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Performance Indicators of Railway Infrastructure

C. Stenström, A. Parida and D. Galar
Division of Operation and Maintenance Engineering
Luleå University of Technology, Sweden

Abstract

Railway traffic has increased over the last decade and it is believed to increase further with the movement of transportation from road to rail, due to the increasing energy costs and demand to reduce emissions. As a result of increasing need of railway capacity, more efficient and effective operation and maintenance is required. To manage the assets effectively within the business objectives, the results of operation and maintenance activities must be measured and monitored. Performance indicators are developed to support infrastructure managers in decision making, but they are often *ad hoc* and seldom standardised. In this paper, performance indicators for railway infrastructure, with primary focus on the railway track, have been mapped and compared with indicators of European Standards. The listed indicators can be applied to form a performance measurement system for railway infrastructure.

Keywords: railway infrastructure, maintenance, operation, management, performance measurement, indicator.

1 Introduction

Railway traffic has increased over the last decade and it is believed to increase further with the movement of transportation from road to rail, due to the increasing energy costs and demand to reduce emissions. The key goals of the White Paper 2011 for the European transport system include; a 50 % shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport, and a 60 % cut in transport CO_2 emissions by 2050 [1]. At the same time, the crude oil output reached its all-time peak in 2006 [2]. The available capacity of the railways has to be enhanced in order to meet these new demands in transportation.

As railway infrastructure and their components have a long life span, their management requires a long term sustainable strategy. Ongoing technical and economic assessments are necessary to optimise the performance of railway infrastructure and receive the return on investment (ROI) in a manageable timeframe. Long-term asset management objectives and strategies are developed to steer the operation and maintenance activities in the right direction. These objectives need to be broken down into quantitative operation and maintenance objectives to achieve a high level of robustness, punctuality and capacity within the operational budget, at the lowest life cycle cost, with no or an acceptable level of risk. See work by Espling and Kumar [3], for further discussion on developing maintenance strategies for railway infrastructure.

To manage assets effectively within the agreed objectives, the effect of operation and maintenance activities must be measured and monitored. Performance indicators (PIs) for RAMS (reliability, availability, maintainability and safety), capacity, punctuality, etc., are continuously applied to support infrastructure managers (IMs) to identify performance killers and in making more efficient and effective decisions, but they are often *ad hoc* and seldom standardised. Measuring entails data collection, but since raw data does not give any information by itself, these must be analysed, validated and converted to information in the right format for decision making. This consumes resources, especially, if wrong parameters are measured. However, a good performance measurement system does not necessarily require a high level of precision [4]. It is more important to know whether the trend is up or down and how the current value compares to historical measures and trends. Consistency is therefore especially important in order to capture long term trends, predict future development and take the appropriate corrective actions at an early stage. Thus, if the methods for measuring or analysing are changed, the old information or analysis method should be kept for some time to safeguard the trend tracking. Moreover, performance measurement is also important for feasibility of railway certifications [5]. It is crucial to thoroughly analyse what to measure, as large costs and equally large savings are associated with measuring. Thus, there exists a need to study the railway PIs used by different infrastructure managers (IMs), to find out which are the most important, which are required and which are not required.

A study was undertaken to review the operation and maintenance PIs used by researchers in the field of railways, as well as reviewing project reports, policy documents, handbooks, etc., of European IMs. Interviews were also carried out. About 60 managerial PIs and about 70 infrastructure condition parameters have been identified in the study. Similar indicators have been considered as one in order to limit the total number of indicators.

Increased interoperability and building of a trans-European railway network is another goal of the European Union. The required harmonisation and standardisation of the management of railways have led to increased use of European Standards. The identified PIs have therefore been compared to the European standard; Maintenance key performance indicators (KPIs), EN 15341, in order to find indicators in common [6].

Several projects on indicators and benchmarking for railway transport operations have been carried out, see reviews by [7-11], but similar studies on the maintenance of railway infrastructure are few, which can be seen in [12, 13].

In this study, maintenance performance indicators for railway infrastructure have been mapped and compared with indicators of EN 15341 [6]. The listed indicators form a basis for constructing a performance measurement system (PM-system) for railway infrastructure.

This paper is based upon Stenström *et al.* [14], but the current paper includes the following additional research: grouping of indicators revised, revised text and figures, besides extended literature review.

2 Performance measurement

Measuring is a management tool which facilitates and supports efficient and effective decision making. In and of itself, it does not determine performance, but it can facilitate good management. What gets measured gets managed is not a promise [15].

Organisations use indicators in some form or another to measure their performance. The most common indicators are financial; many of these are mandatory by law. Other indicators are technical, organisational, HSE (health safety and environment), etc. There are few agreements on how to categorise indicators. It is up to each organisation to decide which standards or frameworks to use. Well known standards for maintenance KPIs are the European Standards EN 15341 and SMRP Best practice metrics [6, 16]. Use of standardised indicators or metrics, such as the indicators from the standard EN 15341 or the SMRP metrics, has the following advantages [17]:

- Maintenance managers can rely on a single set of standardised indicators supported by a glossary of terms and definitions
- The use of standardised indicators makes it easier to compare maintenance and reliability performance across borders
- When a company wants to construct a set of company indicators or scorecard, the development process based on standardised indicators is simplified
- The standardised indicators can be incorporated in various enterprise resource planning (ERP) systems and reports
- The standardised indicators can be adopted and/or modified to fit the company's or the branch's special specific requirements
- The need for discussion and debate on indicator definitions is not required and uncertainties are thus eliminated

Organisations' performance measurement system often grows from the need to measure different processes, thus, the number of databases and indicators grows over time. Some indicators stay while others become obsolete or disappear, but at some point, the amount of information is too large and becomes uncontrollable. The performance measurement system needs to be organised or reorganised, databases and indicators must be documented, regulations set, gaps must be identified, the performance measurement system must be aligned to the business goals and the owners of databases and indicators must be clear. See Figure 1, for high level requirements (HLRs) for organising a measurement system. Supportive guidelines for asset management in railways can be found in a work by

International Union of Railways (UIC), as a seven-step procedure based on the following standards and manuals: PAS 55, the asset management standard by British Standards Institute; the International Infrastructure Management Manual (IIMM) by New Zealand Asset Management Steering (NAMS) Group; and the Asset Management Overview by the US Highway Agency [18-22].

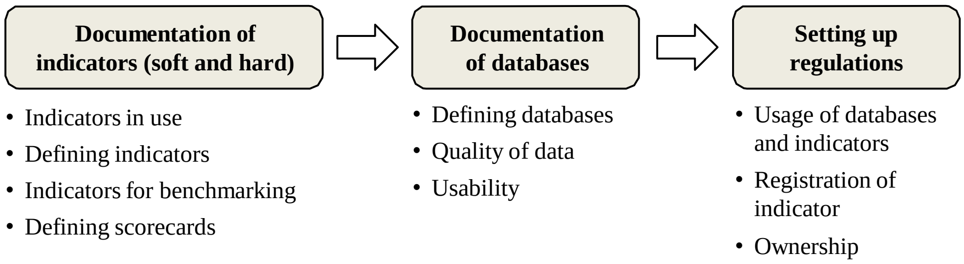
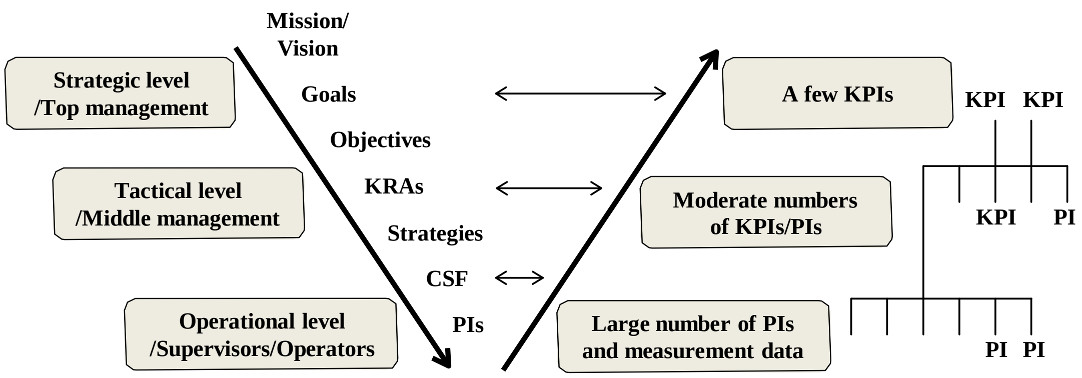


Figure 1: High level requirements for organising or reorganising a performance measurement system (PM-system)

According to Gillet, Woodhouse found that a human cannot control and monitor more than four to eight indicators at the same time [23]. Data aggregation is therefore necessary [24]; see Figure 2. As an example in railways, capacity and availability goals can be broken down to system and component performance requirements at the infrastructure level. The result is then aggregated and compared to the set objectives by use of indicators.



KRA = key result area; where the result and indicators are visualised
CSF = critical success factor; to succeed with set objectives
KPI = Key performance indicator (PI)

Figure 2: Breakdown of goals and objectives and aggregation of data.

It is not possible to measure everything with only quantitative or qualitative methods. Rather a combination of both methods must be used to create a measurement system that is as complete as possible. Qualitative measurement methods are good for measuring soft values, like employee satisfaction, and for checking conformity with quantitative indicators. Galar *et al.* have merged qualitative measures with quantitative indicators and developed an audit that shows the relation between trends in questionnaires and indicators, validating the correlation or highlighting the divergence [25, 26].

As this paper focuses on quantitative indicators, there are few qualitative indicators presented.

3 Railway infrastructure performance indicators

A study was undertaken to review the railway infrastructure PIs used by researchers and professionals in the field of railway infrastructure, as well as reviewing project reports, policy documents, handbooks, etc., of European IMs. Interviews of the Swedish IM were also carried out. In order to manage the large number of indicators, they have been grouped into two overall groups; managerial and infrastructure condition indicators. The managerial indicators are extracted from different computer systems, e.g. enterprise resource planning (ERP), computerised maintenance management system (CMMS), etc., excluding condition monitoring data. Condition monitoring indicators are all the indicators and parameters extracted by sensors and by various inspection methods in the railway network. Managerial indicators are more at an overall system level compared to condition monitoring data that are at a subsystem or component level. See work by Stenström *et al.* [27] for further discussion on terminology of performance indicators.

The PIs of EN 15341 are grouped into three categories; economic, technical and organisational. Health, safety and environment (HSE) indicators are part of the technical indicators. The railway managerial indicators are grouped accordingly, but the HSE indicators have been considered to have such importance that they have been put into a separate group. Condition monitoring data have been divided into six groups, see Figure 3. The groups can also be called key result areas; the few areas where the result and indicators are visualised [28].

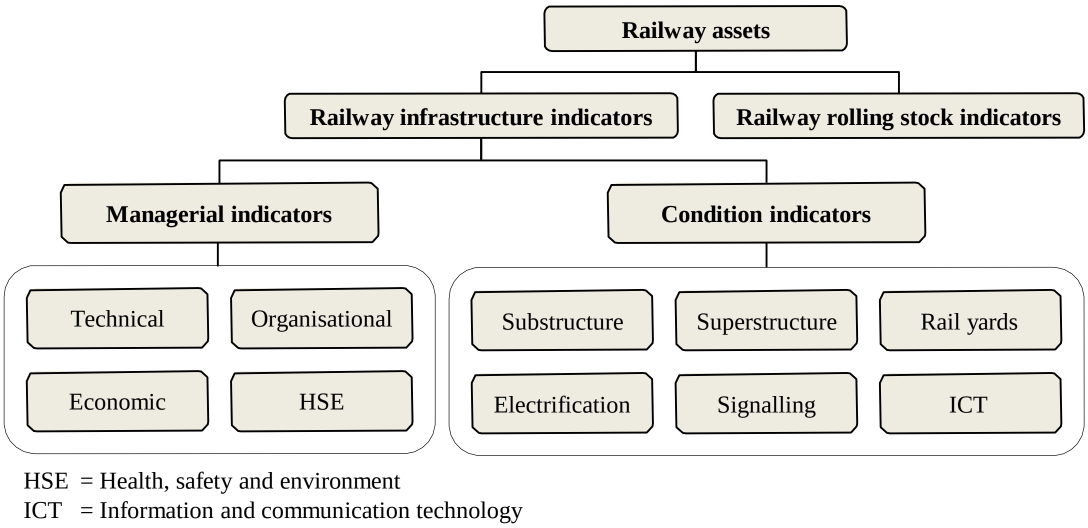


Figure 3: Structure of railway infrastructure performance indicators

The following subsections present the four groups of managerial indicators and the six groups of the condition monitoring indicators.

3.1 Managerial indicators

The managerial indicators are put into system and subsystem levels. System is considered as the whole railway network supervised by an IM. Subsystems are railway lines, classes, specific assets and items. Some indicators are found at both levels, while others are only found at one level. Each indicator has been given an identification number (#) similar to the system used in EN 15341, i.e. starting with E, T, O, and for the fourth group, it starts with H.

Technical indicators are closely related to reliability, availability and maintainability (RAM); see Table 1. The research is extensive, see [29-33] for work on failure frequencies and delays, see [29, 34] for maintainability, see [12] for mapping of maintenance PIs, see [35] for capacity, and [36-38] for overall equipment effectiveness (OEE) and data envelopment analysis (DEA).

Technical indicators			
Category	**Indicators** (comments) [unit]	**Reference**	**#**
Availability	**System level**		
	Arrival punctuality [no. or %, passenger or freight]	[39, 40]	T1
	Train regularity [no. or %, passenger or freight]	[39]	T2
	Failures in total [no.]	[29, 31-33, 41, 42]	T3
	Train delay [time]		T4
	Delay per owner (Operation centrals, Secondary delays, Infrastructure, Train operators, Accidents and incidents, etc.) [%/owner]		T5
	Faults interfering with traffic [no. or %]	[43, 44]	T6
	Temporary speed restrictions (TSRs) [no.]	[45]	T7
	Subsystem level		
	Punctuality per line, line class or area [no. or %/line, class or area]	[39]	T8
	Regularity per line, line class or area [no. or %/line, class or area]	-	T9
	Failures per item [no./item]	[29, 31-33, 42]	T10
	Failures per track-km, line, line class or area [no./track-km, line, class or area]		T11
	Delay per item [time/item]		T12
	Delay per line, line class or area [time/line, class or area]		T13
	Temporary speed restrictions (TSRs) per line, line class or area [no./line, class or area]	[45]	T14
Maintain-ability	**System level**		
	Mean time to repair (MTTR) (or Mean time to maintain (MTTM), or Maintainability)	[34, 41]	T15
	Subsystem level		
	Mean time to repair (MTTR) per item (or Maintainability)	[29, 34]	T16
Capacity	**System level**		
	Traffic volume [train-km or tonne-km]	[12, 39]	T17
	Subsystem level		
	Traffic volume per line, line class or area [train-km or tonne-km/line, class or area]	[12, 39]	T18
	Capacity consumption (or Capacity utilisation) (24h and 2h) [%]	[12, 35, 39]	T19
	Harmonised capacity consumption (double track counted twice) [train-km/track-metre]	[43]	T20

Table 1: Technical railway infrastructure maintenance indicators

Technical indicators			
Category	**Indicators** (comments) [unit]	**Reference**	**#**
Riding comfort	**Subsystem level**		
	Track quality index (TQI) (e.g. K-/Q-value) [index]	[45]	T21
OEE and DEA	**Subsystem level**		
	Overall equipment effectiveness (OEE) per line, line class or area [%/line, class or area]	[37]	T22
	Data envelopment analysis (DEA) [-]	[36, 38]	T23
Age	**Subsystem level**		
	Mean age of assets (Rail, S&C, OCS, ballast, etc.) [time]	[46]	T24

Table 1: Continuation

Quantitative indicators should always be complemented with qualitative indicators, like questionnaires. This has special importance in the organisational perspective due to strong human interactions. See Table 2, for quantitative organisational indicators.

Organisational indicators			
Category	**Indicators** (comments) [unit]	**Reference**	**#**
Maintenance management	**System level**		
	Preventive maintenance share (or Corrective maintenance share) [%]	[3]	O1
	Mean waiting time (MWT) (or Maintenance supportability, or Organisational readiness, or Reaction time, or Arrival time) [time]	[34]	O2
	Maintenance backlog [no. or time]	[45]	O3
	Maintenance possession overruns [time or no.]	[30]	O4
	Subsystem level		
	Preventive maintenance share (or Corrective maintenance share) per line, line class, area or item [%/line, class, area or item]	[43]	O5
	Mean waiting time (MWT) per line, line class, area or item [time/line, class, area or Item]		O6
Failure reporting process	**System level**		
	Faults in infrastructure with unknown cause [no. or %]	[43, 44]	O7
	Subsystem level		
	Faults in infrastructure with unknown cause per line, line class, area or item [no. or %/line, class, area or item]	[43, 44]	O8

Table 2: Organisational railway infrastructure maintenance indicators

Many overall financial indicators are regulated by the ministry of the IM and are therefore easy to find; see Table 3. Besides annual reports, those indicators are also often used in high-level benchmarking, e.g. [22, 23]. Similar cost indicators at operational level, i.e. per item, are scarcer, but research is carried out, e.g. on switches and crossings by [24-26].

Economic indicators			
Category	**Indicators** (comments) [unit]	**Reference**	**#**
Allocation of cost	**System level**		
	Maintenance cost (inclusive or exclusive management cost) [monetary]	[39, 45, 46]	E1
	Maintenance management cost (or Indirect maintenance cost) [monetary]	[39, 46]	E2
	Maintenance cost per train-km, track-km or gross-tonne-km [monetary/train-km, track-km or gross-tonne-km]	[39, 45, 47, 48]	E3
	Maintenance contractor cost	[46]	E4
	Corrective maintenance cost [monetary]	[43]	E5
	Preventive maintenance cost [monetary]		E6
	Subsystem level		
	Maintenance cost per line, line class, area or per item [monetary/line, class, area or item]	[49-51]	E7

Table 3: Economic railway infrastructure maintenance indicators

Maintenance staff are exposed to hazards and suffer from bad ergonomics due to unstandardized or non-routine work, lowered barriers, leakage, pressure, electricity, etc. [26]. As in all forms of rail transportation, the safety is a critical factor. Thus, HSE has a special importance in the management of railway infrastructure maintenance. General HSE indicators are easy to find and often required by law, but specific indicators for maintenance are scarcer. Both types have been considered in Table 4.

HSE indicators			
Category	**Indicators** (comments) [unit]	**Reference**	**#**
Health	Maintenance personnel absenteeism [time or no.]	General	H1
	Maintenance employee turnover [no.]		H2
	Maintenance employee talks [no.]		H3
Safety – general	Urgent and one-week inspection remarks [no.]	[43]	H4
	Harmonised inspection remarks		H5
	Deaths and injuries (or casualties and accidents) [no.]	[45, 46, 52]	H6
	Accidents at level crossings [no.]	[12, 45]	H7
	Accidents involving railway vehicles [no.]	[12]	H8
	Incidents (or Mishaps, or Potential injuries) [no.]	[46]	H9
Safety – maintenance	Maintenance accidents and incidents (occurred and potential) [no.]	[52]	H10
	Failure accidents and incidents (occurred and potential) [no.]		H11
	Derailments [no.]	[45, 46, 53]	H12
	Bucklings (or Sun kinks) [no.]	[45]	H13
Environment	Environmental accidents and incidents due to failure [no.]	General	H14
	Energy consumption per area [J/area]	[12]	H15
	Use of environmental hazardous materials [-]		H16
	Use of non-renewable materials [-]		H17

Table 4: HSE railway infrastructure maintenance indicators

3.2 Condition monitoring indicators

The railway condition monitoring indicators have been divided into six groups; substructure, superstructure, rail yards, electrification, signalling and information communication technology (ICT). Condition monitoring of these assets has been mapped by studying various inspection methods, mainly in [45, 54, 55]; see Table 5. Ocular inspections and manual inspections using gauges have not been considered due to their large number of routines. Bridges and tunnels condition monitoring have not been considered either; they are out of the scope of this paper. Wayside detectors are monitoring rolling stock; only the infrastructure is considered in this paper. Nevertheless, the rolling stock is as important as the infrastructure since it will be in similar condition [56]. See work by Bracciali [57] for a state-of-the-art review on wayside detectors.

Features	**Method**	**Parameters (component level)**	**PIs (subsystem level)**
Substructure			
Embankment			
Ballast composition	- Ground penetrating radar (automatic)	- Ballast composition (layered structure)	-
Track stiffness (related to bearing capacity)	- Hydraulic loading (automatic with stops)	- Track deflection/stiffness/ strength	Deduced: Stiffness loss inspection remarks [no. or no./length]
	- Deflectographs (continuous)	- Track deflection/stiffness/ strength and deflection speed	
Ballast contamination	- Thermographic imaging	- Contamination	Deduced: Contaminated ballast and bad drainage inspection remarks [no. or no./length]
Moisture content	- Resistivity tomography	- Moisture content (related to drainage)	
Track geometry			
Geometry	- Contact axles - Optical system - Gyroscope system - Inertial system	- Gauge - Cross level - Cant - Longitudinal level - Twist - Geometry of rails (spatial pos.) - Alignment - Wheel rail contact profile	- TQI (Track quality index), based on standard deviation, commonly for each 200 m. Deduced: - Track geometry inspection remarks [no. or no./km]
	- Failure reporting	- Bucklings (or Sun kinks)	Bucklings [no.]
Track surroundings			
Clearance and signal visibility	- Video system	- Vegetation clearance - Signal visibility	- Track surroundings inspection remarks [no. or no./km]
Superstructure			
Rail			
Integrity	- Continuous monitoring using sensors	- Temperature - Stress (longitudinal)	Deduced: - Potential buckling hazards [no. or no./km] - Potential rail breaks [no. or no./km] - Bucklings [no. or no./km] - Rail breaks [no. or no./km]
	- Ultrasonic inspection	- Discontinuities in central part of head, web, foot and running side	Deduced: Ultrasonic and eddy current inspection remarks [no. or no./km]
	- Eddy current inspection	- Discontinuities in the running surface	

Table 5: Condition monitoring of railway infrastructure and data extracted

Features	Method	Parameters (component level)	PIs (subsystem level)
Superstructure			
Rail			
Rail profile, rail surface and fasteners	- Optical profile and surface sys. - Differential transformer (LVDT) corrugation sys. - Axle box accelerometers	- Profile - Gauge wear - Running surface wear - Rail inclination - Rail type - Corrugation (amplitude and λ)	Deduced: - Inspection remarks requiring grinding [no. or no./km] - Inspection remarks requiring rail replacement [no.] - Inspection remarks requiring component replacement - Rail breaks [no.]
	- Video system	- Rail breaks - Rail joints - Burns/patches - Corrugation - Fastenings	
Switches and crossings (S&C)			
Geometry and integrity	- Geometry car	- Track deflection at switches	Deduced: Switches deflection inspection remarks [no. or no./switches]
	- Continuous monitoring using sensors	Switch blade position; - Contact area of blade and rail - Switch flangeway (open distance) - Operational force - Power and current usage - Residual stress (retaining force) - Detector rods position	Deduced: Malfunctions per switch type [no. or %] (in open, in closed, residual stress, detector rods, power or current consumption)
		- Impacts on frog (wear)	Deduced: Axis passing [no.]
		- Temperature - Stress (longitudinal)	
	- Mechatronic system	- Gauge	Switch total deviation
		- Switch blades groove width	
		- Cross level	
		- Twist	
	- Ultrasonic testing	- Discontinuities at critical spots	Deduced: Ultrasonic testing remarks [no. or no./switches]
Electrification			
Overhead contact system (OCS)			
Position and condition	- Optical system (laser)	- Vertical and lateral (stagger) position of contact wire - Contact wire thickness - Abrasion patches at contact wire	Deduced: Inspection remarks requiring adjustment or replacements of OCS components [no. or no./km]
	- Video system	- Condition of catenary wire, droppers, clamps and contact wire	

Table 5: Continuation

3.3 Constructing a railway maintenance scorecard

A scorecard, scorebook or scoresheet in business is a statistical record used to measure achievement or progress towards a particular goal [58].

For a successful performance measurement system, it needs to be able to provide the right information at the right time, to the right people, in the right quantity and format [59]. Moreover, according to Gillet, Woodhouse found that a human cannot control and monitor more than four to eight indicators at the same time [23]. By these reasons, it is essential to find the right indicators for the different organisational levels, indicators that match the objectives and strategy of the business. With use of a scorecard the top management can oversee the indicators for each responsibility, e.g. maintenance, operations, financial, etc. The indicators and parameters in Tables 1-5 have been brought together into a scorecard; see Table 6.

Perspective	**Aspect**	**Indicators [No.]**	
Managerial		**System**	**Subsystem**
Technical	Availability	7	7
	Maintainability	1	1
	Capacity	1	3
	Riding comfort	-	1
	OEE and DEA	-	2
	Age	-	1
Organisational	Maintenance management	4	2
	Failure reporting process	1	1
Economic	Allocation of cost	6	1
HSE	Health	3	-
	Safety – General	6	-
	Safety – Maintenance	4	-
	Environment	4	-
Condition monitoring		**Subsystem**	**Component**
Technical	Substructure	6	16
	Superstructure	10	30
	Rail yard	-	-
	Electrification	1	4
	Signalling	-	-
	Information communication tech.	-	-

Table 6: Railway infrastructure performance measurement scorecard

4 Linking railway indicators to EN 15341

The indicators of EN 15341 consist of 71 key performance indicators (KPIs) categorised into three groups and three levels. The groups are economic, technical and organisational indicators, and the levels are going from general indicators to more specific indicators. The KPIs have been constructed by taking the ratio of two or more factors, or PIs. The railway indicators have therefore been compared both with the factors and the KPIs of level one to three, see Tables 7 and 8. Indicators at the same row are considered to be closely related to each other.

Railway indicators		**EN 15341 indicators**	
#	**Name**	**#**	**Name**
E3 = E1/T17	Maintenance cost / Traffic volume	E3	Total maintenance cost / Quantity of output
E2/E1	Maintenance management cost / Maintenance cost	E13	Cost for indirect maintenance personnel / Total maintenance cost
E4/E1	Maintenance contractor cost / Maintenance cost	E10	Total contractor cost / Total maintenance cost
E1/H15	Maintenance cost / Energy consumption per area	E14	Total maintenance cost / Total energy used
E5/E1	Corrective maintenance cost / Maintenance cost	E15	Corrective maintenance cost / Total maintenance cost
E6/E1	Preventive maintenance cost / Maintenance cost	E16	Preventive maintenance cost / Total maintenance cost
H10/Time	Maintenance accidents and incidents / Time	T5	Injuries for people due to maintenance / Working time
H11/T3	Failure accidents and incidents / Failures in total	T11	Failures causing injury to people / Number of failures
		T12	Failures causing potential injury to people / Number of failures
O2+T16	Mean waiting time (MWT) + Mean time to repair (MTTR)	T21	Total time to restoration / Number of failures
O3	Maintenance backlog	O22	Work orders performed as scheduled / Scheduled work orders

Table 7: Relationship between railway and EN 15341 indicators

Railway indicators		**EN 15341 indicators**	
#	**Name**	**#**	**Name**
E1	Maintenance cost	E1.1	Total maintenance cost
T17	Traffic volume	E3.2	Quantity of output
E2	Maintenance management cost	E13.1	Cost for indirect maintenance personnel
E4	Maintenance contractor cost	E10.1	Total contractor cost
H15	Energy consumption per area	E14.2	Total energy used
E5	Corrective maintenance cost	E15.1	Corrective maintenance cost
E6	Preventive maintenance cost	E16.1	Preventive maintenance cost
H10	Maintenance accidents and incidents	T5.1	Injuries for people due to maintenance
T3	Failures in total	T11.2	Total number of failures
H11	Failure accidents and incidents	T11.1	Failures causing injury to people
		T12.1	Failures causing potential injury to people

Table 8: Relationship between railway indicators and EN 15341 factors

5 Discussion

Maintenance performance indicators for railway infrastructure have been identified and listed in Tables 1-6. Similar indicators have been considered as one indicator. Some indicators have been added, since they are considered as general indicators, e.g. maintenance personnel absenteeism. The listed indicators form a basis for constructing a performance measurement system for railway infrastructure. Though, the focus has been on the railway track, besides considering some parts of the overhead contact system, other systems have not been considered, e.g. bridges, tunnels, and signalling. Moreover, studies have shown that the railway infrastructure and train operating companies (TOCs) are responsible for 20-30 % and 30-40 % of the train delay, respectively [3, 29, 31]. The studies also showed that the rolling stock, vehicle failures, is responsible for 10-20 % of the delay. Performance measurement and indicators for assessing the performance of rolling stock and operations are therefore likewise important for the credibility and dependability of railways. Extensive work on indicators and benchmarking on this have been carried out in [7-11].

The identified indicators have been compared to EN 15341 [6] in Tables 7 and 8. It was found that 11 PIs are similar. A number of the indicators in the European standard are general for any maintenance functions. Nevertheless, it has to be kept in mind that the standard is mainly for manufacturing businesses and not for linear assets. Thus, many railway indicators cannot be found in the standard.

The scorecard in Table 6 has two groups called availability and capacity, respectively. Availability related indicators are considered as indicators of punctuality, regularity, failures, delay and temporary speed restrictions, while capacity related indicators are of traffic volume and capacity consumption. The latter one is according to UIC [35]. However, any general availability indicators for railways could not be found, such as uptime measures, or like indicator T1 of EN 15341: Total operating time / Total Operating time + Downtime due to maintenance. Regarding capacity, the indicator Capacity consumption [35] by UIC is extensively used by IMs, which is a measure of how occupied an infrastructure is. Thus, the amount of output, effective capacity, or such, is not measured.

Performance measurement of railway infrastructure provides information regarding the condition of systems and components. Failure rates, failure causes and the corresponding delays can be monitored and compared to expected lifetime calculations. Thus, it provides additional inputs to lifecycle costing and cost-benefit analysis, which can be made more accurate. However, it requires a well-developed performance measurement system with consistency over time for trend tracking. For a thorough review of railway maintenance cost estimation, see work by [60].

6 Conclusions

A detailed state-of-the-art study of the performance measurement of railway infrastructure was undertaken. As a result, performance indicators of railway infrastructure have been listed in Tables 1-6 and categorised into two groups; managerial and condition monitoring indicators. The identified indicators have been compared to EN 15341 [6]; 11 indicators were found to be similar, which can facilitate external benchmarking.

Infrastructure managers use performance measurement to study whether results are in line with set objectives, for predicting maintenance and reinvestments, decision support and benchmarking, i.e. business safety. The listed indicators can therefore be used by infrastructure managers for reviewing and improving their performance measurement system. It also provides a background for a possible future standardisation of railway indicators. However, harmonising between infrastructure managers for benchmarking is a challenge, since the operational and geographical conditions varies extensively.

This study has been mainly focused on the railway track. Scope of future work can be on other infrastructure assets and the rolling stock.

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