Integrated Logistic Support Optimization applied to railway asset: The pantograph case study.

Abstract: This paper aims to demonstrate the application of ILS analysis for railway industry as part of RAMS program implementation, which enable to predict the effect of the logistic on the railways asset performance. The basis for the ILS are the main RAM methods such as LDA, RAM, FMEA and RCM results as discussed in previous chapters. Therefore, the spare parts level, the level of repair analysis, life cycle cost and supportability analysis will be the main topics of this paper. Finally, the case study concerning ILS concepts applied to critical equipment such as pantograph will be presented at the end of this paper.

Key Words: LSA, LRA, spare parts, Life cycle cost, supportability.

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1 – Integrated Logistic Support concepts

Integrated Logistic Support has been applied to military, aerospace and railways industries worldwide, and after some decades has proved to be a successful methodology.
The Integrated Logistic Support (ILS) is an integrated and iterative process for developing material and a support, maintenance strategy that optimizes functional support, leverages existing resources, and guides the system engineering process to quantify and lower life cycle cost and decrease the logistics footprint, making the system easier to support. Although originally developed for military purposes, it is also widely used in commercial asset support such as railway industry. The primary objectives of the ILS study are as follows:

- Detailed Reliability and Maintenance (preventive, predictive and corrective) operational Planning;
- Supply (Spare part) Support acquire resources;
- Perform the life cycle cost analysis throughout the asset life cycle;
- Support and Test Equipment;
- To provide training support;
- Technical Data / Publications,
- Computer software resources support;
- Packaging, Handling, Storage, and Transportation;
- Support design interface.

The ILS manages all information from the end of the design phase of the operation phase, integrating the design phase with the operational phase. In addition, based on ILS it´s possible to influence on the product design and develops the support solution to optimize supportability and Life Cycle Cost (LCC). The ILS key principles based on standard JSP 886 are the following:

- **Influence on Product Design**. Ensure where appropriate, that product design (including associated packaging), and the use of facilities, services, tools, spares and manpower are optimized to maximize product availability at optimal TLF.

- **Design the Support Solution**. Create an integrated Support Solution to optimize asset logistic performance. Ensure that the through life use of facilities, services, tools, spares and manpower is optimized to minimize whole life costs. Use of standard and / or common facilities, tools, spares and manpower shall be encouraged where appropriate.

- **Deliver the Initial Support Package**. Decide and procure the facilities, services, tools, spares and manpower required to support the product for a given period. Ensure that the physical deliverables of the Support Solution are in a position to meet the Logistic Support Date (LSD) requirements. Ensure, through life support is in place where appropriate.

- **Acquisition of Product**. ILS applies to the acquisition of all products for the MOD including Technology Demonstrator Programs, major upgrades, software projects, collaborative projects and off-the-shelf procurement.

- **Supportability of Product (Su)**. ILS will be applied to ensure that the product is designed to be supportable, that the necessary support infrastructure is put in place and that the asset logistic is optimized.

- **Requirement for ILS**. ILS is still required even when the product selected is already developed, is Commercial Off the Shelf (COTS) or Military Off the Shelf (MOTS), and design

The integrated logistic support programs intended to integrate different issues such as supply support, maintenance, packaging, handling, storage and transportation, technical information, training, disposal, reliability, equipment test and human factors as shows the figure 1. In fact, without a well-defined ILS program is almost impossible to integrate all such topics. In addition, the big challenge for all industries including the railways is not to implement all RAMS analysis during the concept and design phase, but to integrate all such assessment recommendations in the operation phase based on procedures and training to enable the maintenance and operators to execute all actions to enable the railway's assets to have a smooth logistics management throughout operation phase without jeopardizing the asset performance.

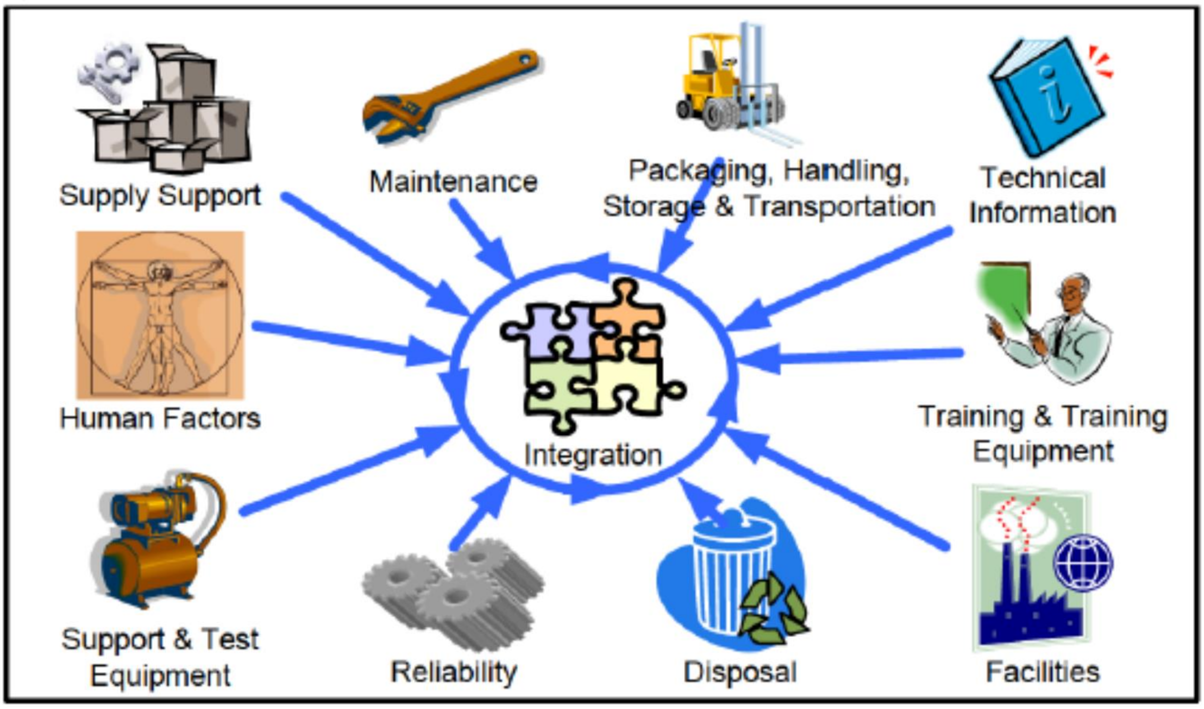


Figure 1: ILS Program Elements. Source: JSP 86

In order to implement the ILS program, the first step is to define the ILS strategy and policy during the asset concept phase. The second step is the integration of all reliability engineering methods applied during the concept and design phase to the commissioning and operation phases by delivering documents to be used during the operational phase as shows figure 2.

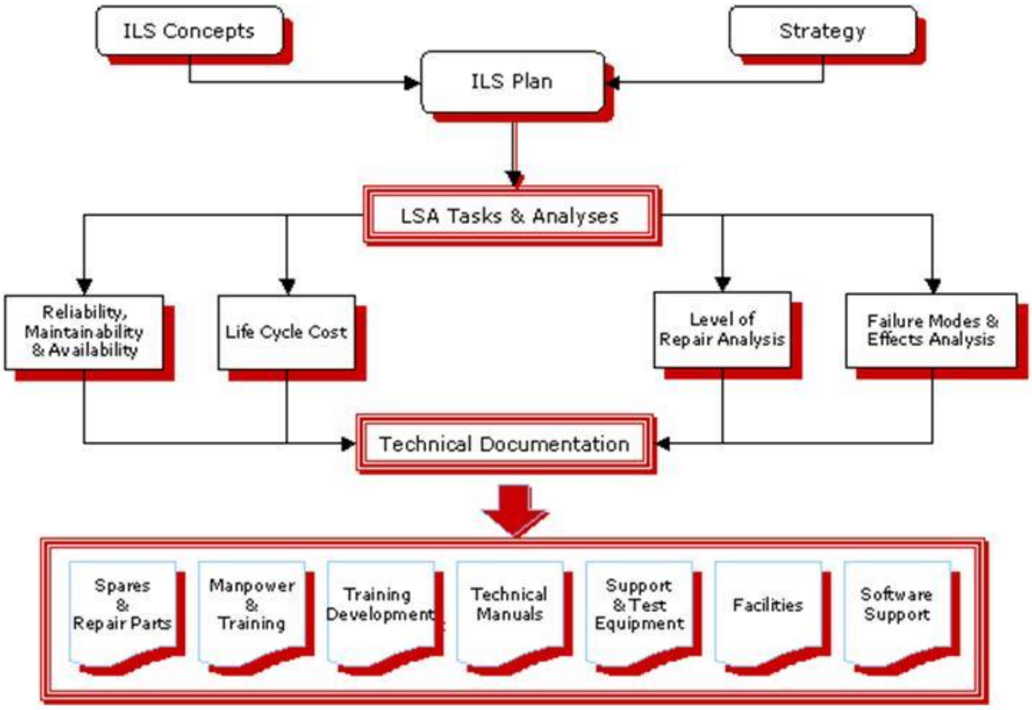


Figure 2: ILS information flow. Source: http ://www.mulkerin.com/images/

To accomplish such requirement, it’s been necessary to apply different reliability engineering methods and gather information as input data to ILS from the following sources:

- Utility Flow Diagrams, Process Flow Diagrams, P&IDs & descriptions;
- Discussions with project/operations personnel;
- FMEA Analysis;
- RCM Analysis;
- RAM analysis;
- LDA;
- Human Reliability Analysis.

In order to achieve the best result from ILS it´s necessary to implement additional mathematic methods such as optimization which enable to minimize life cycle cost and maximize operational availability and reliability.
Despite of all information available, software tools, standards and procedures, is still a big issue the gap to connect the information from design phase to operation phase in many asset life cycle. Such gap requires an organized ILS program implementation, which will be discussed in the following section.

2 – Integrated Logistic Support Optimization

The further step, after ILS program implementation is the ILS optimization process starts with the asset data collection based on different information not only concerning reliability methods but also the information from ERP, EAM and CMMS.
Finally, all this information is put together to define which is the best time to perform preventative maintenance, inspection and the spare part levels in order to maximize the operational availability and minimize the Life cycle cost. The ILS optimization cycle is demonstrated in figure 3. The ILS optimization allows to take into account the spare parts and resources allocation for all types of maintenance as well as preventive maintenance and inspection, which allows the lower LCC and maximum performance (operational availability, production efficiency and reliability). The Optimization can be implemented at different levels, such as equipment or component based on the LRU (line Replaceable Unit) concept. Therefore, the idea is to establish a good schedule to perform the preventive maintenance, inspection and order spare part to minimize the lifecycle cost and maximize the asset operational availability.

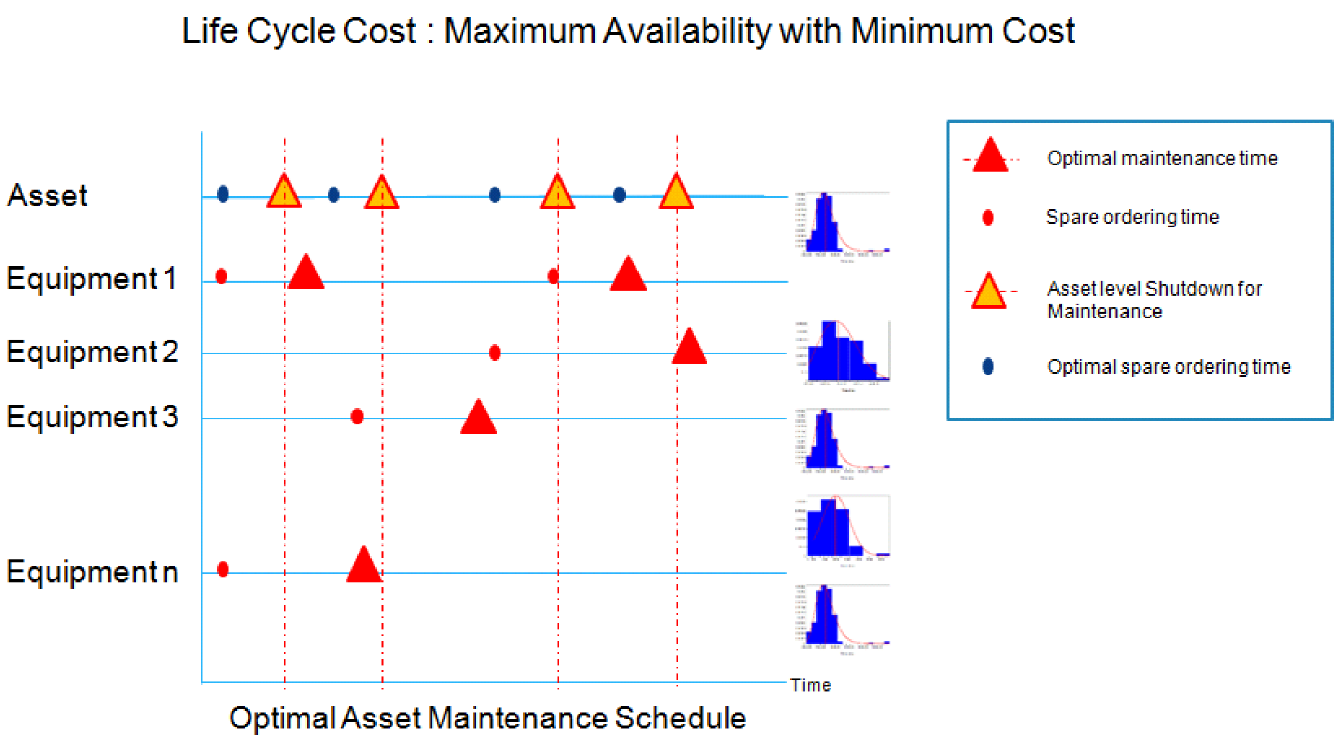


Figure 3: ILS for System Asset Performance Optimization. (Source: Calixto.E, Bot.I 2015)

The ILS optimization theory will be demonstrated in item 3 based on a dynamic programing theory, which concerning different aspects of physical asset such as maintenance reliability, human factor and life cycle cost. In real life, the challenge of optimizing the whole asset is related to the huge number of constraints such as environmental, safety, law, client, performance and cost. In addition, there are different goals, which in many cases, do not allow to optimize the whole asset as wanted, such as zero stock policy, minimal operational cost and minimum number of teams.

However, the idea of asset optimization is to support the leader's decision based on a mathematic method approach, which save time and have a potential to optimize system assets performance.

The mathematical optimization methodology concept encompasses information such as spare parts, preventive maintenance and inspection policies, reliability and logistic parameters of many equipment and component as well as the hierarchical relation between them. For this reason, the Dynamic Program (DP) is one of the ideal tools for this task.

Gustafsson (Gustafsson, 2010), presented a DP method for maintenance optimization in which St and dt represent the state of the system and decisions made respectively, at time t. Furthermore, it is the exogenous information that arrives at time t. φ represents the transition function and with these notations the system evolves in time according to:

$$S_{t+1} = \phi(s_t, d_t, i_t)$$

For each decision we make, a cost C has to be paid. If we assume a stochastic system, the objective is to minimize the expected total cost over some planning period or maximize the system performance.

If we assume that the system is in some state at time 0, and we have to make decisions for the time horizon 0, . . . ,T , our problem is to :

$$MIN_{x_0, x_1 \ldots, x_T} : E\left(\sum_{t=0}^{T} C(s_t, d_t) \right)$$

Subject to:

$$S_{t+1} = \phi(s_t, d_t, i_t)$$

The proposal DP method includes the operational availability, reliability and cost targets considering the maintenance policy decision, which is described as following:

For each item prepare a set of possible maintenance policies and calculate their cost and resulting item availability. Next, use these possibilities to construct a new set of possible maintenance policies for blocks each containing several items. In this way possible maintenance policies are constructed for every level in the asset hierarchy and the optimal policy is eventually chosen.

The second optimization possibility is to consider the Hierarchal System Model Optimization. The challenge is to optimize the maintenance policy for the system i.e. to find the cheapest policy subject to a requirement that system availability be larger or equal to required.

Suppose that the system optimal policy P1,1 is known (Pi,j denotes the policy for block j that belongs to level i) and it has a system availability denoted by A1,1≥ A required. Similarly, the set of policies and availabilities for the blocks of level 2 is denoted by (P2,i) and (A2,i). The system optimal maintenance policy is a union of optimal policies belonging to level 2 blocks:

$$P_{1,1} = \bigcup_i P_{2,i}$$

Therefore, with availabilities A2,i, and more generally:

$$P_{m,j} = \bigcup_i P_{m+1,i(j)}$$

where i(j) denotes the indices of blocks in level m+1 which are children of block j. Since A2, j has not known a-priory, different optimal policies are constructed for different A2,j values, and the optimal P1,1 is constructed by choosing the best combination of level 2 component policies. The process can easily be generalized to systems with many hierarchal levels.

In fact, there are different optimization algorithms, which enable to define an optimal solution. It´s not the scope of this paper to discuss in detail each individual optimization model and algorithm, but present a feasible solution which was successfully applied in the railway industry.

4– Integrated Logistic Support applied to railway industry: the pantograph case study.

The optimization algorithm described above was implemented into the apmOptimizer (BQR) software for different optimization modules such as Preventative Maintenance (PMO), Inspection optimization (PIO), Spare parts (S2A), Resources (R2A), level of repair (LORO).

The apmOptimizer is a Modeling, Analysis and Optimization tool designed to bring Asset maintenance to an optimal state, maximize Availability and minimize Cost of Ownership over lifetime (Bot, 2014).

The Optimization applied to preventive maintenance, inspection, spare parts and life cycle cost will be presented in the next item based on different case studies.

The pantograph system will be the scope of the second lifecycle cost optimization case study. The following equipment will be considered under the Supportability analysis are the following:

➢ Pantograph Base System
- Frame;
- Insulator;

➢ Valve Plate.

➢ Elevation System
- Cylinder;
- Spring;
- Draht;
- Insulate Hose.

➢ Pantograph Arm system
- Pantograph Arm A
- Guide Rod A
- Power Strap;
- Shear Frame;
- Pantograph Arm B;
- Guide Rod B.

- ➢ Collector head System
- Carbon Strip A;
- Carbon Strip B;
- Bearing A;
- Bearing B;
- Pantograph Horn A;
- Pantograph Horn B;
- Spring and damping contact.

Based on the list above the first step is to define the RBD and input the reliability, maintainability, corrective maintenance, preventive maintenance cost applied to the pantograph in order to predict the life cycle cost related to the pantograph lifecycle of 25 years as well as the performance prediction. The figure 4 shows the Bogie RBD for LCC prediction.

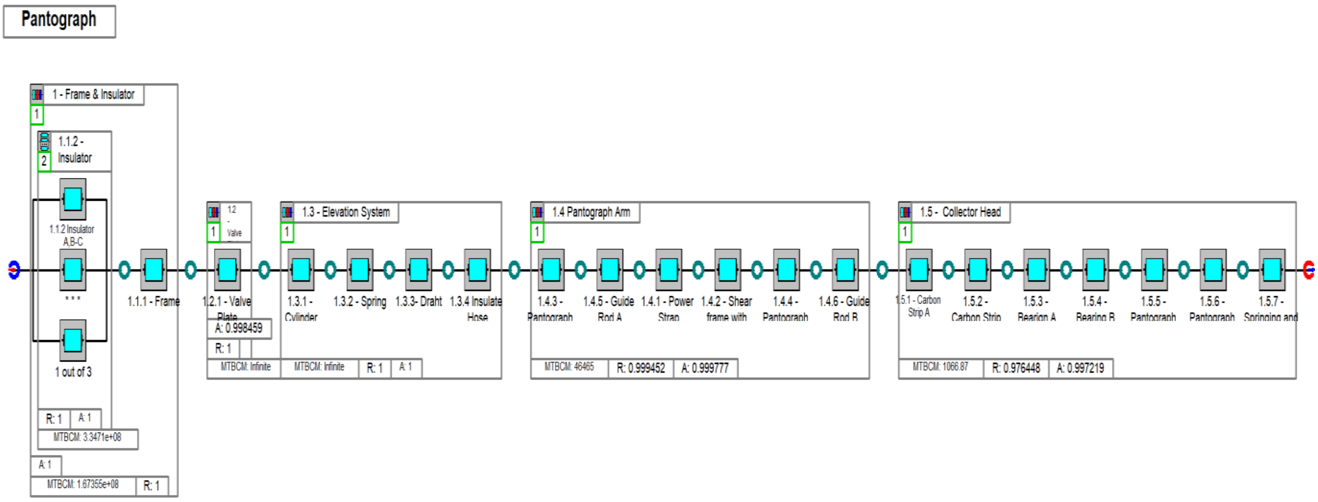
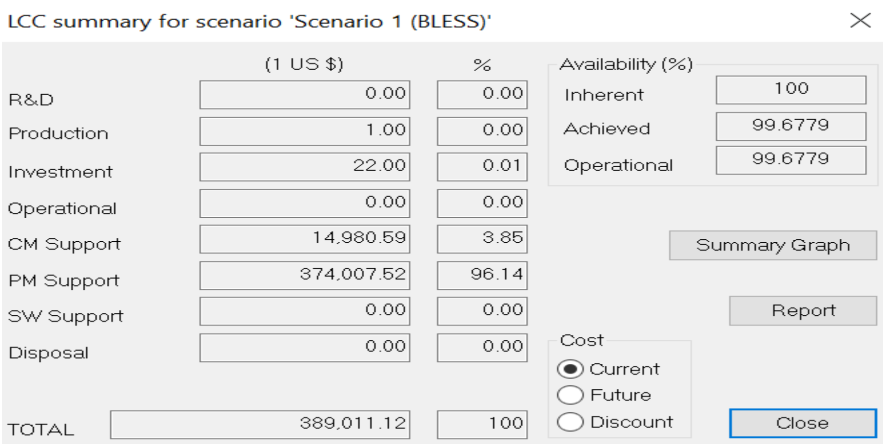


Figure 4 Pantograph RBD

The next step of the supportability analysis is to predict the LCC and performance of the pantograph and have the first idea about how much percent of the LCC is related with preventive maintenance and how much percent is related to corrective maintenance as shows the figure 5 below.



LCC summary for scenario 'Scenario 1 (BLESS)'

	(1 US $)	%
R&D	0.00	0.00
Production	1.00	0.00
Investment	22.00	0.01
Operational	0.00	0.00
CM Support	14,980.59	3.85
PM Support	374,007.52	96.14
SW Support	0.00	0.00
Disposal	0.00	0.00
TOTAL	389,011.12	100

Availability (%)	
Inherent	100
Achieved	99.6779
Operational	99.6779

Summary Graph

Report

Cost: Current / Future / Discount

Close

Figure 5: Pantograph RBD for LCC simulation result

Based on Figure 8.22, 96,14% of the LCC is related to the preventive maintenance, which represent a good practice of maintenance. Concerning the performance, the pantograph achieves 99.67% of operational availability along the life cycle, which is higher than the predefined target, 99.5 %. Therefore, the next step will be assessed of the LCC minimization of the LCC by remaining the achievement of the performance target. The table 1 shows the detailed RBD simulation performance result in LRU level.

Table 1: Detailed Pantograph RBD performance simulation result

Reference Designator	Part Number	Reliability Model	Distribution type	Contribution to system FR %	Availability	Mission Reliabil...	Scheduled PM ...	Failures pr...	CM actions for 1 ...	Corrective repa...	Preventi...	Preventi...
Pantograph	Part Number 1	Serial	-	100	0.996779	0.979654	161	3.87559e-...	147.135	0	0	0
1 - Frame & Insulator	001	Serial	-	0.000709213	1	1	2	3.88798e-...	0.00104688	298.48	298.48	0
1.1.2 - Insulator	003	K out of N	-	0.000709213	1	1	2	1.94399e-...	0.000523438	298.48	250	0
1.1.2 Insulator ...	004	Leaf	Exponential	0.000709213	0.999994	1	2	6.47993e-...	0.000174478	298.48	250	30
1.1.1 - Frame	008	Leaf	Normal	1.1869e-10	0.999994	1	2	0	1.75198e-10	298.48	298.48	30
1.2 - Valve Plate	007	Serial	-	2.65941e-11	0.998459	1	2	1.34468e-...	3.91952e-11	0	0	0
1.2.1 - Valve Plate	006	Leaf	Normal	2.65941e-11	0.998453	1	2	1.34467e-...	3.9195e-11	1350	1000	30
1.3 - Elevation System	009	Serial	-	4.74753e-10	1	1	16	0	7.00787e-10	0	0	0
1.3.1 - Cylinder	010	Leaf	Normal	1.18689e-10	0.999989	1	4	0	1.75196e-10	101.66	50.17	30
1.3.2 - Spring	011	Leaf	Normal	1.18687e-10	0.999971	1	10	0	1.7519e-10	50.17	30	30
1.3.3- Draht	012	Leaf	Normal	1.18687e-10	0.999971	1	10	0	1.7519e-10	172.98	150	30
1.3.4 Insulate Hose	013	Leaf	Normal	1.1869e-10	0.999994	1	2	0	1.75198e-10	116.62	80	30
1.4 Pantograph Arm	014	Serial	-	0.00011869	1	1	11	0	0.000175199	0	0	0
1.4.3 - Pantograp...	015	Leaf	Normal	1.18688e-10	0.99998	1	7	0	1.75193e-10	1342.87	900	30
1.4.5 - Guide Rod...	016	Leaf	Normal	1.17231e-10	0.999994	1	2	0	1.73045e-10	293.4	170	30
1.4.1 - Power Strap	026	Leaf	Normal	1.14791e-10	0.99998	1	7	0	1.6944e-10	9.33	5	30
1.4.2 - Shear fram...	027	Leaf	Exponential	0.000118689	0.999991	1	3	0	0.000175197	6.02	4	30
1.4.4 - Pantograp...	015	Leaf	Normal	1.18688e-10	0.99998	1	7	0	1.75193e-10	1342.87	900	30
1.4.6 - Guide Rod...	016	Leaf	Normal	1.17231e-10	0.999994	1	2	0	1.73045e-10	293.4	170	30
1.5 - Collector Head	014	Serial	-	99.9992	0.998318	0.979654	151	0	147.361	0	0	0
1.5.1 - Carbon Str...	018	Leaf	Normal	27.3936	0.999193	0.994381	121	0	40.4032	171	150	30
1.5.2 - Carbon St...	019	Leaf	Normal	27.3936	0.999193	0.994381	121	0	40.4032	171	150	30
1.5.3 - Bearign A	020	Leaf	Normal	20.9336	0.999639	0.995706	3	0	30.8891	13.87	8	30
1.5.4 - Bearing B	021	Leaf	Normal	20.9336	0.999639	0.995706	3	0	30.8891	13.87	8	30
1.5.5 - Pantograp...	022	Leaf	Normal	0.656277	0.999861	0.999866	45	0	0.9686	87.5	50	30
1.5.6 - Pantograp...	024	Leaf	Normal	0.656277	0.999861	0.999866	45	0	0.9686	87.5	50	30
1.5.7 - Springing ...	025	Leaf	Normal	2.03238	0.999957	0.999589	3	0	2.99988	45.13	20	30

The first column in the table 8.9 shows the pantograph structure from level 1 to level 3. The second column shows the part number of each equipment and component. The third column shows the RBD model configuration. The fourth shows the PDF. The fifth column criticality based on a failure rate index. Based on this column, it´s clear that the collector ahead is the most critical subsystem because impact on 99,99% of the Pantograph failure rate and the most critical components are the carbon strips A/B and the Pantograph Horn A/B which represents around 95% of the Collector Hear failure rate. The sixth column shows the operational availability prediction results. The seventh column shows the reliability prediction results. The eighth column shows the number of PM scheduled. The ninth column failure per equipment. The tenth column shows the number of corrective maintenance. The eleventh columns show the Corrective maintenance cost. The twelfth column shows the preventive maintenance repair cost and the thirteenth column shows the preventive maintenance time.

Despite of all the detailed information about the performance information, it´s also important to understand the LCC cost structure based on elements such as R&D (research and development), Production, Investment, Operation, CM support, PM support, SW support (Software) and disposal as show table 2. In addition, it´s also considered the future & discount, which in this case, was considered 2% discount tax on the LCC calculation.

Table 2: Detailed pantograph cumulative LCC

Short Summary

Cost Elements	Current	% of LCC	Future	% of LCC	Discount	% of LCC	Future & Discount	% of LCC
R & D	0.00	0	0.00	0	0.00	0	0.00	0
Production	1.00	0.000277785	1.00	0.000277785	0.98	0.000333104	0.98	0.000333104
Investment	12.00	0.00333342	12.00	0.00333342	11.76	0.00399724	11.76	0.00399724
Operation	0.00	0	0.00	0	0.00	0	0.00	0
CM Support	42,222.60	11.7288	42,222.60	11.7288	34,520.00	11.7287	34,520.00	11.7287
PM Support	317,755.28	88.2676	317,755.28	88.2676	259,787.72	88.267	259,787.72	88.267
SW Support	0.00	0	0.00	0	0.00	0	0.00	0
Disposal	0.00	0	0.00	0	0.00	0	0.00	0
Total (LCC)	359,990.88	100	359,990.88	100	294,320.46	100	294,320.46	100

Short Summary. Pareto by Future value

Cost Elements	Current	% of LCC	Future	% of LCC	Discount	% of LCC	Future & Discount	% of LCC
PM Support	317,755.28	88.2676	317,755.28	88.2676	259,787.72	88.267	259,787.72	88.267
CM Support	42,222.60	11.7288	42,222.60	11.7288	34,520.00	11.7287	34,520.00	11.7287
Investment	12.00	0.00333342	12.00	0.00333342	11.76	0.00399724	11.76	0.00399724
Production	1.00	0.000277785	1.00	0.000277785	0.98	0.000333104	0.98	0.000333104
Disposal	0.00	0	0.00	0	0.00	0	0.00	0
SW Support	0.00	0	0.00	0	0.00	0	0.00	0
Operation	0.00	0	0.00	0	0.00	0	0.00	0
R & D	0.00	0	0.00	0	0.00	0	0.00	0

In addition to have the cumulative LCC cost it´s also important to define the LCC by year along the operation life cycle, which will be the basis for the LCC target for each year of the operation as shows the table 3.

Table 3: Detailed Pantograph LCC by year

Short Summary by Years (Future value)

Cost Elements	Years																				Total	%
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
R & D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Production	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.000277785
Investment	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.00	0.00333342
Operation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
CM Support	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	2,111.13	42,222.60	11.7288
PM Support	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	15,887.76	317,755.28	88.2676
SW Support	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Disposal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Summary by years	18,011.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	17,998.89	359,990.88	100

After to predict the asset performance and LCC the main objective is to optimize the interval of preventive maintenance to minimize the life cycle cost and maximize the pantograph asset performance. The solution ApmOptmizer enable the preventive maintenance optimization based on the performance target defined to be achieved and the dynamic programming algorithm behind the optimization window as shows figure 6.

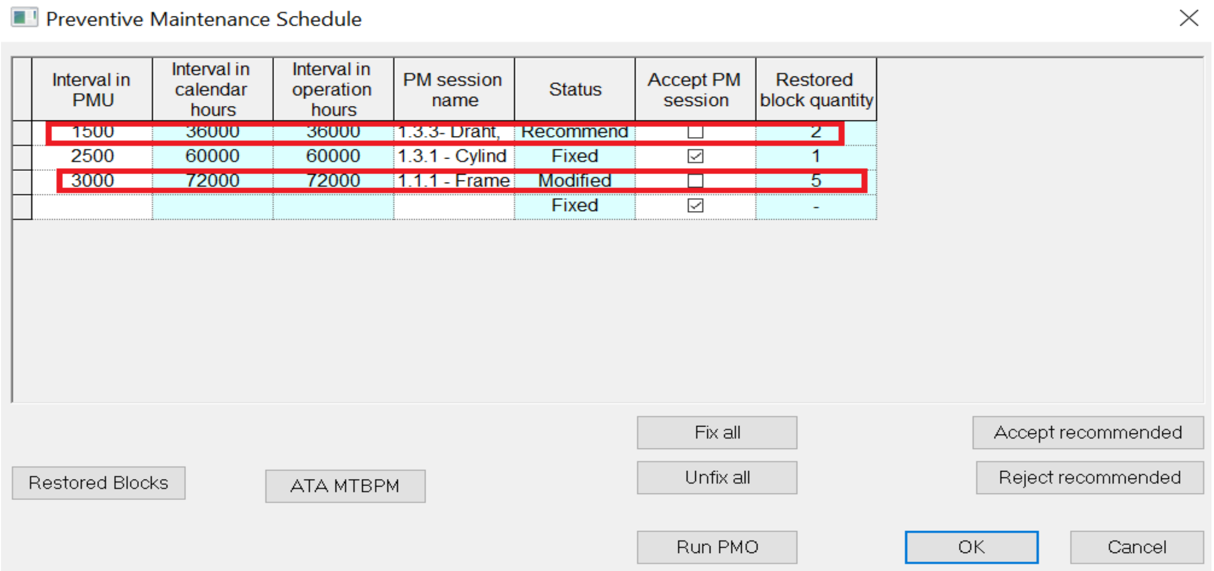


Figure 6: Detailed Pantograph RBD preventive maintenance time interval optimized recommendation

Based on figure 6, once the algorithm recommendation is accepted, the next step is to run again the simulation with the new preventive maintenance interval optimized and check the result as shows table4.

Table 4: Detailed Bogie RBD performance simulation result after optimization.

Reference Designator	Part Number	Reliability Model	Distribution type	Contribution to system FR %	Availability	Mission Reliabil...	Scheduled PM ...	Failures pr...	CM actions for 1 ...	Corrective repa...	Preventi...	Preventi...	Description	Preventi...
Pantograph	Part Number 1	Serial	-	100	0.994655	0.954868	6	1.53723	333.463	0	0	0		0
1 - Frame & Insulator	001	Serial	-	0.00031235	1	1	2	3.888e-06	0.00104717	298.48	298.48	0		0
1.1.2 - Insulator	003	K out of N	-	0.00031235	1	1	0	1.944e-06	0.000523585	298.48	250	0		0
1.1.2 Insulator ...	004	Leaf	Exponential	0.00031235	1	1	0	6.48e-07	0.000174528	298.48	250	30		30
1.1.1 - Frame	008	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	298.48	298.48	30		30
1.2 - Valve Plate	007	Serial	-	0.134652	0.998456	0.999726	0	1.54311	0.45073	0	0	0		0
1.2.1 - Valve Plate	006	Leaf	Normal	0.134652	0.998452	0.999726	0	1.5431	0.450728	1350	1000	30		30
1.3 - Elevation System	009	Serial	-	2.09033e-10	1	1	6	0	7.00795e-10	0	0	0		0
1.3.1 - Cylinder	010	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	101.66	50.17	30		30
1.3.2 - Spring	011	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	50.17	30	30		30
1.3.3- Draht	012	Leaf	Normal	5.22581e-11	0.999989	1	4	0	1.75196e-10	172.98	150	30		30
1.3.4 Insulate Hose	013	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	116.62	80	30		30
1.4 Pantograph Arm	014	Serial	-	1.78245	0.999932	0.999178	2	0	5.97536	0	0	0		0
1.4.3 - Pantograp...	015	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	1342.87	900	30		30
1.4.5 - Guide Rod...	016	Leaf	Normal	0.594133	0.999977	0.999726	0	0	1.99182	293.4	170	30		30
1.4.1 - Power Strap	026	Leaf	Normal	0.594133	0.999977	0.999726	0	0	1.99182	9.33	5	30		30
1.4.2 - Shear fram...	027	Leaf	Exponential	5.22587e-05	1	1	0	0	0.0001752	6.02	4	30		30
1.4.4 - Pantograp...	015	Leaf	Normal	5.22584e-11	0.999994	1	2	0	1.75198e-10	1342.87	900	30		30
1.4.6 - Guide Rod...	016	Leaf	Normal	0.594133	0.999977	0.999726	0	0	1.99182	293.4	170	30		30
1.5 - Collector Head	014	Serial	-	98.0826	0.99626	0.955915	4	0	327.597	0	0	0		0
1.5.1 - Carbon Str...	018	Leaf	Normal	29.49	0.998873	0.986546	0	0	98.7553	171	150	30		30
1.5.2 - Carbon St...	019	Leaf	Normal	29.49	0.998873	0.986546	0	0	98.7553	171	150	30		30
1.5.3 - Bearign A	020	Leaf	Normal	9.75639	0.999627	0.995511	0	0	32.6966	13.87	8	30		30
1.5.4 - Bearing B	021	Leaf	Normal	9.75639	0.999627	0.995511	0	0	32.6966	13.87	8	30		30
1.5.5 - Pantograp...	022	Leaf	Normal	9.79492	0.999625	0.995511	0	0	32.8257	87.5	50	30		30
1.5.6 - Pantograp...	024	Leaf	Normal	9.79492	0.999625	0.995511	0	0	32.8257	87.5	50	30		30
1.5.7 - Springing ...	025	Leaf	Normal	5.22581e-11	0.999989	1	4	0	1.75196e-10	45.13	20	30		30

The first column in the table 4 shows the pantograph structure from level 1 to level 3. The second column shows the part number of each equipment and component. The third column shows the RBD model configuration. The fourth shows the PDF. The fifth column criticality based on a failure rate index. Based on this column, it´s clear that the collector ahead is the most critical subsystem because impact on 98,08% of the Pantograph failure rate and the most critical components are the carbon strips A/B and the Pantograph Horn A/B which represents around 80% of the Collector Hear failure rate. The sixth column shows the operational availability prediction results, 99,46%, which is lower than the previous value 99,67% but still achieves the target 99%. Despite the operational availability than the previous scenario, lower, the LCC is lower than the result before the optimization, which means that the new optimized preventive maintenance interval enables to minimize the LLC as shows the figure 8.24. The seventh column shows the reliability prediction results. The eighth column shows the number of PM scheduled. The ninth column failure per equipment. The tenth column shows the number of corrective maintenance. The eleventh columns show the Corrective maintenance cost. The twelfth column shows the preventive maintenance repair cost and the thirteenth column shows the preventive maintenance time.

The figure 7 shows the trade off analysis comparing all indexes from the first scenario to the second scenario where the Preventive maintenance schedule is optimized. Despite of achieving higher performance (operational availability and reliability) on the first scenario, the optimized scenario enables lower life cycle cost by saving €29.020,84 with only one pantograph. If such values are multiplied by a train fleet of 100 trains the saving will be € 2.902.084,00, Without considering spare part optimization.

Trade off: Reliability - Cost (1 US $)

Scenario	Mark	RAMS parameters							Total Cost	Total investments			Total current cost				
		Mission Reliabilit	MTBCM (h)	Availability	Life Down	Life CM	Life PM	Life inspection		R&D	Production	Investment	Operation	CM support	PM support	SW support	Disposal
Scenario 1	☑	0.97998	1186.91	0.996779	564.2	147.1	161	270	389,011.12	0.00	1.00	22.00	0.00	14,980.59	374,007.52	0.00	0.00
Scenario 1 PM OPT	☑	0.95511	522.587	0.994655	936.4	333.4	6	270	359,990.88	0.00	1.00	12.00	0.00	42,222.60	317,755.28	0.00	0.00

View Graph Close

Figure 7: Detailed Pantograph scenario tradeoff analysis

As a result of the optimization, the pantograph operational will reduce the operational availability from 99.67% to 99.46% in 20 years but will reduce the LCC from €389,011.12 to €359,990.08. The figure 8 shows the different operational availability compared with the correct maintenance and preventive maintenance values.

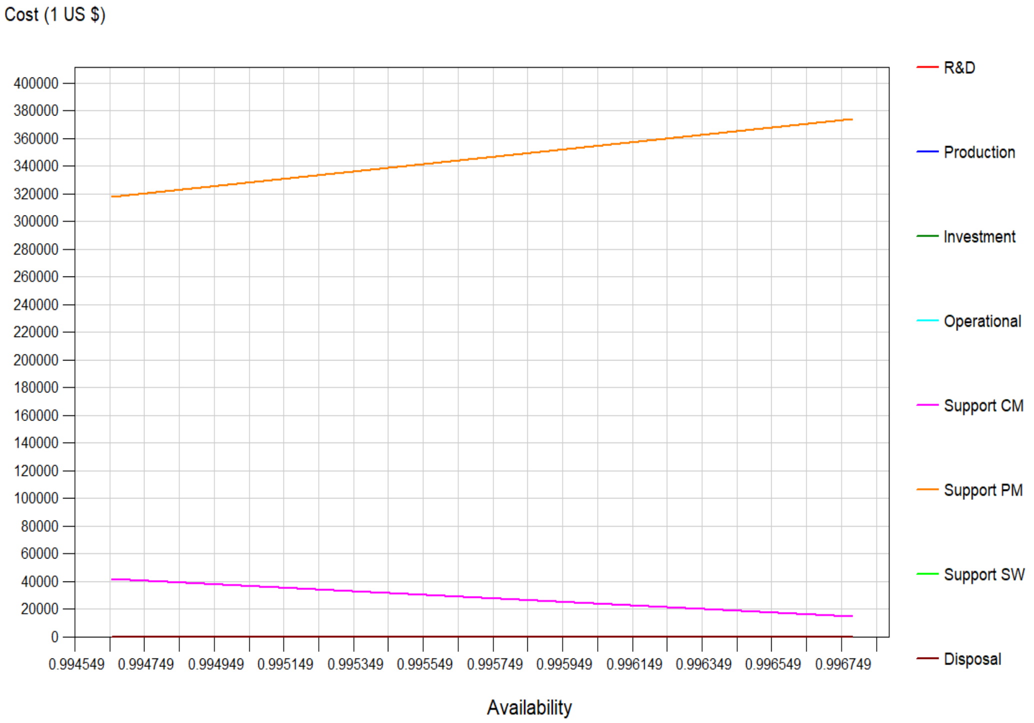


Figure 8: Pantograph Operational availability versus CM and PM cost

5– Conclusion

The ILS model proposed enables to optimize the asset performance and LCC. In order to apply such methodology plenty of failures, repair, maintenance and logistic data are necessary.
The usual reliability engineering methods such as FMEA, RCM, RBI, RAM input are essential to perform the ILS optimization.
In many projects, to implement all such methods requires time and investment, but more important is the culture of ILS as a key success factor to achieve high performance and lower LCC.
In many ILS applications, the optimal solution is not achieved because it required an optimization model, which encompasses all information to define the best inspection and preventative maintenance interval, spare parts levels and resource levels.
As presented in this paper, in order to give an optmized result it´s necessary to have a solution which consider an optmization algorithm code. The RAM analysis nbased on RBD and monte carlo simulation by itself does not provide any optimized soolution. In addtion, it´s necessary to be aware that the idea that optmize each individual equipment will enable to optmized the whole system is false
The case study presented was applied to a pantograph project that the main objective that was considered the logistic effect on system performance and also optimize the asset performance and LCC.
The next step will be to apply this ILS optimal methodology to different railway assets in order to support the asset management in different life cycle phases and optimize the asset performance. The book RAMS and LCC engineerign for railway industry: Analysis, modelling and optimization present the complete concepts concerning the ILS elements as well as additional case study related to the bgie system.

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