UIC ASSET MANAGEMENT WORKING GROUP

Key Cost Drivers in Railway Asset Management

Publication of Short list

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INTERNATIONAL UNION
OF RAILWAYS

UIC ASSET MANAGMENT WORKING GROUP

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CONTENT

1. INTRODUCTION

The International Union of Railways (UIC) offers a platform for national Infrastructure Managers of railways to exchange information and learn from each other. The Asset Management Working Group (AMWG) has been established by the UIC Members to exchange experience on multiple aspects in the field of Asset Management. The Asset Management Working Group is composed of representatives of a number of railways Infrastructure Managers from different European countries. The Members and their respective roles are listed in Appendix I.

To gain insight in the aspect of Maintenance and Renewals cost, AMWG has launched a project called KPI (Key Performance Indicators). The objective of the KPI project is twofold:

OBJECTIVE 1 — **IDENTIFY EXPLANATORY FACTORS FOR THE DIFFERENCES IN MAINTENANCE AND RENEWALS COST BETWEEN MEMBERS**

OBJECTIVE 2 — **IDENTIFY THE LEVERS FOR MAINTENANCE AND RENEWALS COST CONTROL**

These two objectives are reached by identifying and characterizing the most significant Cost drivers that influence the Maintenance and Renewals expenditures, in short; the following mission has been assigned to the AMWG:

> **"Establish a Short list of Cost drivers for railways network Maintenance and Renewals cost supported by all participating Members."**

This publication describes the result of the identification, mutual recognition and understanding of Cost drivers as well as the ranking of the most significant Cost drivers by the AMWG Members.

EXPERT JUDGMENT VALIDATED BY DATA

Over the course of 2014 and the first half of 2015, the Asset Management Working Group (AMWG) has made a joint effort to find the most significant Cost drivers for asset management in railways infrastructure. The method made use of expert judgment for identification followed by a characterization of the Cost drivers using specific data. The following definition of Maintenance and Renewals (hereafter sometimes named "M&R") cost has been used, based on the LICB definition:

> **Total cost for the Infrastructure Manager on maintenance of assets described as "infrastructure"- plus the Infrastructure Manager's capital investment for renewal and investment in the existing network, including outsourced activities.**
>
> **(UIC - LICB, 2004)**

EXPERT JUDGMENT

During the eighteen months of the project, the AMWG Members from different European countries shared their ideas and opinions in collective meetings as well as in individual questionnaires. After an identification of a Long list based on workshops and presentations of the different Infrastructure Managers (IM), the identified Cost drivers were characterized in order to converge to a common understanding among the Members. The next step was to rate the Cost drivers of the Long list (Appendix II) on significance for the Maintenance and Renewals cost. The aggregated information resulted in a ranking of the Cost drivers which allowed for a systematic identification of the most significant ones. In the end, the AMWG Members made a selection of the most significant Cost drivers resulting in a Short list.

In this Short list, the AMWG Members have made a distinction between input and output Cost drivers. *Input* Cost drivers include the IM's strategy and the framework in which the Infrastructure Managers have to make choices on the Maintenance and Renewals program. On the contrary, an Infrastructure Manager does not spend his money on output Cost drivers; they are a result of the IM's choices. Output Cost drivers formalize objectives of performance of the Maintenance and Renewals program. The figure below schematically shows the difference between Input and Output Cost drivers in the workflow of an Infrastructure manager.

The effect of Cost drivers on M&R cost is characterized using members' data

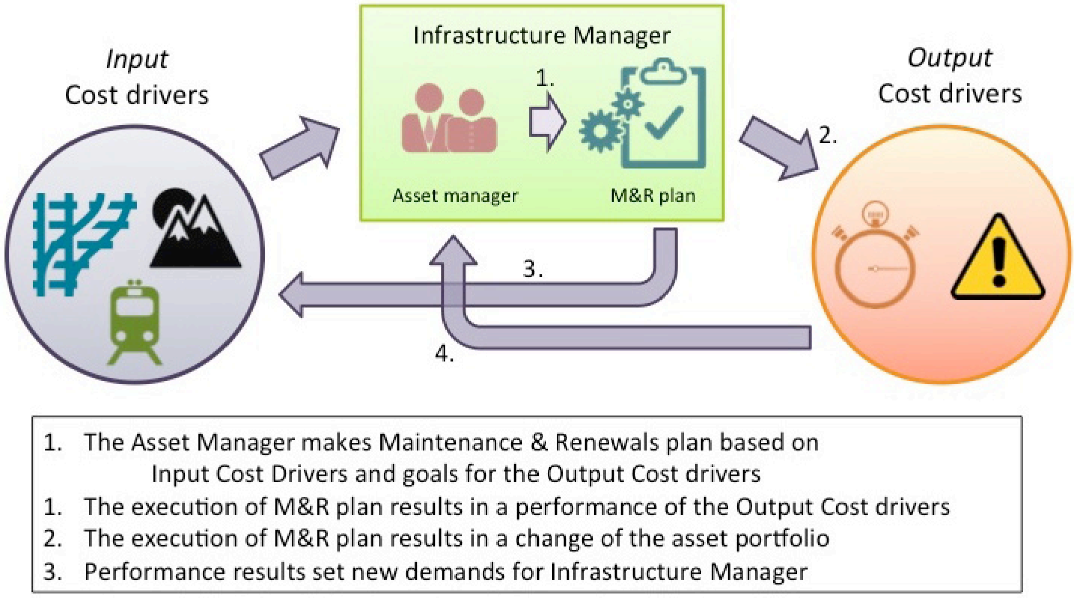


FIGURE 1: THE INFRASTRUCTURE MANAGER IN RELATION TO INPUT AND OUTPUT COST DRIVERS

Some Cost drivers cover a large subject and require a more detailed explanation to account for the differences between Members. Therefore they are cut-up in sub-Cost drivers with each its own indicator, description and characterization. Besides the input/output categorization, the input Cost drivers are grouped in three categories. These categories describe the nature of the Cost driver on a more abstract level. The (sub) Cost drivers listed below will be described one-by-one in the chapter *2. Short list*.

Input Cost drivers		Output Cost drivers
Number of assets	**1. Asset density** *a. Switch density* *b. Other asset density* **2. Tracks per line** **3. Electrification of network**	**8. Quality of service** *a. Punctuality* *b. Safety*
Use of assets	**4. Gross tonnage** **5. Speed**	
Working strategies	**6. Track possession strategy** *a. Safety arrangements* *b. Mean possession time* *c. Weekend & night work* *d. Frequency* **7. Age of track**	

SHORT LIST OF COST DRIVERS AND THEIR SUB-COST DRIVERS, CATEGORIZED BY INPUT AND OUTPUT AS WELL AS THREE CATEGORIES FOR INPUT COST DRIVERS

CHARACTERIZATION

In addition to the expert judgment supporting the Short list, Members' data is used to characterize the Cost drivers where possible. The data is used to describe the influence of a Cost driver on the Maintenance and Renewals expenditures. A distinction is made between quantitative and qualitative Cost drivers. Qualitative Cost drivers are difficult to characterize with data, therefore they are characterized with a description.

Switch density is an indicator for network complexity

2. SHORT LIST

2.1. Asset Density

To put extra emphasis on the importance and measurability of switches, the Cost driver "*Asset density*" is split up into "*Switch density*" and "*Other asset density*".

2.1.1. Switch density

FINDINGS KPI

"Switch density" gives insight in the complexity of a network as a whole as well as the density of a high-maintenance component: the switch. A high number of switches also indicates a more complex signaling system, more control units and more curved track which all increase maintenance cost. Apart from that, the switch itself requires more Maintenance and Renewals than plain track, increasing Maintenance and Renewals cost.

Indicator:
Total number of switch units in main track per main track.km for selected railways [#/km]

With: Switch units; Points in main tracks in maintained working order managed, owned, maintained by the Infrastructure Manager. (UIC definition)

The graph on the right shows anonymized data from the LICB database regarding the Switch density in relation to Maintenance and Renewals expenditures. The data confirms the presence of a medium linear correlation showing more switches per track.km result in higher M&R expenditures.

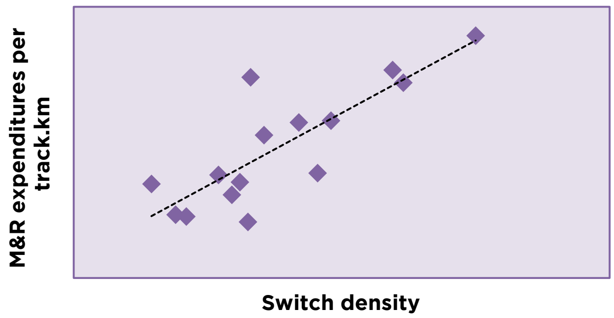


FIGURE 2: INFLUENCE OF SWITCH DENSITY ON M&R EXPENDITURES (LICB DATABASE)

2.1.2. Other Asset density

FINDINGS KPI

This sub-Cost driver is defined as an aggregation of cost-driving assets in a railways network. These assets can be divided in two typologies; linear and point-based assets. The linear asset densities are:

Tunnel density:

Tunnels house numerous installations for safety and operation which all need maintenance. Furthermore replacements are more expensive because it takes more time and requires specialized equipment. Therefore tunnels increase the Maintenance and Renewals cost, and longer tunnel have more installations and are therefore more costly than shorter ones. An indicator has been designed to take into account the length of the tunnels compared to the network's size. A second indicator shows the number of tunnels per track.km, together the indicators also show the difference between networks with few, but long, tunnels, and countries with many short tunnels.

Indicator 1:
Share of total main track.km in tunnel [%]

Indicator 2:
Number of tunnels per main track.km [#/km]

Bridge density:

Just like tunnels, bridges have a specific maintenance regime and therefore influence the overall Maintenance and Renewals cost. Especially when it comes to renewals bridges have a high impact on the M&R expenditures.

Indicator 1:
Share of total main track.km on bridges [%]

Indicator 2:
Number of bridges per track.km [#/km]

Besides these two identified linear asset densities measured in share of track kilometers, the following Cost driver describes a point-based density.

Lines with double track can remain partly available during maintenance

Level crossing density:

Level crossings have a different maintenance regime due to different wear and tear and their contribution to a network's safety. This is due to their non-rail bound users like cars and pedestrians. To ensure a safe passage for all users, several systems like a boom and signaling must work correctly. The number of systems and their reliability requirements result in high Maintenance and Renewals cost.

Indicator:
Number of level crossings/line.km [#/line.km]

Because of the large variety of assets as well as the variety of Maintenance and Renewals activities of assets within the asset groups (e.g. the difference of maintenance between concrete and wooden bridges), this Cost driver "*Other asset density*" is difficult to quantify.

2.2. Tracks per line

FINDINGS KPI

This Cost driver describes the difference between single- and double (or multiple) tracks for one line. Multiple tracks can be more easily maintained because it can accommodate traffic on the track which is not occupied for Maintenance or Renewals.

A Swedish research used an econometric model to come to the conclusion that an increased share of double track reduces maintenance cost, but at a decreasing rate (VTI/TEK & Odolinski, 2015). An approximation of the effect of the number of tracks on the M&R expenses is shown in Figure 3.

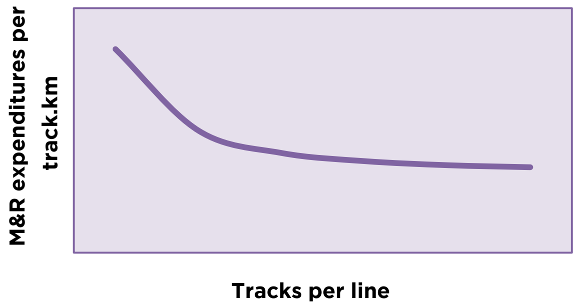


FIGURE 3: APPROXIMATION OF THE EFFECT OF TRACKS PER LINE ON M&R EXPENSES (SWEDISH NATIONAL ROAD AND TRANSPORT RESEARCH INSTITUTE)

Indicator:
Total length of tracks/total length of lines being maintained in working order [ratio]
(UIC definition)

2.3. Electrification of network

FINDINGS KPI

Electrification of tracks is a significant complexification of the edifice. It signifies the high utilization of a track as only frequently used lines are worthwhile to be electrified. Electrified lines require specialized maintenance, furthermore renewals are more costly than non-electrified lines.

Indicator:
Share of electrified line [%]
(UIC definition)

The Members agreed that this Cost driver is "binary", thus that a network can be either considered electrified or not. A percentage of the length of lines electrified supports this notion. In the graph below, LICB data shows 3 different types of networks divided by their rate of electrification.

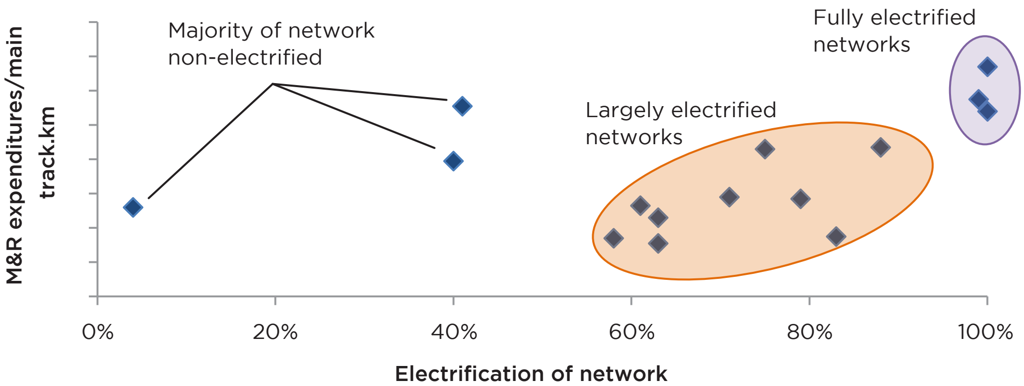


FIGURE 4: DIFFERENT NETWORKS GROUPED BY PERCENTAGE OF ELECTRIFIED TRACK IN RELATION TO M&R EXPENDITURES

The graph shows that in largely electrified networks, the correlation between the percentage of electrification and M&R cost is reasonable. Networks with a low rate of electrification (< 50 %) follow a different cost function.

European networks show large differences in the share of electrification of their lines

Especially freight traffic increases the burdening of the tracks

2.4. Gross tonnage

FINDINGS KPI

This Cost driver indicates the burdening of the track. A higher load means more rail defects that have to be repaired. This Cost driver relates to train frequency and is strongly influenced by the network's users. It is important to use the tonnage of both the passengers and freight users as well as including the weight of the traction vehicle.

Indicator:
Annual gross ton.km per main track.km for selected railways and year for passenger and freight trains.
[Gross ton.km per main track.km]
(UIC definition)

The graph on the right shows the relationship between the Cost drivers "*Gross tonnage*" and "*Frequency*".

There is a clear linear correlation in the data from the LICB database.

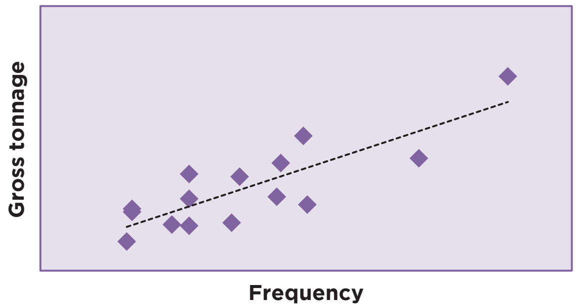


FIGURE 5: RELATION BETWEEN GROSS TONNAGE AND FREQUENCY (LICB DATABASE)

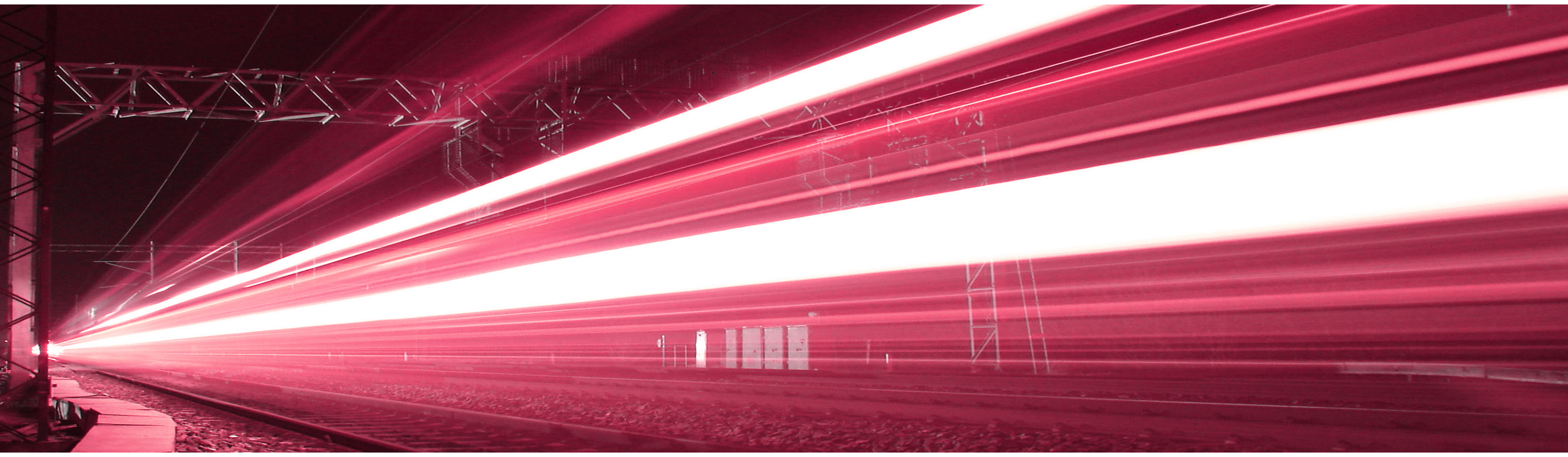
2.5. Speed

FINDINGS KPI

The Cost driver speed has two dimensions. The first one is a measure of the speed of the trains using the network. The second dimension is the difference between the designed speed of the track and the speed of the trains using it.

Indicator 1:
Mean speed of the trains [km/h]

Indicator 2:
Average speed of the trains/average design speed of the tracks [ratio]



The Members agreed that two indicators are necessary as the speed of the trains influences the necessary quality of the infrastructure. UIC literature (UIC/SBB, 2001) gives an example of switches with operating speed of 80-140 km/h that are 5 times more expensive than switches with an operating speed of 30-70 km/h. A higher quality results in higher Maintenance and Renewals expenditures.

Besides this, the difference between designed speed on a particular stretch of track and the actual speed of the trains using it causes high Maintenance and Renewals cost. If a train is moving at 130 km/h on a track designed for 80 km/h, the wear on the track is bigger and results in higher M&R cost.

2.6. Track possession strategy

FINDINGS KPI

Track possession strategy has been given the highest ranking possible; both a maximum score on the Members' rating and a maximum score on quotations. It is evident this is a significant Cost driver. The reason is that it covers multiple "sub-"Cost drivers that apply to different areas of the Infrastructure Managers' work. This Cost driver covers the following sub-Cost drivers:

Safety arrangements:

Each time workers go on to the track to do Maintenance and Renewals work, safety procedures have to be followed. These safety procedures take time and "steal" from the available time window for M&R work. A shorter safety procedure at the start and end of the work on the track results in a higher efficiency of M&R time window. Furthermore, a longer time window for Maintenance and Renewals increases the efficiency because the safety procedures are shorter relative to the total work time.

Indicator:
Mean time used for safety procedures / mean track possession time per Maintenance and Renewals operation [%]

The Members have identified this Cost driver as "qualitative". Characterization with data is therefore not elaborated in this publication.

Mean possession time:

Besides working during train-free nights and between trains, it is also possible to take a line out of service for a longer period. This affects the efficiency in a positive way because it increases the time window for Maintenance and Renewals work.

In some cases, it is impossible to do the work in a night, for instance when replacing a bridge.

Indicator:
Mean possession time for Maintenance and Renewals activities [h]

Trains that run faster than the track's designed speed result in more maintenance and renewals actions

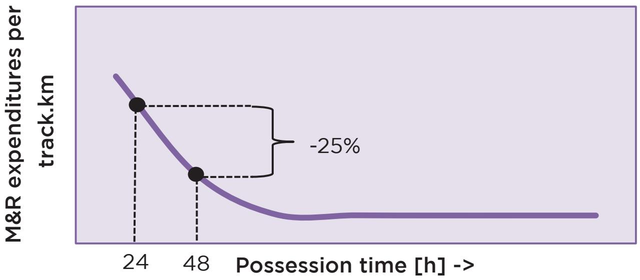


FIGURE 6: RELATIONSHIP BETWEEN POSSESSION TIME AND M&R EXPENDITURES (MEMBERS' DATA)

Members' data show that a longer possession time window results in lower cost of track renewal per km. The effect of the possession time follows an exponential function resulting in the renewals cost difference being bigger when possession times are smaller. This effect is shown schematically in the following graph.

The same data shows the difference in renewals cost per track kilometer is reduced by 25 % when enlarging the possession time window from 24 to 48 hours.

Weekend & night work:
Using the nights and weekends to minimize the nuisance of Maintenance and Renewals work for the users influences cost because labor in these unconventional hours is more expensive.

Indicator:
Share of hours worked in weekend and night hours [%]

Members' data shows that the difference between the renewals cost for track replacement can be up to 20 % more expensive in weekends for possession times of 24 hours. The difference is reduced to 8 % when the possession time is 48 hours.

Frequency:
The frequency of the trains using the track indicates the time available for Maintenance (mostly inspections) during operation of the network. A high frequency means that workers have to interrupt their work more often for a passing train, which reduces efficiency and increases cost. Furthermore, frequency is a measure of the utilization of the network. The more a network is used, the more Maintenance and Renewals are required.

Indicator:
Annual train-km per main track-km for selected railways and year, stacked columns separated by passenger and freight trains [k train.km per main track.km] *(UIC definition)*

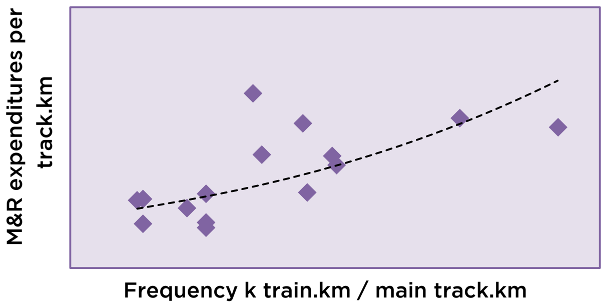


FIGURE 7: RELATIONSHIP BETWEEN FREQUENCY AND M&R EXPENDITURES (LICB DATABASE)

The chart on the left is retrieved from UIC's LICB project (UIC - LICB, 2013) and shows a weak correlation between the frequency and the M&R expenditures. The dots in the graph represent European countries that have collected data for over ten years. The graph suggests that a higher frequency results in higher M&R expenditures. From experience, AMWG Members noted that the relationship is exponential; increase in frequency can lead to an exponential increase in cost. The low correlation suggests there are more indicators than "Frequency" that influence the Maintenance and Renewals budget.

2.7. Age of track

FINDINGS KPI

Tracks are the main assets for Railways Infrastructure Managers and require expensive replacement and periodic maintenance (tampering, grinding, etc.). Traditional track consists of three components; rails, sleepers and the ballast bed. Of these three components the lifetime of the sleepers is leading in the Maintenance and Renewals program. In general, when the sleepers are replaced, the entire track is replaced. Therefore the indicator focusses on this component of the track. Members agree that the older the tracks in the network, the more maintenance is required and therefore the M&R expenses increase. In order to be able to see the difference between a network with half of its tracks installed 50 years ago while the other half is brand new, and a network with all its tracks at the age of around 25 years old, a second indicator is introduced. With only indicator 1, the differences of these networks would be averaged out. The second indicator shows the share of the network that has old tracks and gives an additional insight in the distribution of the age of tracks in a network.

Indicator 1:
Mean age of sleepers [years]

Indicator 2:
Share of km.track over thirty years old [%]

Track sleepers are used to indicate the age of track

The quality of service is an indicator for the performance of the M&R policy

OUTPUT COST DRIVERS

As noted in the previous paragraph, a distinction is made between input and output Cost drivers. The seven Cost drivers described previously are inputs for the Infrastructure Manager's Maintenance and Renewals program.

The eighth Cost driver is the only output Cost driver in the Short list. Output Cost drivers are a result of the Infrastructure Managers actions and serve as a performance target.

2.8. Quality of service

FINDINGS KPI

The Cost driver "*Quality of service*" is divided in two sub-Cost drivers which cover both a different side of railway infrastructure performance. In general, it can be mentioned that IM's with a higher quality of service will have higher M&R costs in order to attain this level, compared to an IM with a lower quality of service.

Punctuality:

Lack of punctuality is one of the most important nuisances of the railway infrastructure users; the passengers. Because it is also relatively easy to measure, it can be used as a measure of performance of the IM. The "*Punctuality*"-Cost driver covers delays caused by traffic management, failing rolling-stock and operating causes as well as the more technical causes (such as infrastructure failure).

Extreme weather conditions are not taken into account.

Indicator:

Cumulated delayed minutes for passenger train / Number of passenger train [min/pass.train]

(With a minimum delay of 5 minutes)

Safety:

Safety is an aspect that is of special importance to the Infrastructure Managers. Of course the goal is to reduce any injuries and fatalities but it is impossible to cover all risks, especially if they come from outside the sphere of influence of the IM. The two indicators are designed to account for the frequency of accidents and together they indicate the gravity of the accidents.

Indicator 1:

Number of fatalities per year per train.km [#/year/train.km]

Indicator 2:

Number of accidents per year per train.km [#/year/train.km]

3. INFLUENCE MATRIX

The influence matrix below shows the influence of the Cost drivers on the different railway infrastructure items. On the horizontal axis on the top, the ten railway infrastructure items, as defined by the LICB (UIC - LICB, 2004), are listed. On the vertical axis, the Cost drivers from the Short list are shown in the categories presented in the previous chapter. The cells indicate the level of influence of a Cost driver on the Maintenance and Renewals expenditures of a specific infrastructure item. The influence of the Cost driver "*Switch density*" for instance, has a high level of influence on the infrastructure item "Track and track bed".

The influence is classed with the levels "None", "Low", "Medium" and "High". The members have individually completed the table according to their expert judgement; table 1 is an aggregation of their input. The goal of the matrix is to identify the Cost drivers with the biggest influence in order to prioritize the data collection in the next steps of the project.

LICB Railway infrastructure items:	Ground area	Track and track bed	Engineering structures	Level crossings	Super-structure	Acces way	Safety, signalling	Lighting installations	Plant for transforming and carrying electric power for train haulage	Buildings
Short list Cost drivers			bridges, culverts, tunnels ...		including rails, sleepers, ballast, points, crossings	for passengers and goods including acces by road	and tele-communications installations	for traffic and safety purposes	sub-stations, supply cables between sub-stations and contact wires, catenaries	
1 Asset density										
Switch density	None	High	None	None	High	None	High	None	None	Out of scope
Other asset density	None	None	Medium	High	None	Medium	None	None	None	
2 Tracks per line	Low	High	Low	Low	High	None	High	Low	Medium	
3 Electrification of network	None	None	Low	None	None	None	None	None	High	
4 Gross tonnage	Low	High	High	Low	High	None	Low	None	Low	Out of scope
5 Speed	None	High	Medium	Low	Medium	None	None	None	High	
6 Track possession strategy										Out of scope
Safety arrangements	Low	High	High	High	High	High	High	Low	High	
Mean possession time	Low	High	High	High	High	None	High	Low	High	
Weekend & night work	Low	High	High	High	High	None	High	Medium	High	
Frequency	Low	High	High	Medium	High	None	High	Low	High	
4 Age of track	None	High	None	None	High	None	None	None	None	
8 Quality of service										Out of scope
Punctuality	None	High	Low	Medium	High	None	High	None	High	
Safety	None	High	High	High	High	None	High	None	High	

TABLE 1: INFLUENCE MATRIX

Most connections are linked directly to the presence of a certain Infrastructure item; the “Age of track” influences the M&R expenditures of “Track and track bed” because a higher age of the network results in more maintenance.

But there are also less obvious conclusions to be made. As discussed in the Short list, the most important Cost driver, “Track possession strategy”, shows a lot of red cells with high influence on M&R expenditures. The table shows a big red block, signifying high influence of “Track possession strategy” on five major infrastructure items: Track and track bed, Engineering structures, Level crossings, Super structure and Safety, signaling and telecommunication installations (see dotted square in the table).

Furthermore, the table reveals the influence of the Cost driver “Safety” on the M&R cost. In general it can be concluded that when safety requirements increase, Maintenance and Renewals expenditures will increase as well.

4. NEXT STEP: DATA COLLECTION

The KPI project has resulted in a first characterization of the most significant Cost drivers. This chapter will propose the next steps necessary to come to a more detailed explanation of differences in Maintenance and Renewals expenditures between the Members.

In order to come to a more detailed comparison, more data is required. Within the Short list there are Cost drivers with indicators that are hard to measure or difficult to compare and Cost drivers that are easier to compare. In the following list, the Cost drivers are ordered by their feasibility of data collection.

COST DRIVERS FOR WHICH THE COLLECTION OF DATA IS HIGHLY FEASIBLE

- 6b. Mean possession time (sub-Cost driver of "*Track possession strategy*")
- 6c. Weekend & night work (sub-Cost driver of "*Track possession strategy*")
- 6d. Frequency (sub-Cost driver of "*Track possession strategy*")
- 8a. Punctuality (sub-Cost driver of "*Quality of service*")
- 8b. Safety (sub-Cost driver of "*Quality of service*")

COST DRIVERS FOR WHICH THE COLLECTION OF DATA IS FEASIBLE

- 2. Tracks per line
- 1b. Other asset density (sub-Cost driver of *"Asset density"*)
- 7. Age of track
- 5. Speed; indicator 1: M*ean allowed speed of the trains*

COST DRIVERS FOR WHICH THE COLLECTION OF DATA IS NOT FEASIBLE

- 6a. Safety arrangements (sub-Cost driver of "*Track possession strategy*")
- 7. Speed; indicator 2: *Average speed of the trains/average design speed of the tracks*

DATA ALREADY COLLECTED BY LICB

- 1a. Switch density (sub-Cost driver of "*Asset density*")
- 4. Gross tonnage
- 3. Electrification of network

In the follow-up of the KPI project, it is recommended to start collecting data from the first and second list. By focusing on the relatively easy part, the Members can identify and explain levers of cost control and therefore benefit from the so-called “low hanging fruit”. Furthermore, the first and second lists correspond to the “High” influence cost driver identified in the Influence matrix.

Experience in the data collection over the past months learned that some Cost drivers require a more detailed definition of its indicator. “Bridge density” for instance requires a minimum length of a bridge. These refinements of the existing indicators will have to take place in the next steps.

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APPENDIX I – LIST OF AMWG MEMBERS 2014-2015

Organization	Country	Representative	Role
UIC	-	Teodor Gradinariu	UIC project manager
Infrabel	Belgium	Dominique Gardin (2014)/ Jan Cocquyt (2015)	UIC AMWG chairman (2014) AMWG member
RFI	Italy	Gian-Piero Pavirani	AMWG member
Jernbaneverket	Norway	Hans Svee	AMWG member
Trafikverket	Sweden	Viviane Karlsson	AMWG member
SNCF	France	Marc Antoni	AMWG member
FTA	Finland	Vesa Männistö	AMWG member
Network Rail	United Kingdom	Andy Kirwan	AMWG member/ Chairman (2015)
CIE	Ireland	Jude Carey	AMWG member
OBB	Austria	Michael Wogowitsch	AMWG member
ADIF	Spain	Roberto Muela Gutiérrez	AMWG member
Oxand	International consultancy company	Rémy Jacquier David Vervoort	Process facilitator, external advisor and drafting of documents

APPENDIX II - LONG LIST OF COST DRIVERS

Cost driver name	Cost driver indicator	Description
1. Age & condition of substructures	Mean remaining life time of substructures in the network	The cost driver "*Age & Condition of substructures*" drives the M&R cost because an older asset portfolio of substructures requires more maintenance. Settlement of the substructure causes damage or misalignment of the tracks. To capture the condition of the substructure, the indicator uses the remaining technical lifetime as a value that can easily be compared to other networks. The substructures can represent around 40 % of track cost.
2. Age of bridges	Mean remaining life time of bridges in the network	Bridges are special assets in a network's asset portfolio and weigh heavily on the Infrastructure Managers cost, particularly when they need replacement. The age of the bridges in a network gives insight in the necessary renewals, this includes partial replacements.
3. Age of tracks	Weighted average of remaining life time of rails, sleepers and ballast in the network	Traditional tracks consist of three components: Rails, Sleepers and Ballast bed (or concrete slab). The three components can have a different age due to partial renewals throughout the history of the track. Overhead lines or third rails are excluded from this cost driver. Remaining lifetime is used as a measurable value to indicate the condition. The weight factors of the weighted average are to be determined within the AMWG, although there are already existing models (e.g. ICV from SNCF). The weighting must incorporate a means to compare the age of slab track.
4. Alignment/ curvature	Share of curved track with radius < 500 m on main lines	This is a cost driver because curved tracks take on the friction forces of the trains while making a turn. The impact of this lateral force is influenced by the alignment of the tracks; curved track is often slanted to reduce friction and increase travelers' comfort. Because the friction on this type of track is higher than straight track, more maintenance is necessary and the technical lifetime of curved track is shorter. Therefore a network with more curved track will have higher Maintenance and Renewals cost. Furthermore narrower curves result in more maintenance than wider curves. The indicator distinguishes narrow and wide curves based on their radius to be able to incorporate this aspect in a comparison.

Cost driver name	Cost driver indicator	Description
8. Capacity	Maximum tr.km or ton.km/year/track.km	This cost driver describes the designed capacity of the tracks. It is rated unimportant because it does not cover the actual usage of the track, for the actual use see cost driver 32: "*Working out-of-design*". There is a strong link between track possession strategy and capacity.
9. Condition-based maintenance	Share of condition-based (vs systematic) Maintenance and Renewals in cost	This cost driver concerns a strategic choice on how to manage a network's maintenance. Condition-based maintenance requires more data and knowledge but is efficient because it eradicates unnecessary periodic maintenance activities.
10. First-last train	Mean time between last and first trains on main lines	The time window between the last train in the evening and the first train in the morning indicates the daily time available for maintenance. The longer the time window, the more work can be done in one night. This cost driver has a strong relation with "*Track possession strategy*".
11. Gauge	Share of track.km with non-European standard gauge on main lines	The presence of a European standard gauge in a country's network makes it possible to use standardized track-bound maintenance equipment. For instance tampering equipment (yellow machine). On tracks without the European standard gauge, specialized equipment or other methods must be used increasing M&R cost.
12. Gross tonnage	Gross annual ton.km/track.km	This cost driver indicates the burdening of the track. A higher load means more raildefects that have to be repaired. This cost driver relates to capacity and train frequency.
13. Insourcing vs outsourcing	Share of outsourced expenses for Maintenance and Renewals	The insourcing or outsourcing of the maintenance activities influences the cost because with outsourcing one benefits from market competition while with insourcing one benefits from economies of scale. Different ways of organizing M&R activities exist amongst the European Infrastructure Managers. The definition of "insourcing" remains ambiguous, in-house engineering for instance, covers a part of M&R activities that are outsourced. A maintenance activity can therefore be partially insourced and partially outsourced.

Cost driver name	Cost driver indicator	Description
14. Work preparation time	Mean journey time between work base and work site	The journey time between a maintenance post and the actual location of the maintenance activity must be paid, both in terms of labour cost and in transport of travel cost. Therefore a longer journey time would increase maintenance expenses. This is a cost driver which is hard to measure.
16. Length of electrified lines	Share of electrified line length	Electrified lines require more Maintenance and Renewals hence they are more expensive. Therefore a network with more electrified lines will have higher maintenance expenses.
19. Level crossings density	Number of level crossings/line.km	A level crossing of a road with a railway track often requires special installations like movable barriers, traffic lights and signaling. These installations require maintenance, therefore a network with a high number of level crossings will have high maintenance cost.
21. Mixed traffic or not	Share of passenger train.km	A network with mixed traffic will have different customers with different demands. It will increase maintenance cost if they require smaller maintenance time windows or higher quality standards
27. Rolling-stock-usage adequacy	Share of rolling-stock units specifically specified for use on network's track	A railway track is designed for a specific type of train with specific parameters like wheelbase and wheel shape. If the actual use deviates from the designed typology, the expected lifetime will not be met, resulting in more repairs and renewals. This cost driver describes the use of rolling-stock that is not designed to be used on the existing track. This drives up the M&R cost. For example, InfraCost proved that HSL dedicated has costs 20 % lower than mixed-traffic HSL
32. Working out-of-design	Weighted average gap between current maximum parameter (speed, gross tonnage...) and design parameter / extreme climatic conditions (out-of-range)	With an overlap with cost driver 27, this cost driver also includes parameters like the speed and tonnage of the rolling-stock that use the track. Besides the parameters of the use, this cost driver includes environmental aspects like temperature and vegetation. If the parameters of the actual situation are different from the designed parameters, technical lifetime is reduced, affecting the maintenance need and subsequently the maintenance cost.
32bis. Speed	Mean speed of the trains	The speed of trains using the track is different per train type and track type. Linespeed influences the maintenance regime and increases technical degradation of the track. Higher speeds require more accurate adjustments of track components.

Cost driver name	Cost driver indicator	Description
33. Switch density	Number of switch units/km of main tracks	Switches require specific maintenance to their moving parts and control system. Switches are a critical component for the network safety so must adhere to high quality standards. A network with many switches will require much maintenance and will therefore increase the maintenance expenses.
36. Train frequency	Tr.km/year on main tracks	The frequency of the trains using the track indicates the time available for maintenance (mostly inspections) during operation of the network. A high frequency means that workers have to interrupt their work more often for a passing train, which reduces efficiency and increases cost.
39. Type of tracks	Share of slab tracks	In general there are two type of tracks to be distinguished: Slab tracks and Ballast tracks. The two types of track have different maintenance requirements of which the most important is the tampering of the ballast bed with traditional tracks. No tampering is needed for slab tracks but the replacement cost are higher. Because of the different maintenance regimes this cost driver influences the Maintenance and Renewal cost. Note that type of sleepers (e.g. wood, concrete or other) or the weight per meter of rail is not incorporated in this cost driver.
43. Weekend & night work	Share of hours of works done either in week-end or night	Working in the weekend and nights reduces the nuisance for the traveler but labor cost are higher than during normal working hours. Therefore the share of work that is done in weekend and night hours influences the Maintenance and Renewals cost.
7a. Axle load	Maximum axle load on line	This cost driver describes one usage parameter. Higher axle load causes more fatigue problems for rails. In general more use means more wear and degradation. This results in more maintenance or earlier renewals which increase the M&R expenses. The "*Maximum axle load per line*" is chosen as indicator because a network often has different types of lines with different maximum axle loads.
7b. Axle load	Average annual axle load on main lines	This cost driver describes one usage parameter. In general more use means more wear and degradation. This results in more maintenance ore earlier renewals which increase the M&R expenses. This indicator allows for a more direct comparison between networks by considering only main lines. The differences in line type (regional/national) are not present in this indicator.

Cost driver name	Cost driver indicator	Description
26a. Renewals backlog/rate of renewals	Average remaining useful life time of asset at renewal for assets over expected life time	This cost driver describes the amount of renewals that should have been done and their failure risk. A network with much overdue maintenance will require a big renewals budget to get back on track and will require a higher maintenance budget to repair the incidental damages of old assets.
26b. Renewals backlog/rate of renewals	Ratio between real renewal rate and steady state renewal rate	This cost driver describes the amount of renewals that should have been done and their failure risk. A network with much overdue maintenance will require a big renewals budget to get back on track and will require a higher maintenance budget to repair the incidental damages of old assets.
17. Length of lines/tracks	Total length of tracks (main/side)/lines	This cost driver allows for a comparison of networks in absolute terms. The more tracks, the more the track-maintenance and therefore higher maintenance cost. Analyzing the difference between the length of tracks and lines, gives insight in the share of lines that has multiple tracks. Multiple tracks are more easily maintained because it can accommodate traffic on the track which is not occupied for maintenance.
18a. Length of tunnel	Share of tunneled tracks	Like level crossings and switches, tunnels are special components in a network that require special maintenance. A network with a big share of tunnel kilometers will have more maintenance demands than the same network without tunnels.
18b. Length of tunnel	Total length of tunnels	This cost driver allows for a comparison of networks in absolute terms. The more tunnels, the more tunnel-maintenance and therefore higher maintenance cost. The biggest impact of tunnels is on the construction and renewals cost, for maintenance cost it is of lesser concern.
20a. Material price	Material price index	Maintenance and especially renewals activities use materials like gravel, lubricants and steel. The prices influence the total M&R cost but because material prices do not vary much throughout the European continent, the impact of this cost driver is low.
20b. Material price	Material cost/total cost for Maintenance and Renewals	This indicator shows the use of materials in the Maintenance and Renewals budget. It is important to distinguish between different materials. This cost driver is an external driver because an IM cannot influence price levels.

Cost driver name	Cost driver indicator	Description
15a. Labor cost	Labor cost index	Besides material, labor is a major cost component of the total maintenance cost. Labor has a different price per country and therefore influences the total maintenance cost. This indicator reflects the general cost of labor of a country compared to others. This cost driver is an external driver because an IM cannot influence price levels.
15b. Labor cost	Average cost of an hour of labor for M&R activities, PPP adjusted	This cost driver is the same as 15a but the indicator is not on a general country-level but gives a specific comparison between countries' labor cost for maintenance. However, the value of this indicator is more difficult to obtain. Further specification is needed as to which labor cost is to be included; does this only include the cost of labor on site and does it include overhead cost?
25. Reliability/ number of failures/ corrective maintenance	Delayed minutes due to failures, work & traffic management/ passenger.km	Instant failures that require immediate repairs. This corrective maintenance is more expensive than planned maintenance. The number of failures and their gravity is therefore influential to the Maintenance and Renewals cost. This cost driver is in relation to condition based maintenance describing the IM's maintenance strategy
24a. Punctuality	Delayed minutes due to failures, work, traffic management & operating/ passenger.km	This cost driver is similar to the cost driver Reliability but in the case of Punctuality the delays are measured under less strict constrains. In the case of punctuality delays caused by traffic management, failing rolling-stock and operating causes are added to the more technical causes of the Reliability cost driver. Extreme weather conditions are not taken into account.
24b. Punctuality	Punctuality objective of organisation	This cost driver has the same definition as the previous one but here it concerns the punctuality goal set by the government.
28a. Safety	ERA common safety indicators	Higher safety requirements on the network results in higher quality of the asset portfolio. To keep up a higher level of quality, more maintenance is required which results in more maintenance cost.
28b. Safety	Cost incurred for safety e.g. training, protective clothing, etc.	Higher safety requirements on the network results in higher quality of the asset portfolio. To keep up a higher level of quality, more maintenance is required which results in more maintenance cost.

Cost driver name	Cost driver indicator	Description
29a. Work safety arrangements	Mean time lost to safety measures/ total track possession time	Higher safety requirements on the network results in higher quality of the asset portfolio. To keep up a higher level of quality, more maintenance is required which results in more maintenance cost. Safety arrangements during Maintenance and Renewals work take are necessary but take time, this indicator expresses the safety level by means of the time spent on it.
29b. Work safety arrangements	Safety arrangement cost/total maintenance & renewals cost	Higher safety requirements on the network results in higher quality of the asset portfolio. To keep up a higher level of quality, more maintenance is required which results in more maintenance cost. Safety arrangements during Maintenance and Renewals work take are necessary but cost money, this indicator expresses the safety level by means of the money spent on it.
30a. Signaling configuration	Share of remote controlled signaling installations (stations without dispatcher)	Signaling installations are an important portion of the maintenance cost. The type of signaling influences the maintenance regime. This indicator distinguishes remote controlled signaling from locally controlled signaling. Remote controlled signaling has lower operation and maintenance cost than locally controlled signaling.
30b. Signaling configuration	Typology mix: relay based (%), mechanical/lights (%), mounting (%)	Signaling installations are an important portion of the maintenance cost. The type of signaling influences the maintenance regime. This indicator distinguishes different types of signaling
31. Single or double track	Share of single track lines	Having double track has the advantage of working on one track and leaving the second track open or otherwise use track-bound equipment on one track to work on the second track. It also has the advantage of supplying materials to the work site. These advantages are not present with single track making maintenance more costly.
38a. Type of bridges	Share of track.km of steel bridges	Bridges of a different material have a different maintenance regime and therefore influence the M&R cost. This indicator distinguishes the steel bridges from other types of bridges
38b. Type of bridges	Typology (multiple choice): metal, stone, concrete, suspension, truss, arch, movable...	Bridges of a different material have a different maintenance regime and therefore influence the M&R cost. This indicator distinguishes between all different kinds of bridges. E.g. steel, wood, concrete, suspension, arch, movable...

Cost driver name	Cost driver indicator	Description
39a. Type of electrification	Share of track. km with third rail electrification	Electric energy can be supplied by overhead lines or a third rail system. A third rail system is more costly in terms of maintenance. This indicator describes the share of track with the third rail system.
39b. Type of electrification	Typology (multiple choice): overhead, third rail, fourth rail, AC/DC, voltage	In addition to the two systems described in cost driver 39a, there can be more typologies distinguished other than the supply system. The multiple choice indicator also differentiates between voltage, AC/DC currents and if necessary more detailed types.
39c. Type of electrification	Share of maintenance & renewals cost dedicated to electrification assets	This indicator allows for a comparison of maintenance on electrification systems between networks.
35. Track possession strategy	- Mean possession time on main lines [h] - Safety arrangements - First train / last train - Week-end & night work - Frequency	Track possession strategy is a cost driver that consists of many components like the available contiguous time for Maintenance and Renewals, the spread of work during weekend and night, the time needed in advance to reserve a part of the network for maintenance and the frequency of working on the track. Also safety arrangements are involved because each closure requires safety procedures at start and finish. This cost driver is one of the most important ones because it is has a high impact, and meets is categorized as "*internal*", an "*input*", "*measurable*", there are "*differences between IM's*" and it is "*controllable*". There is a big productivity difference between a track closure of 10-30 hours and a 4-hour night closure.
41. Usefulness (e. g. station appearance)		This cost driver represents the soft side of the quality level of the network's assets. For instance the cleanliness of the station.

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