Change management in digitalised operation and maintenance of railway

V. Jägare & R. Karim, PhD
Luleå Railway Research Center, Luleå University of Technology, Luleå, Sweden

P. Söderholm, PhD & P-O. Larsson-Kråik, PhD
Trafikverket, Sweden

U. Juntti, PhD
Omicold AB

ABSTRACT: Globally, railway is experiencing a major technology transformation (or paradigm shift), triggered by the enhanced utilisation of digital technology. This technological transformation affects not only the technical systems, i.e. railway infrastructure and rolling stock, but also regulations, organisations, processes, and individuals. Hence, hardware, software, but also liveware (i.e. humans) are affected. Today, the digitalisation of railway is characterised by digital services. There are also a range of challenges, e.g. data acquisition, transformation, modelling, processing, visualisation, safety, security, quality, and information assurance. To deal with these challenges, the railway industry needs to define strategies, which enable a smooth transformation of the existing configuration to a digitalised system. Digital railway requires a holistic change management approach based on system-of-systems thinking and a set of appropriate technologies and methodologies. The railway digitalisation strategy should be based on systematic risk management that address aspects of, e.g., information security, traffic safety and project risk. In addition, managing changes for a digitalised railway effectively and efficiently also requires a framework for aspects such as needs finding, requirement identification, and impact of changes for individual, teams and organisation. In this work a major case study within the ePilot, has been performed in context of the operation and maintenance processes of the Swedish railway. Therefore, this paper aims to propose a framework for implementing innovations and driving change in a digitalised railway.

1 INTRODUCTION

A robust and reliable railway system is necessary for a well-functioning society. Railway has always been important throughout modern civilisation as key to financial prosperity, where the railway system constitute enormous societal value. The ongoing globalisation, increased mobility, and the environmental challenges are demanding a shift from road transport to rail transport. An improvement of the railway dependability, the effectiveness and efficiency of the operation and maintenance processes are essential.

In Sweden, railway is deregulated. This includes operation and maintenance. In this work, it has been noticed that today's maintenance contracts seldom consider aspects of implementation and innovation. Furthermore, it has also been shown, that planning and decision-making processes in maintenance are organised in completely different ways by different infrastructure maintenance managers, with little integration. To support maintenance planning effectively and efficiently, Information & Communication Technology (ICT) and Operating Technologies (OT) need to be converged. Normally, these technologies and tools are not properly integrated into an overall asset management workflow, which cause insufficient synchronisation with service demand. This hampers a full utilisation of the enormous potential of digitalisation. Organisations maintaining railway infrastructure require routine monitoring and inspection of track condition (Kumar, et al. 2008). Existing sensor technology can replace manual measurements in many cases. The sensor data can be used for e.g detection, localisation and cause identification of anomalies. Coupled with advanced analytical capability based on Artificial Intelligence (AI), deep learning, machine learning, sensor systems can provide maintenance stakeholders with valuable insights into the health of the railway system, including infrastructure and the rolling stock.

Implementation of AI in railway processes, e.g. operation and maintenance of signalling system, requires appropriate information logistics, which can be designed based on a service-oriented approach (Karim, 2008; Candell et al. 2009; Morant et al. 2013)

In the railway industry, large amounts of condition monitoring data is being stored, but most of the information never finds its way to the maintenance decision process (Asplund et al. 2016). Useful information for prognostics is often never used and hence the development of the predictive capability has been on a more moderate level (Galar, et al. 2012). This allows for the increased possibilities of analysing big data sets and develop diagnostic and prognostic approach for the railway industry (Bergquist & Söderholm, 2015, 2016a, 2016b, 2017). Anomaly detection and process mining methods are still being developed to serve the needs of the stakeholders (Zhang, 2016). Existing railway related degradation models, data mining strategies and IT solutions are still under development to improve the diagnostic and prognostic capabilities.

The technology transformation affects not only the technical systems, but also regulations, organisations, processes, and individuals. Today, the digitalisation of railway is characterised by provisioning of digital services. According to Jansson (2017), digitalisation consists of three stages of change: technology, products and services, and behaviour. Two additional dimensions of digitalisation also need to be in place: 1) a well-developed ecosystem where both smooth integration of hardware; and software is necessary and 2) a good cooperation between actors in the value network.

A digitalised railway faces a range of challenges, e.g. data acquisition, transformation, modelling, processing, visualisation, safety, security, quality, and information assurance. To deal with these challenges, the railway industry ought to define strategies, which enable a smooth transformation of the existing configuration to a digitalised system. The digitalised railway affects not only the technical items of the system, i.e. hardware and software, but also liveware (i.e. humans).

Digital railway requires a holistic approach based on a system-of-systems thinking and a set of appropriate technologies, and methodologies. The railway digitalisation strategy should be based on systematic risk management. Managing risk should consider aspects of needs finding, requirement identification, and changes for individual, teams and organisation. In addition, the risk management approach has to address issues of information security, traffic safety and project management. In literature, it is commonly accepted, that a key success factor in technology transformation is the capability of having a holistic change management strategy. Therefore, this paper aims to propose a framework for enhanced railway digitalisation. The proposed framework for implementing innovations and driving change in a digitalised railway is based on a holistic change management approach.

2 THEORY

2.1 *Change management in digital transformation*

Change management takes care of the people side of change. It does little good to create a new organisation, design new work processes or implement new technologies if you leave the people behind. But getting people on board and participating in the change will make the difference. Individuals will have to do their jobs differently, and it is the degree to which they change behaviours and processes that will make the change. The soft side of change is many times actually the harder side of change. Ultimately, change management focuses on how to help employees embrace, adopt and utilise a change in their day-to-day work.

The motivations for change are as varied as change itself. Change ultimately results from people adopting new skills and demonstrating new capabilities. Change has only truly occurred when individuals in the organisation begin working in new ways. Change management is an enabling framework for managing the people side of change. It provides an organisational framework that enables individuals to adopt new values, skills and behaviours so that business results are achieved (Hiatt et al. 2012). Unlike project management, which is focused on the realisation of a technical solution, change management is focused on the achievement of the desired results or outcomes of the change by managing people through their own transitions. The bridge between a quality solution and benefit realization is individuals embracing and adopting the change. Benchmarking studies shows that projects effectively applying change management were six times more likely to meet their project objectives (Prosci, 2012).

The main principles behind change (Hiatt et al. 2012) are: 1) We change for a reason; 2) Organisational change requires individual change where the proficiency, the skills or competency demonstrated by employees directly correlates to the degree the benefits can be achieved; 3) Organisational outcomes are the collective result of change; 4) Change management is an enabling framework for managing the people side of change; and 5) We apply change management to realise the benefits and desired outcomes of change.

There are pitfalls to avoid in digital transformation (Jansson, 2018). If there are no consensus regarding digitalisation and digital transformation, no change will happen. The decision to transform needs to affect all aspects of the company with a mutual understanding of the terminology as a prerequisite for everybody to be on the same page. No indecisiveness but a sense of urgency is needed, otherwise no transformation. A sense of direction needs to be communicated repeatedly to avoid a sense of lack of vision. If there is too much focus on operations, innovation can drown in administration. It may be necessary, to organisationally separate the operational and innovative parts. Focus on what rather than how. Which culture and skills does the company need and how should the expertise be coordinated. Employ digital specialists before digital generalists, since the generalist understands which effects of digitalisation affects the company, how the company should respond. The generalist should be a link between technology, people and business. Company environments can limit digitalisation if infrastructure, policies, processes and culture get in the way and does not let new colleagues utilise their knowledge. Departments in silos can prevent the transformation due necessary companywide collaboration. To become data-driven requires reducing the influence of politics and hierarchies on decision-making in favour of facts. The management need to support and apply the digital transformation to achieve change.

2.2 *Systematic risk management*

Performing risk analysis is an essential step in the change management process, which provides a useful communication tool for sharing concerns and communicating vision. Understanding risks related to change first requires an analysis of the potential risks and then agreement on the actions that will manage the risks effectively. As defined by ISO 31000 (Risk management – Principles and guidelines), risk is the effect of uncertainty on objectives. This uncertainty can be related to both threats and opportunities, i.e. events or circumstances that have negative or positive consequences respectively. Hence, it is important to manage both threats and opportunities in a systematic way in order to succeed with change. Often the risk is calculated as the product of the probability (or frequency) of a potential event and the consequences of that event. The risk management process includes activities like identify, assess, plan, implement and communicate. One way to use risk analysis within change management is to identify the possible barriers to successful organisational change and then assess the likelihood that they will materialise (Smith et al. 2014).

Within railway, the regulation (EU) 2015/1136 (Common safety method for risk evaluation and assessment, CSM-RA) also puts some requirements on how to perform the change management process, see EU (2015). The regulation states that any change, including organisational changes, with safety impact on maintenance and operation is required to follow the CSM-RA risk assessment requirements. Hence, the first step is to evaluate if the change may impact traffic safety or not. If traffic safety might be affected, the next step is to evaluate if the change is significant or not. This evaluation is based on six criteria, where the change might be significant if any of the criteria is not fulfilled, i.e.: low failure consequence, low novelty, low complexity, easy monitoring, high reversibility, or low effect in additionally. If the change is both safety-related and significant, the risk assessment process of CSM-RA should be applied. Finally, the CSM-RA requires that a risk acceptability of the changes under assessment shall be evaluated by using one or more of the following risk acceptance principles (EU, 2015): the application of codes of practice; a comparison with similar systems; or an explicit risk estimation. However, besides requirements on e.g. principles and the overall process, the regulation does not give any advice on which specific methodologies to apply. In addition, for changes in the maintenance programme an explicit risk estimation is required (with exception for changes of maintenance intervals, where a comparison with similar systems may be relevant).

For changes in the technical system, the standard EN 50126 / IEC 62278 (Reliability, Availability, Maintainability & Safety) provides methodological support. For changes in the maintenance programme, a combination of RCM (Reliability-Centered Maintenance) according to IEC 60300-3-11 (Application guide RCM) and barrier modelling is applicable (Nyberg et al. 2012; Nilsen & Syvertsen, 2015; Söderholm & Nilsen, 2017). The barrier modelling is based on the principles of bow-tie analysis, with the aims of reducing the probability of hazardous events and the severity of their consequences (see e.g. De Dianous & Fiévez, 2006; Khakzad et al. 2012; Nilsen & Syvertsen, 2015). This approach is an adaptation and extension of the barrier analysis as described by Bird & Loftus (1976), Heinrich et al. (1980), Bird & Germaine (1996), Reason & Hobbs (2003), and Hollnagel (2016). RCM is a proven dependability approach to systematically manage a living maintenance programme (see e.g. Nowlan and Heap, 1978; Moubray, 1997; IEC 60300-3-11; Ahmadi et al. 2007; Ahmadi et al. 2010).

In addition to traffic safety, information security is very important when managing change in railway based on opportunities with digitalisation. Hence, standards like ISO 27000 (Information security) provides valuable support. In relation to this there are also common regulations within EU that have to be considered, e.g. the NIS Directive (The Directive on security of network and information systems) and GDPR (General Data Protection Regulation). The NIS Directive is the first piece of EU-wide legislation on cybersecurity. It provides legal measures to boost the overall level of cybersecurity in the EU. GDPR is the most important change in data privacy regulation in 20 years. The regulation will fundamentally reshape the way in which data is handled across every sector, from healthcare to banking and beyond. In Sweden, there are also increasing requirements related to national security and total defence (combination of military and civil defence) that have to be considered. To manage aspects of dependability, the IEC 60300-series (International Electrotechnical Commission) is an extensive collection of standards that provide detailed and useful guidance from a life cycle perspective, as well as application guidelines to specific issues such as reliability analysis (see, e.g., the earlier mentioned IEC-standards in this section).

In addition, to enhance the change management process, continuous risk management is essential. The international standard IEC 62198 (Managing risk in projects – Application guidelines) provides principles and generic guidelines on managing risk and uncertainty in projects. In particular it describes a systematic approach to managing risk in projects bases on ISO 31000. The standard gives guidance provided on the principles for managing project risks, the framework and organisational requirements for implementing risk management and the process for conducting effective risk management. Preferable, the project risk management should be integrated with a systematic project model (e.g. XLPM, Excellent Project Management) to support the management of risk. In addition, actions that steams from risk management activities related to specific risk areas, e.g. traffic safety and information security, should be integrated in the project's plan and risk register.

2.3 *Change management models and strategies*

A way to gain advantages in digital transformation is to create a business where continuous innovation is central and natural. To succeed, an agile organisation with the ability to work with continuous innovation and act on it accordingly is needed. This capability exists in the form of skills, culture, structure, and processes that support the effort (Jansson, 2018). There are a number of different change management models that can be used to create a strategy for change. Five of these models will be highlighted with a short analysis providing examples of which essential factors to include in a framework for change management in digitalised railway.

Lewins's change management model describes three stages of change management (Smith et al. 2014). First, you have to unfreeze your process and perceptions by determining what needs to be changed, ensure strong support from management, create the need for change, manage and understand the doubts and concerns. Second, you deploy your changes and communicate often, dispel rumours, empower action and involve people in the process. Last, you refreeze the new status quo by anchor the changes into the culture, provide support and training, and celebrate success.

The ADKAR change management model is a bottom-up method focusing on the individual behind the change with a set of goals to reach (Hiatt et al. 2012). Change can be planned on an individual and organisational level by focusing on five goals: awareness of the need to change, desire to participate and support the change, knowledge on how to change, ability to implement required skills and behaviours and reinforcement to sustain the change.

Kotter (2012) describes a strategy for the change process in eight stages: 1) Establish a sense of urgency to provide the initial traction you need to get your team on board together with a stock of compelling arguments; 2) Create the guiding coalition consisting of a good span of experience and skills; 3) Develop a vision and strategy, achievement of values and predicted outcome; 4) Communicate the change vision to convince the rest of the organisation and be open to feedback 5) Remove barriers and reduce friction to empower broad-based action; 6) Make sure there are short-term wins associated with the changes to give a sense of accomplishment; 7) Sustain acceleration by consolidating gains and producing more change; 8) Anchor new approaches in the culture, processes and documentation.

The McKinsey 7-S model describes how to highlight the changes you need to make by analysing seven aspects of your company: strategy, structure, systems, shared values, style, staff and skills (Smith et al. 2014). Then the 7-S'need to be cross-examined to find what incremental changes you need to implement, which will not disrupt regular operations too much or alienate the employees.

The Nudge theory (Thaler et al. 2008) is a mind set and tactic which can be used to frame your changes in a more attractive manner, since it is based on the idea that it is better to offer to choose the change than enforce change. The challenge is knowing how to present the nudges and the method to follow is to clearly define changes, take your employees' point of view and use evidence as proof. Then present the change as a choice, listen to feedback, limit obstacles and keep the momentum up with short-term wins.

3 CASE STUDY

To identify stakeholders' needs and requirements from a digitalisation perspective, a major case study within the operation and maintenance processes has been conducted. The case study has been based on a through literature study, interviews, and observations. The case study activities have been performed within a collaborative platform for railway stakeholders, called ePilot. A detailed description of the ePilot is provided in the next section.

3.1 *ePilot*

The ePilot is a development and implementation project aimed at improving railway maintenance. The objective of the project is to improve punctuality and minimize interference in rail traffic as well as improve accessibility and quality. The strategy is to provide more efficient maintenance through eMaintenance and design of decision support to enable context- and condition-based maintenance. The project is based on industry collaboration between infrastructure managers, railroad companies, contractors, maintenance workshops, suppliers, innovators and Luleå Railway Research Center (JVTC) at Luleå University of Technology. ePilot provides a collaboration platform for testing innovations and development of new solutions for maintenance decision support. The solutions are based on needs and requirements from various stakeholders in order to enable and transform the maintenance of the Swedish fragmented rail industry to an integrated digitalised system. Additional project objectives are to: create an industry-wide process-oriented approach, create an industry-wide service-oriented IT infrastructure that provides decision support based on condition data, disseminate results, provide educational materials and provide training opportunities for the railway industry in Sweden.

Various types of data is needed in order to enable context- and condition-based maintenance. The stakeholders have different requirements for collecting data for maintenance decision support. The infrastructure manager needs information about how the section is operated in terms of amount of trains and axles, train speed and actual axle load, vehicle characteristics, but also data about asset condition and the degradation rate. The traffic operator needs condition monitoring information, e.g. trend data for wheel degradation. The maintenance contractor need data on asset condition, amount of traffic, type of vehicles, amount of train kilometres and the supplier wants to know where the asset/component is installed, how it is used and what kind of failures that has occurred.

In the ePilot, a platform for decision making in maintenance has been developed. It provides a cloud based, one-stop-shop for data analysis, which aids research projects and maintenance practices. The eMaintenance Railway Cloud includes:

- A process for gathering information about remaining useful life, dynamic maintenance program, performance measurements, maintenance support and planning
- Services, such as, wheel query, force data analysis, context adaption and data fusion
- Data collected from Luleå Railway research station, Trafikverket's wheel profile detector, mobile sensors and way-side detectors
- Measurement data of track quality, failure statistics and inspection data.

During the course of the ePilot, some examples of different factors influencing implementation of innovations in the railway system, which have been identified are:

- A complex process for changing regulations
- Unclearness and ambiguity regarding data ownership and access rights
- Low organisational readiness and maturity
- Uncertainty of condition data quality
- Unidentified requirements for the end users
- Unclear benefits from implementing the results for the end users
- Unclear responsibilities between the parties
- Insufficient business models
- A lack of incentives in the maintenance contracts for stimulating innovation, implementation, collaboration and information sharing
- A lack of an implementation strategy e.g. a plan for how the new technology would be utilised and evaluated

A first attempt of developing a supportive framework describing factors affecting implementation of innovations in a digital railway context defines five different domains to consider: I) Innovation characteristics, II) Characteristics of the individuals involved, III) Inner settings, IV) Outer setting, and V) Process of implementation (Jägare. V. et al. 2015). The different domains in the framework addresses factors affecting change from a technological, individual and organisational point of view, see Table 1.

Domain	Factors affecting implementation
I. Innovation characteristics (technology)	Uncertainty of condition data quality
	Usability
II. The individual	Readiness and maturity
	Unclear benefits if innovation
III. Inner settings (organisation)	Changing regulations
	Changing processes
	Readiness and maturity
	Unclear rules for sharing data
IV. Outer setting (organisation)	Data ownership
	Data access rights
	Unclear responsibilities
	Non existing business models
	Lack of incentives in maintenance contracts
V. Process of implementation	No implementation strategy

Table 1 A framework describing factors affecting implementation of innovations in a digital railway context.

This framework aids to describe the factors affecting implementation of innovations and can be used as a checklist to reduce the risk of failure in a project. There is also a need for a conceptual framework, which consider and describes how to deal with domains and factors connected to change affecting individuals and organisations.

4 RESULTS

4.1 *A framework for implementing innovations and driving change in digitalised railway*

A methodology has been developed and validated within a project platform for railway, i.e. ePilot. Using this methodology in ePilot has proven to be an efficient way to test innovations in a multi-organisational collaboration, contributing to the digitalisation of railway maintenance. After the innovation has been tested and benefits have been identified, an organisation can make a decision to implement the innovation leading to the start of an implementation project. In this work, a conceptual framework to support implementation of innovations and driving change in digitalised railway is proposed. In order to implement new technology, a systematic project model e.g. XLPM, should be integrated with project risk management that comply with regulations, e.g CSM-RA regarding traffic safety in railway, to evaluate and assess the change. The project management should also consider a checklist describing possible factors affecting implementation. Parallel to the project management, a holistic change management strategy based on a change management model adapted to railway should be considered, in order to ensure the success of implementing an innovation considering the organisation and individuals. In an implementation project, the project management model ensures an efficient way of getting the work done by doing the right things to achieve the goals. The change management model ensures an effective way of doing things the right way and making it stick to make sure the goals are reached. A framework can provide support when implementing innovations in order to digitalise maintenance, see Figure 1.

4.2 *Change management in digitalised railway*

The application of a holistic change management strategy provides the following general benefits:

- Provides a conceptual scaffolding for people, the process and the organisation implementing change
- Ensures the change process to be started and managed by the right people at the right time
- Includes specific tasks and events that are appropriate for each stage in the change process
- Creates understanding in the whole value-chain to support the change

Benefits for the organisation:

- Helps to align existing resources within the organisation
- Allows the organisation to assess the overall impact of a change
- Avoid negative effects on the day to day running of operations
- Reduces the time needed to implement change and decreases the possibility of unsuccessful change
- Provides a way to anticipate challenges and respond to these efficiently
- Decreases the risk associated with change
- Increases return on investment

Benefits for the individual:

- A safe transfer from the old to the new while maintaining morale, productivity, and even company image is supported
- Provides support for concerns regarding changes
- Helps to plan efficient communication strategies
- Manages change to minimise resistance
- Improves cooperation, collaboration and communication
- Reduces stress and anxiety to encourage people to stay loyal to the organisation
- Acknowledges and address personal loss/gain for individuals
- Reduces disruptive aspects of change
- Emphasises positive opportunities in the change process

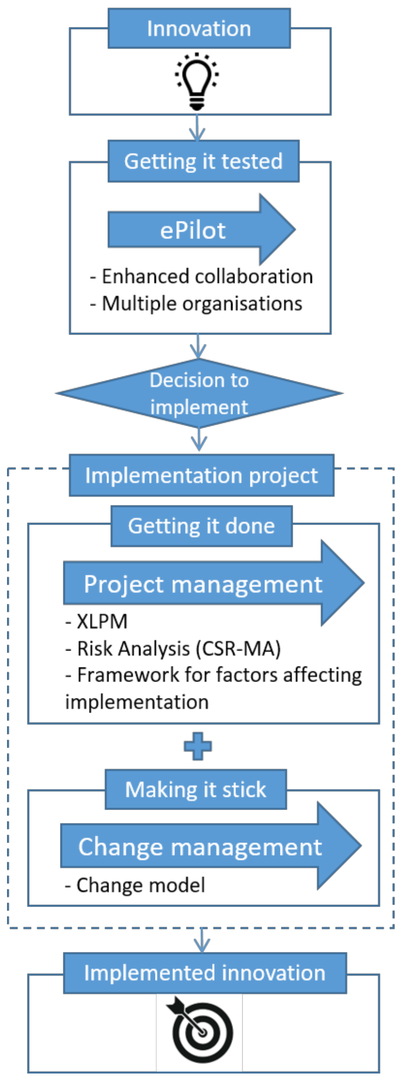

Figure 1. A framework for implementing innovations and driving change in digitalised railway.

4.3 *Controlling the risks*

The application of systematic risk management in the change management process as described earlier provides the following benefits:

- Compliance with existing regulations (requirements) and best practice (standards).
- Systematises maintenance tasks in a traceable way through a system hierarchy.
- Facilitates an understanding of the maintenance objects and the relationships between these.
- Improved overview of failures, effects and the contribution of maintenance to efficient operation.
- Analytical approach and criteria for identification of safety-related maintenance tasks.
- Provides clear criteria for decision-making.
- Gives a sound foundation for effective Key Performance Indicators (KPI) that are relevant for rational follow up of operation and maintenance, e.g. failure codes, consequence types, barrier levels, detection sources, and maintenance economy.
- Documents best practices within maintenance.
- Provides the foundation for a living maintenance programme and dynamic maintenance regulations.

5 DISCUSSION

Operation and maintenance of the the railway system is complex and requires the right skills and competence. In Sweden, operation and maintenance are performed by several commercial and non-commercial organisations, such as regulatory authorities, infrastructure managers, operators, suppliers, maintenance providers, and consultants. The organisations govern collaboration and cooperation through agreements and contracts that need to be based on performance management, incentives and collaboration requirements. However, it is believed that increased knowledge and improved description of the requirements and needs will facilitate change management and smoothen the implementation of innovations in a digitalised railway, which leads to the increased dependability and sustainability of the whole railway, during its whole lifecycle. Hence, traditional railway competence is necessary, but not sufficient to manage the paradigm shift to a digitalised railway. Complementary competence related digitisation and digitalisation has to be adapted, adopted and integrated.

The proposed framework for implementing innovations and driving change can give the necessary support and visualisation of the complex puzzle that needs to be completed, in order to accomplish a more digitalised maintenance process within railway. It is important to include a holistic change management strategy fit to drive implementation of digitalisation of railway maintenance in a cross-organisational environment heavily governed by regulations causing change to inherently be slow. However, by using digitalisation of the management of the regulation itself, digitalisation of the technological, organisational and individual parts of the railway system will be boosted. The railway itself has built-in safety systems (i.e. technical, organisational and methodological barriers) in order to reduce the risk of accidents to an acceptable level. This in itself means that the railway as a technical system will be slow to change compared to the speed with which digitalisation takes place. Therefore, the railway will have to work according to a method that gradually checks that what is being introduced, does not affect safety. The challenge will be to find the changes that do not affect safety negatively and drive them forward in a more rapid pace, and at the same time, work with the CSM-RA, ISO 27000, ISO 31000, and IEC 60300-series principles to ensure smooth digital change in a system life cycle perspective, while maintaining control of safety, information security and dependability.

6 CONCLUSIONS

Digital railway requires a holistic approach based on a system-of-systems thinking and a set of appropriate technologies and methodologies. This case study investigates factors affecting implementation of innovations, aimed at digitalising railway maintenance. In addition, how change management can highlight the human perspective of change i.e. digitalising maintenance decisions within the railway system (e.g. by adapting a Human, Technology, Organisation, HTO, approach).

Based on the conducted case study, a framework has been proposed in order to provide support when implementing innovations in order to digitalise maintenance. The framework describes test of innovations and implementation of innovations in railway organisations. The implementation project need to consider a project management model, integrated with project risk management in line with CSM-RA (and preferable also ISO 27000, ISO 31000 and the IEC 60300-series) together with a checklist describing possible factors affecting implementation. Parallel to the project management, a holistic change management strategy based on a change management model adapted to railway, will consider the organisational and individual perspective.

It can be concluded that a framework for implementing innovations and driving change can give the necessary support and visualisation of the complex puzzle that needs to be solved, in order to accomplish a more digitalised maintenance process leading to a more effective and efficient planning of railway maintenance.

7 RECOMMENDATIONS

As for the next step in this research, the framework for factors affecting implementation will be further developed and verified. There is a further need to compare and categorise the different change management models and strategies in order to fit the models to the conditions in the Swedish railway industry. In addition, a holistic change management strategy based on a change management model adapted to railway will be developed and tested. Finally, the framework for implementing innovations and driving change in digitalised railway, will be tested and packaged into easy to use guidelines.

8 ACKNOWLEDGMENTS

We would like to thank Trafikverket (the Swedish Transportation Administration) for their financial support of this project, as well as all the participating railway organisations and companies.

9 REFERENCES

Ahmadi, A., Söderholm, P., & Kumar, U. 2007. An overview of trends in aircraft maintenance program development: past, present, and future. *In European Safety and Reliability Conference*: 25/06/2007-27/06/2007 (pp. 2067-2076). Taylor and Francis Group.

Ahmadi, A., Söderholm, P., & Kumar, U. 2010. On aircraft scheduled maintenance program development. *Journal of Quality in Maintenance Engineering*, 16(3), 229-255.EU (2015), Commission implementing regulation (EU) 2015/1136 of 13 July 2015 amending Implementing Regulation (EU) No 402/2013 on the common safety method for risk evaluation and assessment.

Asplund, M., Lin, J., & Rantatalo, M. 2016. Assessment of the data quality of wayside wheel profile measurements. *International Journal of COMADEM*, Vol.19, nr 3, sid 19–25.

Bergquist, B., & Söderholm, P. (2015). Data analysis for condition-based railway infrastructure maintenance. *Quality and Reliability Engineering International*, 31(5), 773-781.

Bergquist, B., & Söderholm, P. (2016a). Measurement System Analysis of Railway Track Geometry Data using Secondary Data. *In eMaintenance 2016*: 15/06/2016-16/06/2016.

Bergquist, B., & Söderholm, P. (2016b). Measurement Systems Analysis of Railway Measurement Cars. *In International Conference on the Interface between Statistics and Engineering*: 20/06/2016-23/06/2016.

Bergquist, B., & Söderholm, P. (2017). *Improved Condition Assessment through Statistical Analyses: Case Study of Railway Trac*k. Luleå University of Technology.

Bird, F.E. Jr. and Germain, G.L. 1996. Practical loss control leadership, *Det Norske Veritas*, Loganville.

Bird, F.E. Jr. & Loftus, R.G. 1976. *Loss control management.* Institute Press, Loganville.

Candell, O., Karim, R., & Söderholm, P. (2009). eMaintenance - information logistics for maintenance support. *Robotics and Computer-Integrated Manufacturing*, 25(6), 937–944.

CENELEC. 1999. EN 50126 / IEC 62278: Railway specifications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS), European Committee for Electrotechnical Standardization, Brussels.

De Dianous, V., & Fiévez, C. 2006. ARAMIS project: A more explicit demonstration of risk control through the use of bow–tie diagrams and the evaluation of safety barrier performance. *Journal of Hazardous Materials*, 130(3), 220-233.

EU. 2015. Commission implementing regulation (EU) 2015/1136 of 13 July 2015 amending Implementing Regulation (EU) No 402/2013 on the common safety method for risk evaluation and assessment.

Galar, D., Palo, M., Van Horenbeek, A. & Pintelon, L. 2012. Integration of disparate data sources to perform maintenance prognosis and optimal decision making. *Insight - Non-Destructive Testing and Condition Monitoring,* Volume 54, Number 8, August 2012, pp. 440-445(6).

Heinrich, H.W., Petersen, D. & Roos, N. 1980. Industrial accident prevention: A Safety management approach, McGraw Hill, NewYork.

Hiatt J.M & Creasey T.J. 2012. *Change management. The people side of change.* Prosci Inc. Fort Collins. Colorado. USA.

Hollnagel, E. 2016. Barriers and accident prevention. Routledge.

IEC 60300-3-11, Application Guide Reliability Centred Maintenance.

Jansson. J. & Andervin. M. 2018. *Leading digital transformation.* DigJourney Publishing.

Jägare. V., Juntti. U. and Karim. R. 2015. Implementation of e-Maintenance concept on the iron ore line in Sweden. *IHHA 2015 Conference,* 21-24 June 2015, Perth, Australia.

Karim, R. (2008). A service-oriented approach to e-maintenance of complex technical systems (PhD dissertation). Luleå.

Khakzad, N., Khan, F., & Amyotte, P. 2012. Dynamic risk analysis using bow-tie approach. *Reliability Engineering & System Safety*, 104, 36-44.

Kotter, J.P. 2012. *Leading change.* Harvard business review press. Boston, Massachusetts.

Kumar, S., Espling, U., & Kumar, U. 2008. Holistic procedure for rail maintenance in Sweden. *Proceedings of the Institution of Mechanical Engineers,* Part F: Journal of Rail and Rapid Transit, 222(4), 331–344.

Morant, A., Karim, R., & Larsson-Kråik, P.-O. (2013). Information logistics for maintenance of railway signalling systems : A case study. *The International Journal of Railway Technology*, 2(2), 97–112.

Moubray, J. 1997. Reliability-Centred Maintenance (RCM) II, Butterworth Heinemann, Oxford.

Nowlan, F.S. and Heap, H.F. 1978. Reliability-Centered Maintenance, Report AD/A066-579, National Technical Information Service, US Department Commerce, Springfield, Virginia.

Nyberg, J., Nilsen, T. & Werner Ruud, O. 2012. RCM analys spårväxel EVR UIC60 760 för Trafikverket (RCM-analysis of S&C EVR UIC60 760 for Trafikverket). Lloyd’s Register, Kjeller, norway. In Swedish.

Prosci. 2012. *Best practices in Change Management.* Loveland, Colorado: Prosci Learning Center Publications.

Reason, J., & Hobbs, A. 2003. *Managing maintenance error: a practical guide* (pp. 145-158). Hampshire: Ashgate.

Smith. R. et al. 2014. *The effective Change Manager’s Handbook.* CPI Group (UK) Ltd. UK.

Söderholm. P. & Nilsen. T. 2017. Systematic risk-analysis to support a living maintenance programme for railway infrastructure. *Journal of Quality in Maintenance Engineering*, Vol. 23, no. 3, pp. 326-340

Thaler R.H. & Sunstein C.R. 2008. *Nudge: Improving Decisions About Health, Wealth, and Happiness.*

Zhang, L. 2016. Big Data Analytics for Fault Detection and its Application in Maintenance. PhD dissertation. Luleå.