INTRODUCTION

Companies pay a great price when they cannot manage unplanned shutdowns. Research shows that companies worldwide could be saving as much as €149M per year (TSLG, 2012), if they could avoid unplanned failures.

These unplanned failures cause delays to customer journeys and they originate from many sources. The top contributors to delays to passenger journeys: external causes are the number 1 (e.g. weather and power failure) followed by signalling failures, mostly related to track circuits and point machines, and, train failures.

Predictive maintenance can be used to mitigate many contributors to unreliability. Existing technology can offer direct benefits for the second and third top contributors on the list: signalling systems and trains. Within the group of signalling systems, two types of asset are the top contributor: points (or switches) and track circuits. These three – points, track circuits and trains - combined represent one-third of all reliability problems contributing to the journey delays. In addition to this, being able to predict how assets degrade with the influence of external factors will support, for example, the reduction of the number of delays and false alarms.

This whitepaper discusses the application of intelligent asset solutions to the railway industry.

COST OF INACTION

Delays to customer journeys caused by unreliability originate from many sources and the cost implications vary considerably – from fines to unplanned used of spare parts. Research shows that companies worldwide could be saving as much as €149M per year (TSLG, 2012), if the right strategy is implemented to manage unplanned maintenance.

The opportunity to improve reliability impacts in all areas of rail operations. For instance, unplanned failures will increase the required number of employees required to maintain assets during seasons of peak failure which will consequently increase the operational cost. Reducing the number of unplanned events allows companies to deploy staff more effectively; prioritising the right resources to the most critical components on the network. There is also an impact on safety as the maintenance crew will be less exposed the risks involved in performing trackside repairs or inspections. Increased reliability accrues reputational benefits where customers are more satisfied with the infrastructure operator who is keeping the “timetable promise”. Moreover, train and freight operators are also benefiting from increased availability.

The opportunity for cost saving is enormous and it can only be achieved via intelligent maintenance strategies. The next section discusses the evolution of maintenance regimes and what companies should aim at achieving.

MAINTENANCE REGIMES IN THE RAIL INDUSTRY

Corrective maintenance was and still is, the first maintenance strategy implemented by many industries. This strategy takes a run-to-failure approach i.e. wait until a failure occurs to repair the equipment/component. Although rare, some rail infrastructure companies still take this approach to maintenance strategy but this is highly dependent on local regulations and the health and safety culture.

Traditionally, the rail industry has relied on time-based maintenance to support its maintenance planning. This strategy involves planned interruptions with fixed periods of time for specific asset types. The main objective of this strategy is periodically learning about the condition of assets and preventing unplanned shutdowns. The frequency of these planned shutdowns is normally based upon maintenance and operations experience, and equipment vendor’s advice.
When infrastructure companies are implementing a new technology or asset type and do not have experience on the equipment’s behaviour, they typically revert to the equipment vendor for advice. The latter tends to be very conservative as it has to provide one single shutdown frequency that covers all different types of operations and conditions. Furthermore, without specific knowledge about the asset condition, asset owners and maintainers will have the tendency of over-maintain an asset with the objective of reducing potential unplanned failures. For example, the reliability of assets in the network will change depending on its utilisation – a point that moves 100 times will have a different Mean Time To Failure (MTTF) when compared to another point that moves only 10 times. This means the old planned maintenance interval will lead the asset to be over maintained as it takes into consideration another operational scenario.

Another challenge to the experienced-based approach is the ageing of the workforce (RSSB, 2008). With the existing workforce getting older and retiring, a lot of knowledge is lost forcing companies to revert to vendor’s advice. In addition to this, statutory maintenance periods for specific types of asset, usually related to safety-critical elements such as braking and wheel condition, are mandated by many rail regulators. Generally, this approach has been proven effective in achieving high levels of safety in the railway industry but this comes with a substantial cost. Closures due to engineering work impact services considerably in addition to unplanned failures that are not captured by this maintenance regime due to the long interval between planned maintenance activities.

With the introduction of remote condition monitoring (commonly known as, RCM) techniques, it is possible to retrieve information about the status of assets. This extends the potential capabilities of more flexible time-based maintenance strategies and gives the opportunity to learn how the asset is behaving throughout the time. Armed with this information, infrastructure owners are able to identify imminent failures and act prior to its occurrence. The impact on maintenance cost varies and it depends fundamentally on how companies are applying the condition monitoring techniques. Figure 2 shows the main drivers to maintenance cost plotted against a timeline. Companies might start over-maintaining assets if the threshold that triggers a site visit is not properly defined or adjusted as more knowledge on asset operations and behaviour becomes available. However, in the long-term, RCM should lead to maintenance cost reduction.

![Figure 2: Drivers to Maintenance Cost](image_url)

Companies that move beyond traditional condition monitoring systems are able to identify trends and provide diagnoses to specific problems. In order to have a complete view of the asset performance, additional variables that correlate with potential failure mechanisms must be included. Some of the extra information required might include:

- **Asset data:** Population, age, a percentage of worn out, maintenance plan and history, previous faults (specific and population), geospatial position, historical usage, historical measurement readings
- **Planned Asset Usage:** Traffic management system schedules, demand, possessions, train cargo
- **Secondary information:** Weather – historical and forecast, risk appetite, staff profiles

This additional information will allow companies to understand the current health of the asset which advances the capability of planning the repair task. This means maintainers are able to take only the necessary equipment and resources to perform the repair.
Finally, the next generation of maintenance strategy involves intelligent assets, as described in Figure 3. At this stage, the new maintenance strategy is capable of offering a prognostic assessment along with the future health and remaining life of the equipment item. The end result is being able to predict faults - this is the first step into the world of predictive maintenance.

Apart from indicating the status of the asset condition at a specific point in time and offering insights around trends, this method offers advice on what is the best strategy. These recommendations can only be achieved by extensive industry knowledge incorporated into machine-learning algorithms that consider all information available. Deep learning, an example of Machine-Learning techniques, will play an important role in taking all this data and transforming it in potential action-plans to improve reliability and maintenance. All these techniques are intended to help maintainers and operators to identify the signal from the background noise of data.

The vast amounts of data acquired during the operations and maintenance phase can be used to make informed decisions during future design-phases. Essentially, the considerable amount of information can be used to ensure projects meet their specified functions whilst taking into account specific conditions for the expected lifetime.

TECHNOLOGY ENABLERS

This is the perfect storm for the implementation of predictive maintenance techniques. The advent of big data platforms combined with near limitless cloud storage and processing power will allow the introduction of inexpensive software applications to support the decision-making process in the rail industry. The cost of data storage and processing has been exponentially reducing over time together with bandwidth cost (Buyya, et al., 2009). This enables the deployment of applications that account for a large number of variables and data points.

Another important technology enabler is the Industrial Internet of Things (IIoT) and the potential connectivity between different machines. Industry reports accounted for 8.4 billion connected “things” in use worldwide in 2017 (Gartner, 2017). This number shows an increase of up to 31% from 2016 and the trend suggests the number of “things” connected in 2020 will reach 20.4 billion. IIoT will connect signalling systems, rolling stocks, communication systems, level-crossings, station information, surveillance cameras, traction substations, point machines and many other data sources. This new opportunity for connecting machines will greatly impact the rail operations.
Lastly, cyber-security will play a central role in. The large volume of data being transferred between different systems requires an advanced cyber-security system. The internet has grown exponentially since its earlier days in 1991 (Schueler & Hall, 2017) and so have the number of cyber-attacks (Thales, 2013). As of January 2017, there were more than 3.5 billion internet users in the world (Statista, 2017). Today’s hackers are more persistent, more targeted and more threatening (Thales, 2018). Thus, end-to-end information security is vital and the focus should extend beyond simply attempting to prevent and detect attacks but also to react rapidly when they occur.

**IMPACT OVER THE ASSET LIFECYCLE**

The implementation of intelligent asset techniques offers different benefits throughout the asset lifecycle. The knowledge acquired throughout the different stages of the asset life can be used to support the decision-making process for new projects. Thus, apart from the immediate return on investment coming from savings in maintenance expenditure and avoidance of penalties, the knowledge acquired to improve new projects is invaluable. Safety will also benefit greatly from the implementation of intelligent asset solutions – for instance, reduced site visits will also reduce the risk to the maintenance team.

The vision for supporting assets throughout its lifecycle also includes a Digital Twin. A Digital Twin is a virtual replica of the asset which is constantly updated when new information becomes available. Gartner (2017) predicts that organisations will gain as much as 10% improvement in effectiveness because of these digital twins.

**Figure 5: Impact over the lifecycle**

The following section describes the benefits for each stage of the asset life.

**Project phase**

New projects rely considerably on industry and company knowledge to avoid errors. However, these analyses normally use a generalised or “average” experience which describes a large number of scenarios, lacking actual data evidence. Taking an asset intelligent approach allows companies to easily manipulate data to display the correlation between specific variables for a detailed scenario. For instance, instead of taking an “average” view of what the performance of point machines for a high-speed railway crossing a country might be, one could break it down by specific sections of the line, manufacturer, actuator type etc. This would allow investigation and the identification of correlations between the performance of specific asset types to a number of variables such as topography, weather information and distance from maintenance depots etc.

For companies that are identifying areas for investment, it is possible to identify critical areas of existing assets and plan for upgrading projects, resulting in a better return on investment.

**Commissioning phase**

During the commission-phase, it is possible to considerably reduce the time taken to test a new line or a signalling system. One example of the application of intelligent asset solutions during the commissioning phase refers to new urban rail systems. The Test & Commission (T&C) phase must demonstrate that all technical and project requirements developed during the concept and design stages are met. Asset intelligent solutions can be a great integrator, providing additional testing to the interface of maintenance and operations teams and systems. One key goal of the testing and commissioning process is to confirm that all systems and equipment items can operate in an integrated manner and are fulfilling the performance standards. Furthermore, this phase must prove that all systems will operate satisfactorily in actual service. This encompasses testing all equipment under actual operating conditions in addition to degraded mode tests (such as checking “incident recovery time”, etc.) and endurance tests (to prove the system can operate for long periods of time). Asset Intelligent solutions allow the system to gather a great amount of information whilst testing the line. This can be used to prove that equipment is behaving properly and meeting the expected performance. Also, the data acquired can be compared with existing operations to benchmark the behaviour of new systems. Added to this, this maintenance strategy is able to pinpoint a problem more effectively, allowing the maintenance crew to fix the actual problem, reducing the number of recurrent tests.
Finally, all the data and information generated by Asset Intelligent solutions can be used as a way of reporting that the system is operating under the specified conditions, meeting performance and safety standards.

**Operations**

Improved reliability and reduced maintenance periods will directly impact passenger satisfaction which is likely to drive more business and lead to more passengers. Capacity will also increase as the rail network becomes more available. Moreover, the impact in punctuality is significant, reducing the number of penalties.

One example of operational decision-making based on asset intelligence refers to securing points. If a point is diagnosed with an emergent failure trend, the operations team could potentially secure it in a specific position and use an adjacent point instead. When the traffic reduces, this could give the maintenance team the opportunity to repair the point. If the problem is more serious, the operating company can re-route trains to minimise disruption.

Another scenario would involve an imminent failure – at this stage, the benefit would be quickly communicating the impact of potential delays to passengers.

**Maintenance**

This is the area where asset intelligent benefits are most visible. The main benefits range from reducing the repair time by easily identifying what component will fail and where this failure will occur. Further benefits result from being able to mobilise the right resources to perform the repair as well as making sure these resources are available when required (i.e. not mobilised performing a different task). One critical area of maintenance is having the required spare parts available to perform maintenance tasks however having too many in stock is a waste of money. By understanding the utilisation of spare parts, companies can optimise the number of spares in the warehouse as well as the restock level.

Upon completion of the maintenance work, intelligent solutions can be used to determine whether repairs have actually corrected the identified problems or led to further abnormal behaviour before releasing possession of the system. This minimises repeat failures and site visits often necessary to revise incomplete or inadequate repairs. By allowing the maintainers to more effectively identify and locate failures the number of repeat failures and site visits decreases.

Asset intelligent solutions also overcome one problem of condition monitoring. Condition monitoring systems will raise alarms every time an abnormal behaviour is identified – however, this abnormal behaviour might not lead to an imminent failure; it may not even be abnormal for that particular asset but is classed as so for the greater population. Without the ability to identify whether a trend indicates an imminent failure, this alarm will mobilise a maintenance crew which will go to the site without actually being required to do so.

Another example of the optimisation of number of visits to the rail track concerns point heaters. The build-up of ice on the rail track in cold climates can cause severe disruption during winter months. In order to overcome this problem, operators invest in heating systems – the most critical parts of the rail track in this scenario are switching points, which can cause signalling problems resulting in major disruption. Thus, testing point heaters are essential for the safety and performance of the railway. In the UK, for example, there are 4,000 point heaters which are each tested every four weeks, leading to close to 12,000 visits every winter. By implementing condition monitoring systems, it is possible to track emergent failure patterns and mobilise the maintenance crew only when required. In this case, the repair will take considerably less time when comparing a failure occurring in between two tests which will have to wait around 2 weeks to be repaired if it was undiscovered and could also pose a derailment risk.

The following section offers insights on how to predictive maintenance and asset intelligent solutions can optimise the efficiency and utilisation of assets in the railway industry.

**OPTIMISING THE EFFICIENCY OF THE RAILWAY INDUSTRY**

Specific asset types in the railway industry will benefit from intelligent asset solutions in different ways. The section below describes one insight that reduces the risk of a service impacting failure. This insight is available in Thales’s intelligent solution – TIRIS.

**Points Machines**

Point machines are typically under the periodic routine maintenance regime. To optimise the frequency of these planned shutdowns, companies have traditionally taken a risk-based approach to select assets that are showing imminent signs of failures i.e. prioritising assets with the highest probability and consequence of failure.

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\text{Risk} = \text{Consequence of Failure} \times \text{Probability of Failure}
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Risk-based maintenance requires a robust mechanism to detect developing faults to address the probability side of the risk equation. This results in reducing in-service failures in addition to ensuring that the point machines are not being over maintained. The implementation of machine learning algorithms and artificial intelligence is fundamental to automatically identify and classify a developing fault within a point machine.
In TIRIS, a list of all assets is displayed in a map, allowing the maintainer to identify the region affecting the failure. These assets can be ranked by many parameters including health. In the context of thousands of assets spread in a country-wide rail network, this view allows users to easily identify what assets should be prioritised when it comes to maintenance tasks. Figure 6 shows the map view with many assets - the point machine selected is showing a high probability of failure.

By clicking on this point machine, the maintainer can investigate in details and get information such as the number of swing operations, which would inform the criticality and allow for a usage-based maintenance approach. Figure 7 shows a detailed view of the point machine. The Machine Learning algorithm is detecting a number of swing operations which resemble the behaviour of a locking issue. Typically, the maintainer would select the last curve (in blue) and one curve where the behaviour was normal (in orange). This approach allows the maintainer to easily compare the behaviours of

The next step in this process is identifying how much time is available to plan a repair and what is the degree of confidence on the emerging failure. TIRIS takes the degradation rate and calculates when the asset will be reaching a level of “zero” health, predicting when the failure is likely to happen. This calculation, obviously, takes a probabilistic approach, allowing for a 10% range.
The Machine Learning algorithm runs every time the point machines moves. Figure 9 shows two curves – the brown shows a “faultless” behaviour and the green curve shows an emerging failure pattern. The trend in the brown curve shows TIRIS losing confidence that the point machine is behaving normally. This approach allows maintainers to understand whether the asset is consistently behaving abnormally, indicating that it may require attention. The curve in green shows the emergence of one of the failure modes pre-defined in TIRIS. The more data is captured (i.e. the more the point machine moves), the more confidence TIRIS has around the predicted behaviour of the asset. At the time of the analysis, TIRIS is showing a 72% confidence in this failure mode.

**CONCLUSION**

Predictive Maintenance and intelligent asset solutions are vital for the success of the railway industry. The cost of inaction is extremely high and the pressure from passengers will only increase with time.

By utilising existing data sources, companies can move beyond traditional maintenance regimes. These new maintenance regimes are now possible cheaper and easier to implement considering the advent of new technologies such as Industrial Internet of Things, Cloud-enable applications and big data analytics.

The benefits of implementing intelligent asset solutions are vast – from improving reliability and availability of assets and systems by enhancing the financial performance of rail operations to rising safety levels. Companies implementing TIRIS will typically achieve:

- High-return on investment
- 30% reduction in maintenance costs
- 75% reduction in unplanned site visits
- 40% reduction in downtime
- ZERO unplanned maintenance target
THALES TIRIS

TIRIS is Thales Big Data Analytics platform for the rail industry. It takes advantage of technologies such as the Industrial Internet of Things, which offers connectivity between assets, cloud-based solutions, which offers storage and processing capabilities, and data analytics, to create insights and knowledge from small and big data sources. This technology agnostic foundation is used to support the implementation of predictive maintenance and operations optimisation techniques. In addition to this, TIRIS supports Thales Digital Service offering which includes advisory and data science services.

TIRIS is a cost-effective solution to analyze, process and report large amounts of data that are normally underutilised by rail operators and maintainers. The implementation of advanced data analytics helps maintainers and operators to go beyond traditional remote condition monitoring. This is achieved the implementation of machine learning techniques to calculate the asset health and its remaining life. These machine learning techniques are implemented as part of Thales Digital Service offering which includes data science, software engineering and rail domain expertise capabilities.

Rail maintainers and operators will be able to “program” their expert knowledge into health assessment, diagnosis and prognostic models in the TIRIS platform. In return, they will benefit from new models and insights created by TIRIS’s user-community spread all over the world. Even though Thales promotes collaboration for everybody’s success, the asset owner retains rights to the information they provide into the TIRIS platform, which is secured at rest and in transit. Access to this data is enabled through the access control mechanisms within the platform, where the data owner uses delegation to allow access for Thales to apply the TIRIS models and analytic tools. This delegation can be withdrawn at any time.

TIRIS managed service offering:

- Cloud data storage, data processing, security and visualisation
- Weekly customer review meetings and pro-active incident management
- Periodic report of railway anomalies (including “catch of the week”)
- Continuous improvement of algorithms, adapting to changing customer environment and assets, through the continued collaboration of Thales software engineers, data scientists, subject matters experts and customer knowledge
- Data scientist investigation into anomalies, creating new improved failure algorithms
- User enhancements tailoring TIRIS visualisations to customer requirements

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