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Deliverable D 5.1
Identification of operational constraints

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1. Executive Summary

The LOCATE project aims to develop a generic framework for condition-based and predictive maintenance (CBM) of locomotives bogies. To achieve this aim the research has followed the high-level framework for condition monitoring and diagnostics of machines included in ISO-17359. This has included: the selection of use cases and identification of failure modes, effects and criticality (WP2), identification of parameters to be measured and relevant measurements techniques (WP3). The remaining work packages aim to establish the reference behaviour (WP4) for the selected use cases, the thresholds and rules to apply to the measured and reference behaviour to diagnose a fault and determine the required maintenance actions (WP5) and finally the integration and testing of the developed CBM scheme (WP6).

To support the development of a decision-making framework for the diagnosis and scheduling of bogie maintenance it is important to understand the main operational constraints in maintenance depots which are relevant to the LOCATE project. This deliverable describes the work conducted during Task 5.1 of WP5 to identify the common maintenance activities and relevant information to support the definition of: decision variables, objective functions and several constraints associated with bogie maintenance to support the optimisation of a maintenance decision-making framework in subsequent tasks.

In general, the key constraints consist of technical constraints (e.g. constraints associated with the vehicle type, depot arrangement, resources and spares inventory) and non-technical constraints (e.g. personnel, depot management, competence/skills and working conditions). Although there are some variations in the maintenance planning due to these constraints within different international rolling stock maintainers; the adoption of international standards and interoperability means that they are similar.

Relevant technical and non-technical constraints have been identified by collecting and reviewing current maintenance instructions and programs associated with freight locomotives from Ferrocarrils de la Generalitat de Catalunya (FGC). This will support the definition of objective functions to describe these constraints for inclusion in the maintenance decision framework during the WP5 of the LOCATE project.

2. Abbreviations and acronyms

Abbreviation / Acronyms	Description
CBM	Condition Based Maintenance
FGC	Ferrocarrils de la Generalitat de Catalunya

3. Background

The present document constitutes the Deliverable D5.1 “Identification of operational constraints” as part of the WP5 “Operational behaviour”.

It does not contribute any TD/WA.

4. Objective/Aim

Work package 5 (WP5) of the LOCATE project aims to develop a decisions-making framework for condition-based and predictive maintenance (CBM) of bogies which can be effectively integrated into the current fleet maintenance programme. Initially this will be a generic framework for locomotive bogie maintenance, regardless of the type of locomotive or depot management regime, which will subsequently be applied to the maintenance of the Serie 254 locomotive bogie operated by FGC.

Therefore, this document defines the common maintenance activities, decision variables and constraints associated with train maintenance planning. This includes both technical, e.g. associated with depot, resources and spares inventory, and non-technical, e.g. daily services, human resources, competence/skills and working conditions, constraints. These have been identified following discussions with maintainers and a review of available literature and relevant standards.

These common constraints and derived maintenance planning activities are based on the following generic maintenance process model.

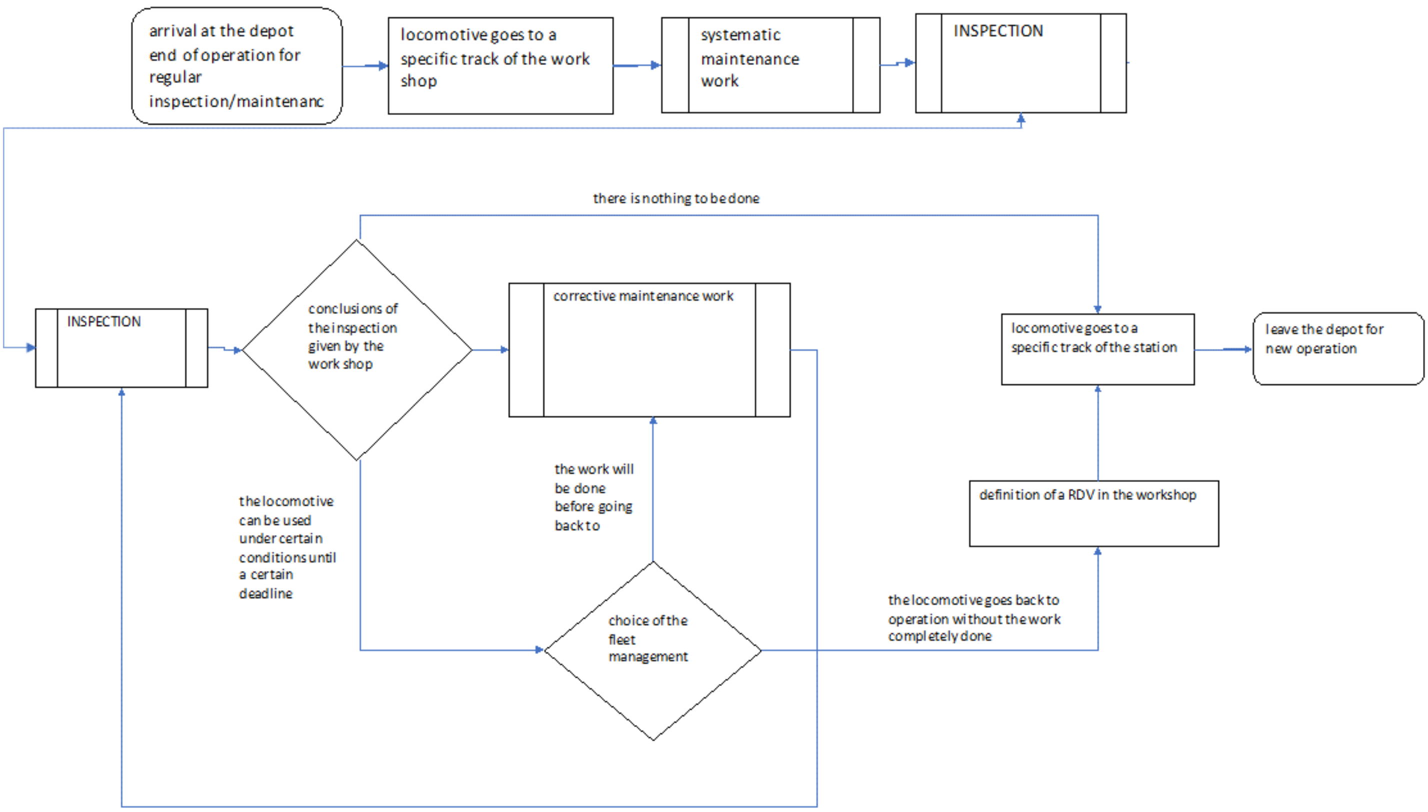

Figure 1 Generic maintenance process model

In general, the maintenance process starts immediately after the locomotive arrives at depot. Then the locomotive will be inspected systematically, following some standardised rules. Depending on the results of the inspection, some components/subsystems will be repaired or replaced according to the severity of the observed fault. After the maintenance is carried out, the locomotive will be checked again to ensure the quality of maintenance and will leave the depot to start a new cycle of operation.

In addition, the key decisions, priorities and variables associated with the bogie maintenance process at

FGC, for the Series 254 locomotive bogie, have also been identified to support the development of the decision-making framework and to establish areas for optimisation during subsequent tasks in WP5 of LOCATE.

5. Key operational and economic constraints

In general, the maintenance of a locomotive should be compliant with various national and international standards and regulations, e.g. EN 17023 and EN 16910. It is clear from reviewing the relevant standards and best-practice in maintenance planning that there are several common operational factors which influence the development and execution of a maintenance plan. These factors are summarised below:

- *Operational plan* – In spite of its name, an operational plan denotes the number of trains engaged in commercial service on a daily, monthly or annual basis. The operational plan is usually aligned with the company's business plan and defines the required fleet availability (to achieve the required operational commitment and provision for reserve trains to meet maintenance demand or special customer requirements) and maintenance requirements.
- *Maintenance budget* – A maintenance budget is prepared for the maintenance work in consideration of the workload (operational plan and availability), unit price and comparable standards to achieve the maintenance requirements.
- *Maintenance personnel* – The maintenance plan is subject to the number and competency of necessary maintenance personnel. This becomes more important as maintenance is shifted from a preventive to a condition-based strategy, where a different range of skills may be required at different times.
- *Operation of the maintenance depot* – This includes how the technical maintenance is planned within the depot. For example, preventive, corrective and condition-based maintenance.
- *Protocol for emergency (accident) repair* – This is the protocol/procedure for how accidents and emergency repairs are dealt with in the depot and accommodated in the maintenance plan.
- *Seasonal variations* – Maintenance and operating constraints can also be influenced by the period of the year. For example; impact of weather conditions, e.g. summer – increase in usage and maintenance of air-conditioning systems, winter – efficiency of braking system, increase on low-adhesion events, lower availability of staff during certain periods of the year and access to spare parts. Therefore, it may be appropriate to change a maintenance plan based on the season of the year, e.g. reduction in wheel re-profiling interval in autumn.
- *Routing and stabling* – A maintenance plan needs to consider the various shunting and positioning of the train during operations. Factors include: traffic between terminal stations and maintenance sites; maintenance undertaken at various locations on the route (e.g. safety equipment test points, cleaning area, sand replenishing and re-fuelling points). The layout of the maintenance depot also plays a key role, for example the location of the vehicle stabling and maintenance lines.
- *Heavy maintenance operations* – Heavy maintenance actions, which includes the replacement/renewal of large components (e.g. diesel engines, transformers), are generally undertaken on an interval basis and therefore can be scheduled into the maintenance plan. However, these should be spread out during the course of the year and linked with other (non-heavy) maintenance actions. This may impact on maintenance costs and fleet availability.
- *Spare parts* – A number of constraints relate to the consumption, obsolescence and quantity of spare parts. Consumption of spares varies through the year due to the constraints identified above

– inventory control model should therefore be implemented. Obsolescence of components should be monitored with the various suppliers. The quantity of parts required in stock should be optimised in coordination with the service requirements and depot capacity.

The maintenance framework to be developed during LOCATE will need to consider these operational constraints in the context of the current maintenance practices, key decisions, priorities and variables associated with bogie maintenance at FGC. These are investigated in further detail in the subsequent sections.

6. Introduction of current maintenance programme

Ferrocarrils de la Generalitat de Catalunya ("Catalan Government Railways"), FGC, is a railway company which operates several unconnected lines in Catalonia, Spain. In addition to passenger services, FGC currently operates two types of freight services on the Llobregat–Anoia line; one of which carries potash and salt from Súria and Sallent respectively to Martorell and the Port of Barcelona, and the other carries cars from SEAT's main factory in Martorell to the Port of Barcelona. In the LOCATE project, we will focus on the maintenance of the Series 254 locomotive bogies operating on the line from Martorell to the Port of Barcelona and maintained at the depot located at Martorell.

The main focus of the current maintenance regime adopted by FGC is to ensure availability of the locomotive to meet the operational demand and therefore the time in the depot is minimised. To achieve this, the failed subsystems/components are currently replaced with spares and repaired in the depot off the locomotive. This provides additional constraints in terms of the number of spares required to service the three locomotives and the quality of the repairs. These constraints are discussed in further detail in the Section 6 of the report.

6.1. Maintenance programmes

Currently, the bogies of the Series 254 locomotive are periodically maintained at the depot. Scheduled maintenance activities (e.g. inspection, replenishing of fluids and identified corrective actions etc.) are performed at a series of pre-established intervals. This is internally referred to as "intervention" and will form part of the "maintenance programme" in the LOCATE project. Overall, there are five levels of intervention defined depending on the frequency (e.g. distance and time based) of the programme and the severity of the intervention (e.g. criticality). Table 1 below lists the basic intervention types of these programmes: Safety, Basic, Level 1, Level 2 and General Revision.

Table 1 Current maintenance programmes (interventions)

		Intervention type				
Frequency		**Safety**	**Basic**	**Level 1**	**Level 2**	**General Revision**
Distance [km]	**Min**	3500	10500	43000	172000	718000
	Max	4500	13500	53000	212000	818000
Time	**Average**	1 month	3 months	1 year	4 years	16 years

Each programme includes a list of pre-defined activities, which generally consist of taking observations and measures to monitor the condition of specific components. For example, the activities on the bogie frame in each programme are listed in Table 2.

Table 2 Activities of Bogie frame maintenance

	Intervention type				
BOGIE FRAME	**Sft**	**Bsc**	**Lvl 1**	**Lvl 2**	**GenRev**
Inspect to detect fissures and deformations	x	x	x	x	x
Inspect fissures and deformations in the fastener of the DIMFAP	x	x	x	x	x
Inspect elements fastened under bogie frame		x	x	x	x
General and NDT revision					x

For instance, in the current practice there are two activities associated with the Bogie Frame in the programme named as Safety interventions: 1) inspect to detect fissures and deformations; 2) inspect fissures and deformations in the fastener of the DIMFAP.

The information obtained from the inspections of the component condition is assessed (against physical thresholds/rules or previous experience of imminent failures) and additional maintenance activities are programmed based on the reported condition. To complete each activity, it can often take several steps/tasks for example, (a) check/measure, (b) repair or (c) replace and (d) report/log/document. In the LOCATE project, we will keep these in a simple architecture for the purpose of further analysis and optimisation, as illustrated in Figure 1.

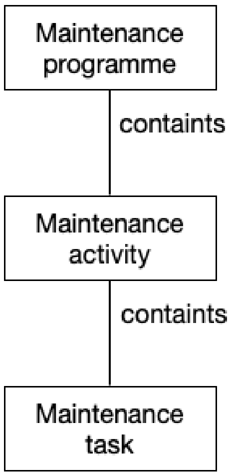

Figure 2 Maintenace concepts

The introduction of CBM through the application of sensors on the critical components during the LOCATE project will provide the opportunity to adjust the programme of inspection as the 'health status' of these components will be continuously monitored during operations

6.2. Capacity of Martorell depot

At the depot, FGC currently operate with three maintenance teams, which are capable of carrying out maintenance of the locomotive bogie. Each team consists of 6 technicians. When a bogie is in the depot for maintenance, these technicians are assigned to different roles. The skills and competency of these technicians will be an important input to the maintenance framework developed during LOCATE, to ensure that the appropriate resources are available to undertake the required tasks identified by the decision model. This is potentially be more important with the application of CBM as components, which are older but still performing adequately, remain in operation longer.

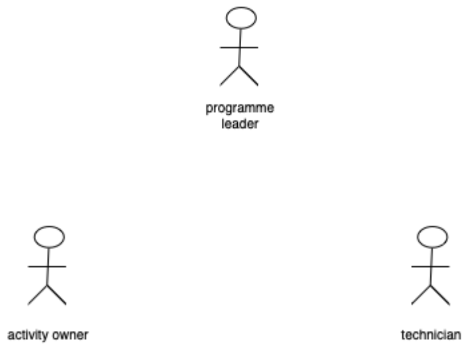

Figure 3 Roles in maintenance

In the current maintenance practices, the resources are assigned to the maintenance team members. Table 3 shows the resource requirements for each programme.

Table 3 Resource requirements of each maintenance programme

	Intervention type			
	Safety	Basic	Level 1	Level 2
Number of shifts (8h/shift)	1	3	6	8
Number of technicians	3	3	3	3
Total inspection time (h)	24	72	144	192

For example, in Safety interventions, the total time spent on all maintenance tasks is required to be completed in 24 hours. Once the roles in the maintenance team are clear, the maintenance can be ideally completed within 8 hours (3 technicians working in parallel). In reality, there are some other constraints attached to each task, for example the availability of maintenance staff with the required skills (e.g. technician) and the dependencies among the maintenance tasks etc.

The LOCATE project aims to optimise the current maintenance procedures to improve routine maintenance tasks that consume resources. To achieve this further information on the areas where resource is spent and where additional resource is needed for each intervention type will be required to input into the maintenance decision framework.

In the subsequent sections, the constraints associated with the current maintenance programme have been identified which might provide some opportunity for improvements in efficiency and productivity of maintenance.

6.3. Current maintenance decision process – failure detection, intervention planning and execution

To support the future implementation of predictive CBM it is essential to understand the current decision process, along with the tactical and technical strategies in the depot and the day-to-day operation of a locomotive. This will enable a true assessment of any benefit from moving to a predictive CBM regime.

Currently, depot intervention planning is generated via a mixture of on-board diagnostic system alarms, reports of abnormal behaviour observed by the train operational crew during service and scheduled periodic inspection of component condition. Whilst in operation a locomotive may encounter varying degrees of failure risk ranging from safety critical to operationally critical that determine the course of action for maintenance interventions in the depot. Safety critical events are operationally damaging and typically warrant immediate corrective action resulting in alterations to established maintenance regimes impacting on the planned operations of the locomotive. Typically, the locomotive is currently only stopped for safety critical failures, with other failures planned into the current maintenance activities. Whilst these events are not beyond a degree of predictability, they are nonetheless reactionary and not governed by a systematic plan and execution of strategic goals of reducing costs and improving the efficiency of locomotive, depot and resources of the maintainer.

The following table provides a typical example of the warnings/failures which are generated for a similar locomotive to the FGC Series 254 locomotive. As previously mentioned, these are either reported by on-board diagnostic system, the train crew during operation or identified through inspection. All of which result in depot interventions, maintenance planning and execution. Similar to that presented in Table 4 will be obtained from FGC for the selected use cases to support maintenance optimisation.

The LOCATE WP5 aims to propose and develop a decision-making framework which optimise the current maintenance procedures based on the sensory data and outputs from simulation models.

Table 4 Failure modes and maintenance information

Code	Subsystem	Failure Mode/ Recorded Event	Repeatability	Maintenance Priority	Category					Locomotive Model					Intervention Type				
					Internal event	Technical defect	Operating warning	Severe warning	Breakdown	Class A	Class B	Class HF	Class Z	Model X	Safety	Basic	Level 1	Level 2	General Revision
0002	Brake	MVB coupling card BSG1.1 defective		2	X								X		X	X	X	X	X
0003	Brake	'brake / release' contacts disturbed		2			X			X	X		X		X	X	X	X	X
0004	Brake	Analog converter: A pressure disturbed		6				X							X	X	X	X	X
0008	Brake	Control deviation analog converter		6	X						X					X		X	X
0009	Brake	Analog input' HL pressure sensor defective		2		X							X			X	X	X	X
000F	Brake	'Control' brake / release 'disrupted		6		X			X				X			X	X	X	X
0022	Brake	Module xxx is off or not available	X	6	X										X		X	X	X
0023	Brake	Contact for indicator lights of the PB disrupted		6				X											X
…	…	…																	

7. Maintenance constraints in LOCATE project

This section explores the constraints associated with bogie maintenance in the LOCATE project. Section 7.1 focuses on the technical constraints, Section 7.2 on the operational constraints and Section 7.3 on the economic constraints.

7.1. Technical constraints

Technical constrains include constraints associated with the life-cycle of maintenance programme, with the potential dependencies among maintenance tasks, capacity of the depot and maintenance team, with the replacement and stocking policy and the verification of maintenance quality.

7.1.1. The life-cycle of maintenance programme

Once the locomotive returns to the depot, there is a schedule for when the required maintenance programme should be completed. The life-cycle of maintenance programmes includes several stages: plan and allocation of resources, completion of maintenance tasks, verification of maintenance and documentation of maintenance programme. The estimated time requirement for each stage is listed in the Table 5 below.

Table 5 Maintenance programme life-cycle

	Number of working days				
	Safety	**Basic**	**Level 1**	**Level 2**	**GenRev**
Plan and allocation	0.5	0.5	1	1	1
Completion of tasks	1	1.5	2	3	5
Verification	1	1.5	2	3	5
Documentation	0.5	0.5	1	1	1
Total	**2**	**4**	**6**	**8**	**12**

Through the introduction of a CBM framework it is possible that some of the tasks in the maintenance programme life-cycle could be reduced, for example the replacement of inspection with condition measurements.

7.1.2. Dependencies among maintenance tasks

As a whole, the bogie will be maintained entirely within each maintenance programme. In practice, the maintenance is completed at a subsystem/component level. Some maintenance task, for example inspection, may require specialist equipment, for example an ultrasound detector. The dependencies among maintenance tasks will determine the maintenance job workflow. The identified dependencies are categorised as follows:

- Physical dependency: two subsystems are physical connected. To inspect one, the other has to be dismounted/inspected first.
- Functional dependency: two subsystems are co-operated to complete a function. There is an order or interaction between subsystems to inspect them.
- Platform dependency: the completion of maintenance on two subsystems depends on the same equipment or platform.
- Technician dependency: only certain type of technician role can complete a maintenance task.

7.1.3. Capacity of depot and maintenance team

The depot can operate in different modes of capacity. Depending on the maintenance task, the depot manager will divide the maintenance work into small groups, and set the time required for each task as Tn. Then Total time for each task is Tt = Σ Tn (n = 1 to n). In order to determine Tn, each personnel must report the work to be carried out and the amount of time required to complete it.

Example: When three maintenance personnel are allocated for bogie (P1, P2 and P3)

	T1			T2			T3			T4		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
day1	5	5	5									
day2				5	5	5						
day3				2	5	3	3		2			
day4				2	5	3	3		2			
day5							5	5	5			
day6										5	5	5
day7										5	5	5
total	15			35			25			30		

According to the above formula, Tt = T1+T2+T3+T4= 105, the Total work time per year is:

Ty= Tt*Ny+α

Where:
Ny: The number of trains maintained per year and
α: Backup time for the maintenance.

At FGC, Backup time is usually set to be 40% to 50% of Ty time (including training, cleaning of workshop, meetings, research, etc.). In this case, backup time α is 12 to 25% of Ty. Total working hours of personnel per year: Pt= 8*(365- d1-d2-d3-d4)

Where:
d1: Number of weekends in a year
d2: Annual national holidays
d3: Annual paid holidays
d4: National holidays for various reasons
"8": represents the number of working hours in a day in FGC.

Thus, the required number of personnel is: Pn= Ty/Pt

The capacity of depot also varies in different seasons. Over a year, it is assumed that the depot should be able to service two locomotives at one time. In different working conditions (e.g. shorter working day in the summer), the depot can also operate in a degraded mode with limits on tasks completed. In the degraded mode, it is assumed that the capacity of depot will reduce to 50% of its full capacity. The timesheet of maintenance teams are also adjusted based on rules.

7.1.4. Policy on replacement and stocking

The depot has implemented a policy of replacement and repair of faulty components/subsystems off the locomotive, to minimise the time the locomotive is in the depot. Meanwhile, in order to control the cost, the depot also has a policy of keep a stock of spare subsystems/components. The quantitative method to decide initial spare parts are based on the Recommend Spare Parts List (RSPL), the subsystem's failure rates (λ) or the Mean Time Between Failure (MTBF). The current decision on spare parts is made based on a method which takes the criticality of part and the long-term availability from market into the consideration.

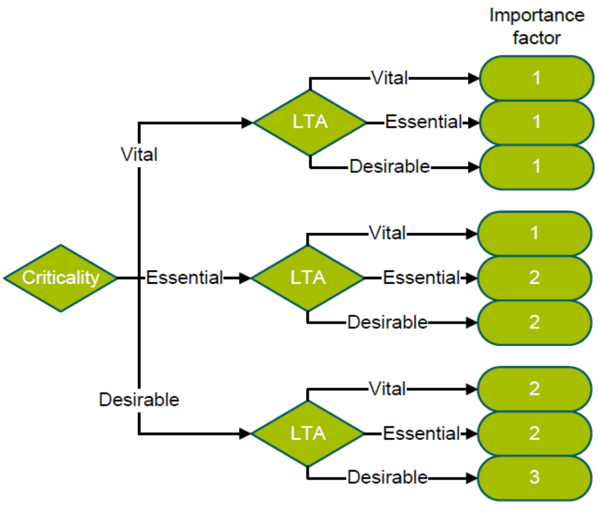

Figure 4 Decision making process of spare parts

The entire decision-making process is a logic tree, and the outcomes are the importance factors, e.g. 1 – very important; 3 – least important. At FGC, it is believed that the information on spare parts are managed in a database and further information on the specific rules for managing the spares inventory will be required to support the development of the LOCATE maintenance framework. Typical database entries are provided in Table 7 below.

Table 7 Component spares inventory

Subsystem	Spare stock	
	Repaired	**New**
Wheelset	3	3
Traction Unit – model xxx	0	1
…	…	…

7.1.5. Verification of maintenance quality

Typically, different subsystems and components will require different threshold and rules for triggering a maintenance activity. Moreover, due to the policy of reusing repaired components, the threshold of a repaired component may not be the same as a new one. The following table provides some typical examples of rules for maintenance activities for the selected subsystems. Further work during Task 5.2 (and reported in D5.2) will identify the current (or typical) thresholds and rules applied to each of the use cases. These will be replaced with information (either physical measurements or data features) from the measured or model data in WP3 and WP4.

Table 8 Maintenance quality control

Subsystem	Maintenance activities	Maintenance tasks	Safety limits for new component	Safety limits for repaired component
Bogie frame	Inspect to detect deformations	Repair/fix		
	Non-destructive testing for fatigue cracking	Replace	Bogie crack severity and location	
Wheelset	Visual inspection for wear and tear	Reprofile wheel tread	Flange height/thickness Damage severity	N/A
	Measure wheel diameter	Renew wheelset	Minimum wheel diameter	N/A
	Ultrasonic axle testing	Renew wheelset	Axle crack severity	N/A
Electric traction engine	Check for unusual noises	Repair		
	Inspect condition of collector, bushes etc	Replace		
	Inspect robustness of electrical connectors	Repair		
	Clean using pressurised air	Cleaning		
	Check gear lubrication	Replace		
Suspension system	Check suspension height	Adjust suspension height	Suspension height limits	
	Inspect suspension component condition	Replace		
	Check for fluid leaks	Repair/replace		
	Clean and testing	Cleaning		
Braking system	Check for air leaks	Repair		
	Clean and apply grease	Cleaning		

7.2. Operational constraints

In order to develop an optimised plan and schedule of the required maintenance activities, especially the maintenance tasks, it is critical in CBM to have the ability to estimate the next failure (or maintenance event). This requires significant information of how the network and locomotives are operated, and the characteristics of the different train journeys. The necessary information includes:

- Usage of locomotives (frequency and load)
- Maintenance activities undertaken following each service (e.g. re-fuelling, inspections)
- Typical departure, arrival and dwell times
- Tasks undertaken at each dwell point (if any)
- Geographical information of network (gradient, radius or curves, speed limits)
- Typical traction and braking profiles

7.3. Economic constraints

There are always some economic constraints attached to maintenance activities, for example annual maintenance budget, cost of spares, etc. In the LOCATE project, we have identified some initial economic constraints:

- Cost of each maintenance action
- Cost and constraints on human resources
- Cost, including logistics, of spare parts
- Cost of shunting
- Cost of locomotive out-of-service

In addition, there is a priority/importance index to indicate which factors are more important in the case where a trade-off between undertaking certain tasks is required.

7.4. Factors influencing condition monitoring

In addition to the constraints associated with bogie maintenance discussed above, a number of factors that may influence the application of the proposed condition monitoring system will also need to be considered. These factors are summarised in ISO-17359 and have been considered in the definition of the system requirements in WP2 and sensor specifications in WP3. These include accuracy of the monitored parameters, operating conditions during monitoring, monitoring interval, data sampling rate and staff training.

8. Discussion and conclusions

To support the development of a condition based decision-making framework for a locomotive bogie, the high-level approach defined in ISO-17359 [2] has been adopted, as summarised in Appendix A. This has included the selection of specific use cases and identification of failure modes, effects and criticality (WP2), identification of parameters to be measured and relevant measurements techniques (WP3).

During Task 5.1 and 5.2 of WP5, the current failure modes for the selected use cases, as defined in WP2, have been reviewed to identify the current means of detection and the relevant threshold which trigger the required maintenance actions. These will be combined with the operational constraints identified in this report to support the development of a decision-making framework during Task 5.3 and 5.4. The replacement of existing detection methods (e.g. visual inspection) with the selected CM data within the decision-making framework will be evaluated in Tasks 5.2 and 5.3, by matching the observed faults to the proposed measurements parameters.

Following this, Task 5.2 will define initial thresholds (or alert criteria) based on the initial outputs from the pre-liminary measurement campaign (WP3) and modelling (WP4). Subsequent measurements will confirm the quality of the measurements and selected thresholds. Prognostic techniques (or rules) will also be established to determine the required maintenance actions and timeframe. The accuracy of the prognosis will be confirmed by depot staff and modified to improve the confidence level in the developed decision-making framework

The current maintenance programme associated with bogie maintenance at FGC has been reviewed. This includes general inspection, maintenance and renewal activities. The key constraints that will need to be considering during subsequent tasks in WP5 to support the development of CBM decision-framework have been identified and are summarised below.

8.1. Conclusions

The objective of this task was to identify the common decision variables, constraints and non-negativity restrictions associated with bogie maintenance. Typically, these consist of technical (e.g. associated with the type of locomotive, depot layout and capacity, resources and spares inventory) and non-technical constraints (e.g. personnel, depot management, competence/skills and working conditions). The general maintenance instructions, programs and failure records associated with freight locomotives and the actual maintenance practices at the FGC depot have been reviewed. The key constraints related to the maintenance of locomotive have been identified and summarised in this deliverable. These include a mixture of:

- Operational constraints – business model of FGC, service requirements, depot management, resource requirements and spares inventory policy
- Technical constraints – type of locomotive, regulations/requirements of maintenance related to the select component/sub-system
- Economic constraints – specific budget of maintenance

Although there are some variations in the maintenance planning due with the constraints of different international rolling stock maintainers; the adoption of international standards and interoperability means that they are similar.

The current maintenance regime for the FGC Series 254 locomotive has been reviewed to identify the specific constraints and dependencies for selected use cases. The current regime focuses on the safety and availability of the locomotive and includes the replacement and repair of components off the vehicle. This makes the planning of spares more important, especially when moving to a CBM approach (where components may be in-service for a longer period). Examples of typical maintenance threshold/rules and resulting maintenance activities have been provided – this will be developed further during Task 5.2 and reported in deliverable D5.2 along with the threshold/rules to be applied in the maintenance decisions framework, when combined with monitoring data.

Finally, specific data requirements have been identified which will support the definition of objective functions to describe these constraints for inclusion in the maintenance decision framework during the WP5 of the LOCATE project.

9. References

[1] A. Martinetti, A.J.J. Braaksm, J. Ziggers, and L.A.M van Dongen. Initial spare parts assortment decision making for rolling stock maintenance: a structured approach, in Proceedings of the 49th ESReDA Seminar, Brussels, Belgium, October 29-30, 201.
[2] ISO-17359 (2018), Condition monitoring and diagnostics of machines, 28th February 2018.

Appendix A – Condition monitoring procedure flowchart