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<tr>
<th>Decision level</th>
<th>Time frame</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Strategic</td>
<td>&gt;24 hours</td>
<td>Preparation for extreme events; modelling high-risk track sections for capital improvements</td>
</tr>
<tr>
<td>Tactical</td>
<td>5-18 hours</td>
<td>Cleaning culverts, fortifying track bed and positioning resources ahead of forecasted storms</td>
</tr>
<tr>
<td>Operational</td>
<td>0-4 hours</td>
<td>Targeted physical inspection; operational decision-making (slow/stop train)</td>
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Figure 2. Nokia water events prediction facilitates better operational awareness to reduce flood impacts by predicting flood locations. This improves passenger and crew safety, maintains efficient operations, and reduces risks to profitability.
Scene analytics for rail crossing safety

There have been major gains in rail crossing safety since the 1980s, however, there has been little change in the last decade. One route to reaching the next level in rail crossing safety is to use computer vision (CV) technology to create automated alerting, as a first step, with the eventual goal of improving safety with full automation.

CCTV cameras have been used for different applications in the railway industry for decades. However, CCTV has by and large relied on people to monitor the various video feeds, which generally leads to perceptual overload, with too much video data to be processed. As a result, it has generally proved most useful for after-the-fact forensic analysis, as opposed to real-time response to events as they unfold.

Advances in cameras, data models, machine learning and edge-cloud computing platforms are making it possible to analyze live video and provide actionable real-time data. Raw video or audio is analyzed against historic video data sets to detect anomalous behavior such as objects, people or cars on the tracks, track deformations or defects, and site line changes.

**Figure 3. The Nokia scene analytics for railroad-crossing safety using machine learning for motion analysis.**

Initially, Nokia scene analytics will be used to alert human operators and then display clips containing the anomalies to them. They will be able to confirm if an anomaly represents an actual issue, with which they can then deal. If not, the system allows them to provide feedback to the program that this is something that it can ignore in the future. In this way, the application gets more accurate over time.

This system lowers human review costs and reduces the number of errors due to human processing fatigue, optimizing human decision-making by presenting only video that requires attention. It enables proactive identification of potential issues, allowing operators to slow or stop a train when there are issues down-track, thus reducing accidents and the costs associated with human safety, emergency response and equipment damage and loss.
Forensic analysis after an incident is simplified. The application can sift through the footage to provide clips before and after the event to help in identifying what actually occurred including license plate recognition. Ultimately, the application can become accurate enough to automate actions where operator reaction times are too slow, similar to technology being employed today in many cars.

**Scene analytics for station safety and operations**

A very similar application of video analytics can be deployed in-station to improve passenger safety by analyzing crowd behavior. The application is trained online as soon as it accesses the live CCTV video data for the station. It learns what constitutes normal behavior patterns in order to be able to identify anomalous behavior. Human operators are then alerted and can judge whether or not the incident warrants attention. In this way, they train the application. It includes autonomous learning systems that reduce the need to have humans involved during this training phase.

Various techniques are applied in-real time to do things like:

- Determine anomalous motion activity in a scene
- Filter motion within a subset of the scene
- Filter specific objects or activity detected in the scene (positively or negatively)
- Use external sensors (such as sound, badge reader, etc.) to trigger events.

The built-in video surveillance viewer or an external video management system (VMS) can be used to consume these alerts.

The kinds of anomalies that can be identified in a train station could include:

- Forbidden walk path (e.g., platform exit path being used to ingress)
- People jumping over or going under a turnstile
- After hour activity near rail lines or equipment
- Abandoned object near critical equipment or placed near crowds
- Perimeter surveillance
- Traffic flow leading to congestion issues (for improved crowd control)

This is an improvement over earlier systems that required programmers to anticipate and train the software to recognize specific kinds of behavior. Such systems are only as good as the programmers’ ability to anticipate what kinds of things might happen. The strength of our approach is that it identifies all anomalies, human operators then make the decision about what constitutes an event or issue. In this sense, the goal is not to identify events or issues per se, but to reduce the amount of normal (non-anomalous) video footage that operators have to monitor. By discarding non-anomalous footage, the application can also dramatically reduce video storage costs.

The events captured above are also available for post-event review. Operators may apply forensic analysis to understand unusual activity that happened in the past for investigative or planning purposes. They can filter events by keyword or geo-spatially (on a map). Once the filter is applied, they can consume the alerts:

- Time-sliced by real-time, daily, weekly or monthly alerts
- Geo-spatially using the built-in map viewer
- By searching based on the metadata tags

The application also has a built-in UI for person counting. Users may use this data to understand traffic flow to better plan the station environment.
Smart Rail Station

This concept integrates our analytics and IoT applications to provide a safe and efficient rail station with a better experience for the end user. It includes smart lighting, smart waste, flood detection, platform ice detection, e-paper display and video analytics for station safety (as described in scene analytics section above).

To take the example of smart waste, the traditional waste management approach was fixed schedule pickup. If a waste bin was seen to overflow the schedule might be increased. But this tended to mean more bins were being emptied prematurely. The industry has now, by and large, adopted smart monitors to measure fill level in bins. This information is used to optimize routing (e.g., pickup for bins at 75% capacity) but it is based on real-time data; it has no predictive capability. A predictive analytics approach uses real-time and historical data to model bin use over time. Thus, for instance, a bin that is only 50% full wouldn’t normally trigger a pickup, but historical data indicates that it will become a problem later that day, so it would make sense to empty it now.

Continuing with this example, integrating information from other operational areas increases the capability of each use case. For instance, waste bin pickup historical data could also be correlated to train schedules and passenger traffic or ambient temperature (better to do pickups more often during heat waves). This fully integrated approach allows data collection and sharing across use cases, which can then lead to further cost savings, scalability and streamlining. Integration also promotes best practices by leveraging end-to-end security and scalability and it can monetize IoT by expanding offerings using a modular and flexible mix-and-match architecture.

Figure 4. The Smart Rail Station solution integrates IoT analytics and scene analytics for a better customer experience.

Rolling stock maintenance

The average age of rolling stock in many mature markets is getting very close to lifespan. This presents an opportunity for introducing new rolling stock technologies, but it also puts a special focus on maintenance. The maintenance and repair of rolling stock poses challenges in planning the use of repair equipment and teams. Breakdowns and unscheduled maintenance of aging rolling stock can wreak havoc with even the best maintenance and repair planning.
Predictive maintenance applications, leveraging IoT asset management and advanced data analytics, are designed to improve on today’s preventive and conditions-based maintenance. Many assets fail during operations when using time-based maintenance schedules from the equipment vendor, yet too-frequent maintenance leads to waste by refurbishing or replacing assets that in serviceable condition.

The Nokia asset lifecycle optimization solution uses condition-based asset assessment to predict failure times and optimize maintenance options. It reduces costs, increases utilization, enhances safety, and minimizes delays and revenue loss. Advanced analytics can also break down data silos, correlating data from IoT sensors, environmental information and historical trends to provide operations intelligence, solve specific operational and maintenance pain points, and optimize asset lifecycle.

Optimizing rolling stock performance requires an understanding of each asset’s likelihood of failure and the consequences should failure occur. Confidence in those failure projections cannot diminish as the projections move out into the future. By pinpointing high-risk assets, operations can prioritize maintenance and repair work, confidently justify and allocate capital spending, and increase overall reliability and regulatory compliance.

Nokia’s industry-leading visualizations display analytics in a wide range of intuitive visual formats to provide unique contextual understanding to users. The comprehensive, real-time view enables operators to align their risk tolerances, business objectives and processes, asset management strategies, and capital investment planning for optimum performance.

**Trackside maintenance**

Rail maintenance and trackside asset health are high on the list of rail operator priorities. Unplanned trackside maintenance issues affect service, incur penalties and thousands of people can be inconvenienced by delays. As railways compete with other modes of transportation for passenger and freight miles, it becomes critical to ensure the best service and greatest safety possible by predicting when maintenance is required and scheduling trackside resources.

**Figure 5. IoT for railways showing modular architecture for trackside predictive maintenance.**

Thirty-five percent of delays are the result of failures in either train or track components. Preventive maintenance that is performed with a cyclic set of actuations throughout the year, if done too frequently, unnecessarily increases costs and delays. For the Indian railway system, for instance, 40% of delays were the result of trackside maintenance. The goal of predictive maintenance is to use trackside data and existing knowledge to create more accurate, customized maintenance schedules per asset including bridges, tunnels, machine/track circuits, overhead line equipment, and train-to-track interfaces.
The goal of predictive maintenance is to identify the various fault characteristics of the asset and model custom maintenance activities. The modeling is done using data from historical sources such as rail traffic, rolling-stock flows, maintenance logs, and planning and control activities. Eighty percent of actual track issues resulting in derailments are caused by vertical displacement of the track. IoT sensors installed on trackside assets can detect vertical displacement and temperature changes. They can also monitor the motions of actuators on the trains and catenary tension swings. Anomalies captured by video analytics, rail-related occurrences and traffic events are all additional data that enables more accurate prediction of maintenance cycles, reducing operations costs and maintenance-related delays, while increasing overall safety.

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Building a smarter railway

The capabilities of the Nokia Enterprise Analytics and IoT solutions are essential building blocks for creating a smarter railway. We have covered five use cases above, but the basic capabilities can be expanded by introducing new historical data, connecting to IoT sensors and cameras and training the algorithms to perform similar tasks for other applications.

Possible railway applications include better understanding operational variability, why slowdowns occur and better modeling events that occur between arrivals and departures that affect the schedule. Freight logistics can help to manage the unloading and stacking of container in the freight yard. There are a number of ways in which stations can be made smarter by the use of sensors and cameras, including smart waste, smart lighting, schedule displays, and the detection of water and ice conditions impeding movement at the platform-train interface.

Architecture

The missing ingredient in the previous discussion is the integral role that communications play in all of these applications. The retrieving of data and video from sensors and cameras requires a high bandwidth, scalable network, often wireless and capable of supporting high-speed mobility. In order to support split-second reactions and automation the network has to have multi-edge cloud processing to ensure extremely low latency processing times.

As a result of these requirements, one of the key technologies to enable advanced analytics and system automation will be network technologies such as IP/MPLS and LTE today and 5G tomorrow. Nokia is one of the leading network vendors in the world and has put a special emphasis on developing LTE/5G solutions for private industries, including rail. 5G is specifically designed to support very large numbers of IoT sensors, low latency automation and highly dynamic traffic fluctuations. LTE/5G networks include optical and microwave transport, multiservice IP/MPLS networking, virtualization and network slicing, as well as software-defined networking and the cloud.
In practice, this means that private LTE/5G network technology has all of requirements to support business- and mission-critical digital applications of virtually any description. Full security is built into this technology, which was originally designed for global carrier mobile networks. Even analytics and machine learning are essential characteristics of the network. With the addition of the Nokia scene analytics and our advance analytics applications, as well as IoT and device management (IMPACT), it is possible to customize virtually any kind of video or IoT application with this architecture, the Nokia Future X architecture for industries.
Why Nokia?

Nokia is the leading railway communications solutions provider. Its networks portfolio is field proven worldwide and it has developed the expertise to modernize and migrate rail networks to the highest safety and efficiency standards. Nokia is the market leader in GSM-R with networks deployed in 22 countries serving more than 109,000 km of tracks. We have also deployed more than 80 mission-critical railway IP/optical networks worldwide.

As a leader in communications, we believe that the Nokia Bell Labs Future X architecture is the best starting point for achieving smarter, safer and more passenger-focused railways. From secure wireless, wireline and IoT connectivity to the edge cloud, datacenter and video and IoT analytics, Nokia is well placed to build the essential fabric of the digital railway.

Complementing our full portfolio of railway solutions, Nokia also offers professional and managed services. Bell Labs Consulting will help with planning for the future and for understanding the business case benefits of new technologies using a structured methodology that establishes quantifiable outcomes for rail operators.