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Towards an intelligent and automated platform for railway Asset Management

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Abstract

This paper presents the objectives and the main expected results from IN2SMART Project, funded by the SHIFT2RAIL Joint Undertaking and the European Commission, within the SHIFT2RAIL Research Programme. This project contributes to the development of an intelligent and automated platform for Asset Management decision-making, focused on the planning of predictive, condition and risk-based Asset Management activities. Based on a framework for Asset Management aligned with international standards, the platform receives inputs from tools and models for predictive analytics that are able to extract information on current and future asset condition, using heterogeneous data from the field. In particular, nowcasting and forecasting methodologies, diagnostics and anomaly detection techniques and indicators derived from Risk, RAMS and LCC analysis are used to support decision-making. Finally, real-world business cases are presented to show the expected applicability of the proposed automated platform and the usefulness of the relevant methodology.

Keywords: Railway Asset Management; decision support systems; asset status nowcasting & forecasting.

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1. Introduction

Rail transport is rapidly becoming digitalized with an increasing role of digital technology in all aspects of the rail sector. The digital revolution is opening up many opportunities for railway operators and infrastructure managers. One of the main potential benefits from the digital transformation is the possibility of increasing the efficiency of the Asset Management process through decision support systems with the aim of ensuring the maximum railway network availability and reliability while reducing life cycle costs (LCC). Indeed, Asset Management and, in particular, maintenance can be improved through the use of networked technologies for condition monitoring and asset information systems, achieving prognostic Asset Management strategies. In particular, a new prognostic approach could make possible for operators to be well aware of Asset Management and maintenance needs before failure. Nevertheless, the available data, from new monitoring technologies and sensors, both on-board trains and on-site, are usually heterogeneous and no automated tools are used to extract information from them. In this context, the IN2SMART Project[1][2]is located.

IN2SMART "Intelligent Innovative Smart Maintenance of Assets by integRated Technologies" is funded by the SHIFT2RAIL Joint Undertaking and the European Commission, within the SHIFT2RAIL Research Programme Innovation Programme 3, call for JU members S2R-CFM-IP3-02-2016 – Intelligent maintenance systems and strategies. The project aims at contributing to the development of a decision support platform for prognostic Asset Management, identifying the main 'building blocks' and their interactions, showing how the use of big data and predictive analytical techniques could foster the optimization of Asset Management and the prolongation of asset lifetime.

IN2SMART forms part of the research and innovation projects that deliver the vision and strategy of SHIFT2RAIL Innovation Programme 3 for cost efficient, sustainable, and reliable high capacity infrastructure. Within the IP3, the Intelligent Asset Maintenance Pillar is a driver to deliver innovative Asset Management in the railway sector. As defined by the SHIFT2RAIL Multi Annual Action Plan (SHIFT2RAIL J.U., 2015), the Intelligent Asset Management pillar is made up of three interlinked Technology Demonstrators (TDs) (Fig.1): TD3.7 Railway Information Measuring and Monitoring System (RIMMS), TD3.6 Dynamic Railway Information Management System (DRIMS) and TD3.8 Intelligent Asset Management Strategies (IAMS).

The IN2SMART project delivers the strategic research and early stage development essential to fulfil the TDs objectives in their entirety within the framework of SHIFT2RAIL. In more details, IN2SMART puts solutions from DRIMS and RIMMS into a common context to establish Intelligent Asset Management Strategies (IAMS). The framework completes the processing chain from gathering data (RIMMS), extracting meaningful information and knowledge (DRIMS) by turning them into decisions.

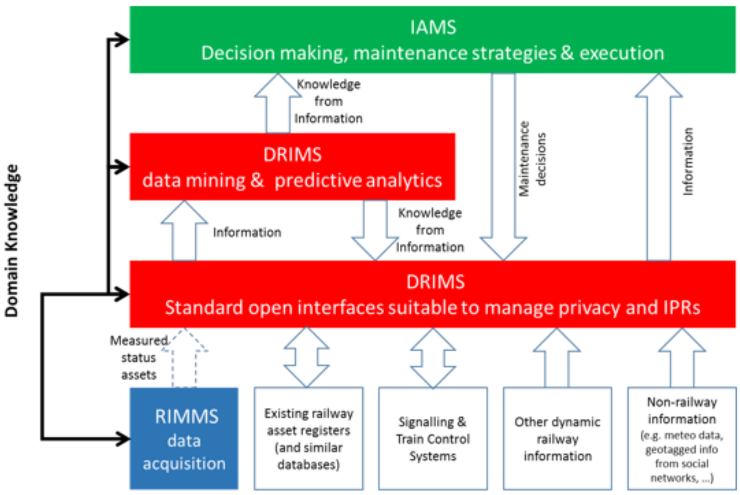

Fig. 1 Relationships between TD3.6, TD3.7 and TD3.8

[1] http://projects.SHIFT2RAIL.org/s2r_ip3_n.aspx?p=IN2SMART

[2] Partners: ASTS (project coordinator), NR, BT, CAF, SIE, THA, TRV, DB, IP, SR, CEMOSA, DLR, FRAU, ACCIONA, SNCF-R, VIF, FCP, WL, MER, OBB, SBB, TCDD. + OTHER LINKED THIRD PARTIES

Moreover, IN2SMART will complement the work already under development in IN2RAIL (Innovative Intelligent Rail Project), one of the lighthouse projects of SHIFT2RAIL programme, to reach a homogeneous TRL4/5 demonstrator. While IN2RAIL lays the foundation of the main building blocks for the next generation Railway Asset Management framework (Stenström et al., 2017), starting the work on nowcasting (Anguita *et al*., 2017) and forecasting techniques (Oneto *et al*., 2017), Open standard Interface and Canonical Data Format (Dambra *et al.*, 2017), degradation models (Guyot *et al*., 2017), condition and risk-based maintenance planning (Van Kalsbeek *et al*., 2017), etc,; IN2SMART proposes a more advanced and integrated Asset Management framework (Papa *et al.*, 2017). The activities developed by the IN2SMART project will be continued within the relevant and following Shift2Rail project that is planned to start in 2019 with the goal of reaching a TRL6/7 by 2022.
Starting from the proposed Asset Management framework, this paper presents the IN2SMART main expected result: an intelligent and automated platform for the management of railway assets focused on the planning of prognostic, risk and condition-based Asset Management activities. Moreover, real-world business cases are presented to show the expected applicability of the proposed automated platform and the usefulness of the relevant methodology.

2. IN2SMART Asset Management Framework

The IN2SMART Asset Management framework (Papa *et al*., 2017) is aligned with the ISO 55000 (ISO, 2014) and the related UIC guideline (UIC, 2016). The Asset Management activities are classified according to the planning horizon as strategic, tactical or operational, considering the three main components identifying by the ISO:

- Strategic Asset Management Plan (SAMP): documented information that specifies how organizational objectives are to be converted into Asset Management objectives, the approach for developing Asset Management plans, and the role of the Asset Management system in supporting achievement of the Asset Management objectives.
- Asset Management Plan (AMP): documented information that specifies the activities, resources and timescales required for an individual asset or grouping of assets to achieve the organization's Asset Management objectives.
- Implementation of the Asset Management Plan (IAMP): activities that are undertaken at each stage of the asset lifecycle, including the application of risk control measures, as specified in the Asset Management Plan.

The benefits of aligning the Framework with ISO 55000 are that:

- It provides an established way of categorizing decisions and activities.
- It provides access to definitions and descriptions that are widely accepted in other organizations and sectors and are relevant to an IAMS development for railways.

The SAMP, AMP and IAMP processes are iterative and there are feedback loops between many of the components. The entire process indeed is based on a Plan-Do-Check-Act approach for the continuous improvement of the management cycle.

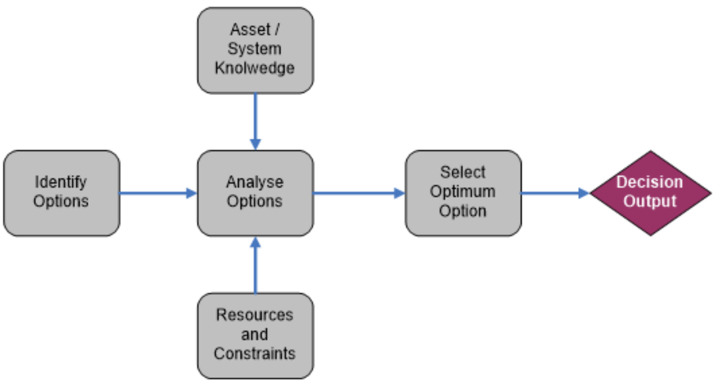

Fig. 2 Generic decision process during SAMP and AMP and stages

The components of the generic SAMP and AMP decision process, which describes how options are identified, analysed, selected, are depicted in Fig. 2. The output from the decision process expresses the optimum option in a form that provides the input to the next stage e.g. from planning to delivery. It captures the risks and uncertainties associated with the decision(s) and provides performance indicators that enable tracking of the effectiveness of the decision(s) and its (their) implementation.

The analysis of the options depends on two key sources of information:

- **Asset and System Knowledge**: Good decisions require timely and accurate information about the asset status e.g. age, condition, work history etc. They also require knowledge about how assets degrade and fail with age and usage and how asset interventions affect condition or mitigate failures.
- **Resources and Constraints**: The feasibility of each option under consideration depends on the resources that are available e.g. human, plant, spares. It also depends on whether there are any firm constraints such as the availability of funding or restrictions on the access to the network to undertake engineering work.

The Implementation of Asset Management Plan (IAMP) is the third step within the Asset Management System Decisions and Activities Framework. The structure of the IAMP (Fig. 3) is different from the SAMP and AMP as the key decisions have been made in terms of what work is required, when it will be delivered and how the network will be operated on a daily basis. There are fewer major options to consider in this stage, the emphasis being on implementing consistent and repeatable processes. The exception is when unscheduled events occur and affect the operation of the network making possible a number of available options. Perturbations may occur for a number of reasons, for example the failure of assets affecting the movement of trains, the receipt of diagnostic information from sensors requiring an intervention, or the overrunning of engineering work. The decisions taken in response to such perturbations are a key part of the requirements for an intelligent Asset Management framework.

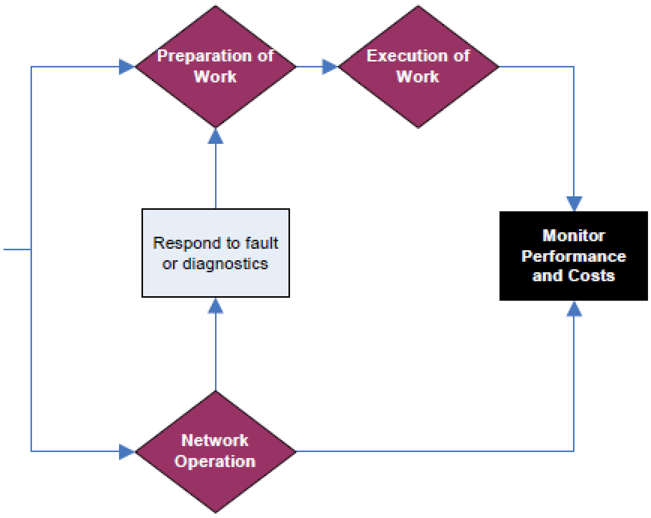

Fig. 3 Generic decision process during IAMP stage

The final component of the decision process is performance monitoring. It is concerned with collecting and analyzing information that does not require an immediate decision but does reveal how the infrastructure is performing and whether the planned work is being delivered within the time and budget allocated. This information provides a measure of the effectiveness of decisions taken at each stage of the Asset Management framework.

3. The Asset Management automated platform

Starting from the Asset Management framework presented above, IN2SMART partners aim at developing an intelligent and automated platform for the management of railway assets focused on the planning of prognostic, risk and condition-based Asset Management activities. The integrated platform consists of "building blocks" with different functionalities and interaction, from which the workflow and the flow of information derive.
In Fig. 4, the "building blocks" that comprise the construction of the intelligent platform for the management of railway assets are described in detail and they can be summarized as follows:

- **Configuration management module**: identification of components and their hierarchies.
- **Risk analysis module and relevant parameters identifications**: evaluation of the relationships between assets and components through risk analysis processes, RAMS and LCC; identification of the parameters to be monitored and the related thresholds.
- **Data collection and Integration Standardization layer**: identification and collection of the available data in a canonical data format.
- **Asset condition module**: Data storage in order to analyze data by prognostic algorithms, assessing asset condition. It consists of:
    - **Anomaly detection module**: algorithms to automatically identify anomalies and provide alarms.
    - **Nowcasting and forecasting module:** models to determine the current status of each asset and to predict its future evolution.
    - **Other analytics or techniques:** such as images processing from drones or SAT solutions, etc..
- **Condition and Risk-based scheduling module**: models for the dynamic and intelligent scheduling of maintenance activities, which are able to determine the priorities of interventions, based on the knowledge obtained from the above-mentioned predictive algorithms and from the assessment of the failure risk and criticality of the assets;
- **HMI Interface**: graphic interface that effectively provides operators and maintenance teams with all the information they need for the optimized management of all maintenance processes.
- **Control module**: Process control and review.

Therefore, the decision-support platform uses the outputs from tools and models for predictive analytics (Karim *et al.*, 2016; Lee *et al*., 2016; Thaduri *et al.*, 2015) that are able to extract information using the heterogeneous data from the field and from different sources. In particular, nowcasting and forecasting methodologies (Fumeo *et al.*, 2016) are used to evaluate the current and future asset status. Moreover, diagnostics and anomaly detection techniques enable automatic anomaly detection and provide alarms; as well, the knowledge about the assets status is used, with other information derived from Risk analysis, RAMS and LCC, in order to support Strategic, Tactical and Operational decision-making. The risk analysis module is able to assess the impact of an asset failure on the entire system performance, evaluating asset criticalities.

The decision support system contributes to the prevention of costly failures and supports operational Asset Management and maintenance decision making, especially with regards to safety and planning interventions, analyzing in real and nearly real time the data to extract information and knowledge.

In particular, the Condition and Risk-based scheduling module aims at scheduling efficiently prognostic, risk and condition-based Asset Management and maintenance interventions in order to optimize the considered objective function, which consists of different elements, such as maintenance costs, spare parts availability, crew availability, contractual constraints and penalties, etc.. Examples of risk-based scheduling models are available in literature (Consilvio *et al*., 2018).

Therefore, the proposed platform is an intelligent and interactive decision support system able to establish the priorities of the Asset Management activities according to the knowledge obtained from nowcasting and forecasting tools and risk assessment, considering how the asset failure affects the entire system.

A feature of the support system is also the ability to dynamically optimize Asset Management operations, dealing with uncertainties and unexpected events, providing flexibility and achieving an increased level of satisfaction for customers. Finally, the interface with operators, maintainers and customers is defined to communicate the necessary information and outcomes, taking into account human factors.

Therefore, the decision support system can be used to trigger Asset Management interventions autonomously. For preventive maintenance interventions scheduling, this leads to move from time-based to predictive criteria.

The proposed approach reduces the uncertainty associated with the asset status, thus increasing the reliability of the infrastructure and reducing maintenance costs.

In addition, it is able to support the optimization Life-Cycle Costs (LCC) over the whole lifetime of the infrastructure providing a better knowledge on asset, predicting failure events, thus optimizing the Asset Management plan and improving performance.

The main advantages in adopting such approach are:

- Characterization of the variables/parameters involved in the evaluation of asset status.
- Integration and correlation of data related to different aspects of the infrastructure.

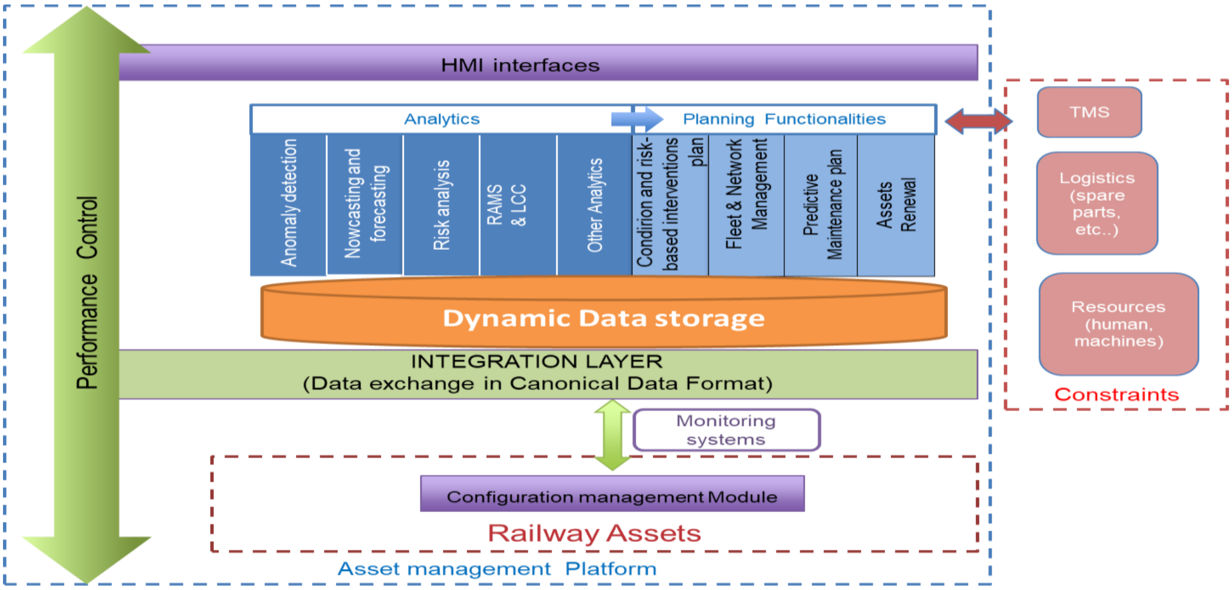

Fig. 4 Building blocks of the automated Asset Management platform

- Reduction of uncertainty and variability of configuration across infrastructure lifetime (Life Cycle Approach).
- Choosing optimized Asset Management plans based on true infrastructure conditions.
- Adoption of condition-based and predictive maintenance logic by leveraging the use of data from inspections and monitoring in probabilistic analysis.
- More precise estimation of failure models (and their effects) on the entire system.
- Earlier/timely identification and correction of critical defects and mitigation of risks of critical defect occurrence.
- Efficient usage of track access times, thus increasing track availability.

Summing up, the main aim of this expected automated platform is to support a reliable and resilient railway infrastructure where remote condition monitoring, prognostic and risk-based strategies are the basis for a coherent and integrated Asset Management from strategic to operational actions.

4. Business Cases

In this section, the applicability of the proposed automated platform is shown, presenting two real-world business cases, selected by IN2SMART partners, and approved by the project Technical Management Team (TMT) and Steering Committee (SC) bodies, for their relevance within the IN2SMART project and for corresponding to the main issues in the Asset Management field.
Both storyboards represent real Asset Management problems, providing different use cases and covering the identification of existing needs (functions to be optimized), identifying the asset to be managed, the relevant parameters influencing the selected Asset Management problem and the available data.

4.1. Storyboard 1: Reduction of walking inspections

The illustrative storyboard, proposed by SNCF, Infrastructure Manager of the French Railway Network aims at reducing walking inspections thanks to improved and smarter data gathering and data-driven support.
This storyboard focuses on optimizing inspections and improving operators working conditions, trying to reduce their presence on track. Indeed, walking inspection is one of the most important and critical maintenance activities for a Railway Infrastructure Manager. The inspections are aimed at gathering information concerning the status and the behaviour of the assets, in order to anticipate maintenance needs and/or adapt maintenance planning, ensuring a high level of safety and performances on the network. Nevertheless, inspection activities are time and human resources consuming, requiring expertise concerning the behaviour of assets, and a precise knowledge of local particularities.

Even though some walking inspections will always be necessary, most of them could be replaced by other inspection means, e.g. video monitoring with train-embedded cameras or drones. New methods and practices will be thus tested and developed by IN2SMART project, such as automatic inspection machineries[3] and new monitoring technologies (e.g. Drones, SAT, UAVs), improving data gathering by their integration. Internal expertise from SNCF Réseau - ALTAMETRIS[4] will contribute to go a step further.

The selected routes and sections, considered in the Storyboard, are depicted in Fig.5 and described in Tab.1.

Fig. 5 Selected routes and sections

Table 1. Routes and sections description

Network type	Routes *(selected sections)*	Selected sections from these routes				
		Track length (km)	S&C	Tunnels / bridges	Catenaries (% line)	Max speed
1 High speed	Paris-Lille	120	37	1 / 46	100%	300
2 Mass Transit	Paris-Creil	72	233	0 / 61	100%	160
3 Regular line	Troyes-Belfort	106	75	1 / 43	100%	160
4 Freight line	Mohon-Thionville	84	37	3 / 37	100%	120

The automated platform, developed by IN2SMART, contributes to this continuous improvement of inspections processes and practices. In particular, within this Storyboard, it enables to:

- Forecast asset status and behaviour, integrating innovative Data Analytics approaches and tools able to use new data sources (e.g. data extracted from processing images gathered by drones, SAT, etc.).
- Optimize maintenance decisions, based on the mentioned innovative data-driven approaches and systemic supporting tools[5][6].
- Adapt allocation of Maintenance needs (track possession, human resources and machineries) as a function of the assets criticality, forecasted behaviour and status.
- Identify subgroups of assets for which walking inspections are still the best practice for ensuring a relevant, efficient and cost-effective management.

To this purpose, the considered function to be optimized is based on monitoring and maintenance costs, technical performances and effectiveness, taking into account constraints related to safety KPIs and the availability of the whole railway system (infrastructure, working and operator crews,..).
The main expected results from this Storyboard are:

[3] https://www.sncf-reseau.fr/fr/reportages/train-surveille
[4] http://www.altametris.com/
[5] http://www.sncf.com/fr/presse/fil-info/internet-industriel-sur-le-terrain/258654
[6] https://www.digital.sncf.com/actualites/open-interview-sncf-optimise-la-maintenance-du-reseau-avec-everysens

- Identify possible configuration for interventions, based on coupling new technologies to existing practices. This could be done while achieving performances objectives, reducing maintenance costs, objectivizing capacity for maintenance and increasing data gathered during infrastructure inspection based on new, reliable and effective enough technologies (technical results at least equivalent to those obtained by human walking inspections).
- Improving maintenance operators working conditions, by reducing their presence on track.

Data related to the economic benefits derived by the application of the proposed approach will be evaluated by the end of the project; any case they will be made public and managed in respect of their sensitivity for the Organizations.

4.2. Storyboard 2: SAMP development for a route section

The storyboard proposed by Network Rail, Infrastructure Manager of the GB Railway Network, considers the strategic Asset Management of a 122 km rail route in the north of England (Fig.6), which links the major cities of Manchester, Leeds and York and is known as the Transpennine Route. This route will be undergoing a major enhancement, the so-called Transpennine Route Upgrade (TRU), with the intention of reducing the journey time and doubling passenger numbers.

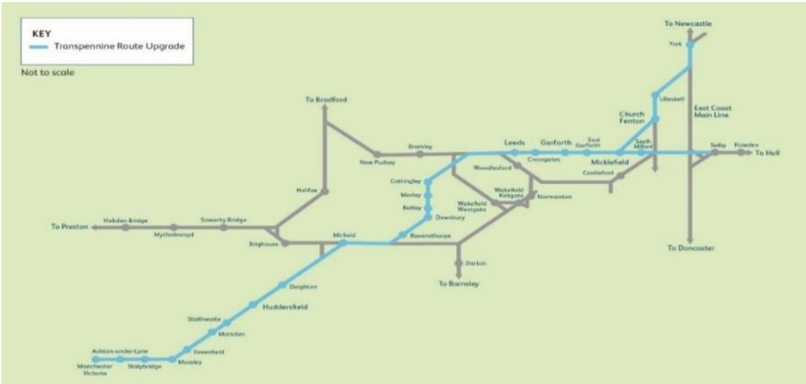

Fig. 6 The Transpennine Route

The focus for the storyboard is the Strategic Asset Management Plan and, in particular, the SAMP component referenced as ‘Analyse Strategic Options’ in Fig.2. Therefore, the storyboard is used to show how the organizational needs and stakeholder expectations are translated into strategies for managing the railway infrastructure.

The current Asset Management process involves models that are specific to individual asset types, e.g. bridges, and to a particular type of activity, e.g. renewals; whereas the new Asset Management strategy requires a whole system approach which integrates decisions across asset types, e.g. track, signaling, bridges and also across intervention types, e.g. maintenance, renewal and enhancement. It should also be able to take decisions optimizing the balance between cost, risk and performance by minimizing the whole life, whole system cost. A decision support tool that meets these requirements has not, to the knowledge of the authors, ever been developed by a railway infrastructure manager, which makes it a suitable storyboard for IN2SMART.

The automated platform, developed by IN2SMART, will integrate the above-mentioned models, achieving the development of a decision support system that optimizes the balance between inspection, maintenance, renewal and upgrade.

In order to be able to quantify the size of the possible benefits, the storyboard will use this automated platform to perform a LCC analysis to support decisions on the modifications of the infrastructure, including the selection of new assets to be installed, calculating the long-term cost and performance, comparing alternative options.

Recent projects and asset management initiatives have built confidence in Network Rail’s commitment to mandate LCC on all projects; hereafter examples are shown. In Fig.7 a first example of LCC forecast, representative of a typical asset with a nominal life of 31 years, and refurbishment planned 15 years after the renewal, is depicted.

The represented LCC evaluation takes into account the asset degradation trend, the average annual failures with their consequent costs, and the costs related to the operations of renewal, refurbishment and maintenance.
In another context, LCC analysis has been used to demonstrate that the relatively small change in asset management strategy involving fitting pads underneath sleepers on new track installations across the network will save more than £300m in the next 10 years and over £3bn in the next 30 years.

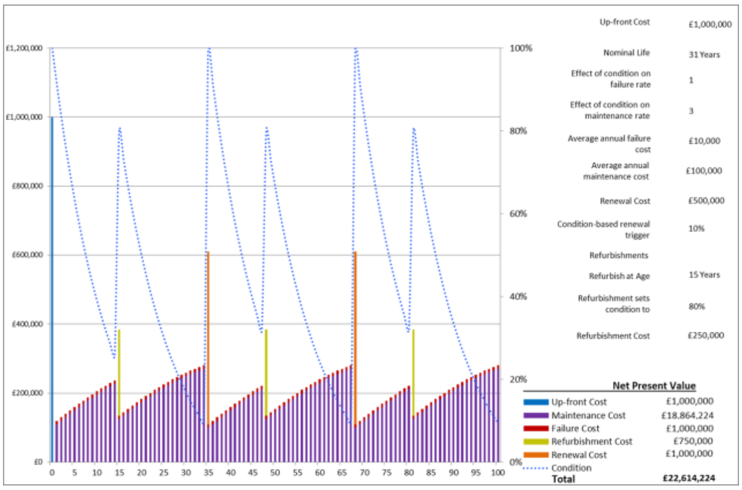

Fig. 7 Life Cycle Cost evaluation for a generic asset

Another example of a successful Network Rail's application of the LCC approach is depicted in Fig.8, where the possible options related to different managing strategies of signalling technologies in the North Clyde railway line, in Scotland, are compared.
Assuming as base case "no changes" to the infrastructure, the LCC implications for a range of potential upgrade options are compared with this base case, to determine the optimal scenario. In particular, the considered scenarios are:

- Base Case – no renewal, ERTMS re-signalling in 2022.
- Option One – like-for-like renewal at end of service life; no recontrol, no ERTMS.
- Option Two – same as option one, but each asset life-extended by 50%.
- Option Three – renewal and recontrol, ERTMS re-signalling in 2022.
- Option Four – renewal and recontrol, ERTMS delayed to 2037.
- Option Five – life extension until ERTMS re-signalling in 2022.

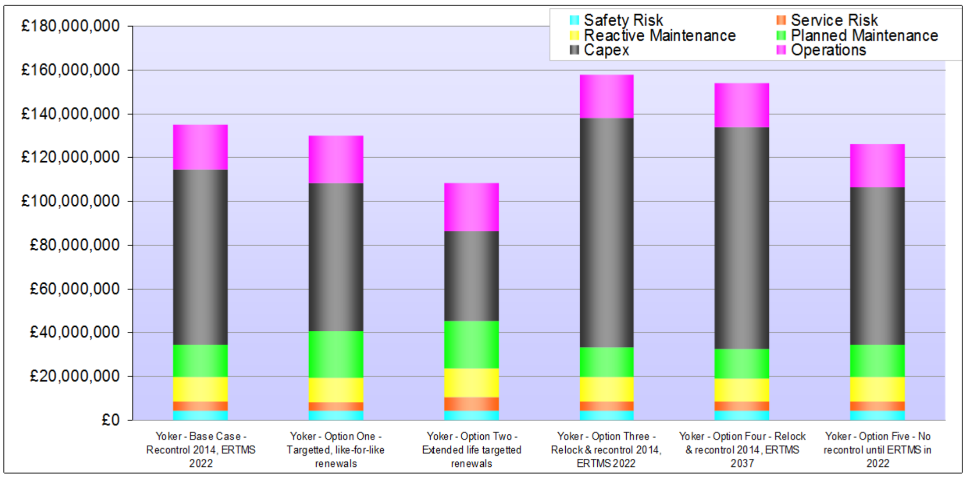

Fig. 8 Options comparison for the re-signalling management on North Clyde Line

Fig.8 puts in evidence that Option Three presents the minimum LCC but implies low and unacceptable service performance. For this reason, the Option Five is considered the preferred scenario.
These examples have represented the possible benefits that could be achieved by applying the IN2SMART

automated platform. In particular, the expected result is the potential of identifying combinations of options, optimizing across asset types and representing the interactions between inspection, maintenance, renewal and enhancement, allowing to deliver infrastructure outputs that improve service, taking into account explicitly customer and stakeholder requirements.
Coming back to Network Rail storyboard, as a preliminary estimation, the Transpennine Route Upgrade has an estimated initial cost of approximately £3bn and will cost a similar amount to be maintained over the next 40 years of operation. Improved decisions during the options selection phase could have a significant impact on both the initial and through life cost as well as on the future reliability and service provided by the infrastructure.
The benefits of applying an advanced lifecycle cost approach to TRU have not yet been quantified, since outcomes of the IN2SMART project will not achieve more than TRL4/5 and numerical estimation could be provided only by the following project.

5. Conclusion

The present paper presents the objectives and the expected results of SHIFT2RAIL - IN2SMART European Project. An Intelligent Asset Management approach is proposed which aims at contributing to the continuous improvement of current Asset Management practices and strategies, by taking into account the dynamic nature and the incoming degradation trends of the railway network. This contributes to manage efficiently the useful life-time of existing infrastructure, increasing service availability and reducing costs associated to time-fixed maintenance tasks. Asset management interventions are conveniently and cost-effectively scheduled and executed, taking into account risk.
Two different business cases are presented and will be used to test the effectiveness and relevance of the proposed methodology. In this way, rail infrastructure could be highly and predictably reliable and resilient, able to offer degradation prediction and detection of failures, reducing risk and costs. Works are in progress to apply and test the platform to different use cases in order to evaluate the benefits of the proposed approach.

Acknowledgements

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