Deliverable D4.10
Tailored decision support for track and vehicle maintenance through conversion of data to information

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Lead contractor

IFSTTAR

Contributors

ADS,
UIC,
TÜ Delft

Project Coordinator

University of Sheffield, USFD
Executive Summary

Three monitoring techniques have been developed in the framework of tasks T4.1, T4.2 and T4.3 of NeTIRail-INFRA project. The first technique, developed within T4.1, is based on versatile and low-cost modules that allows for measuring the vibrations/noise produced by the interaction between the railroad tracks and wheels rolling units in some punctual locations along the track (welding, S&C, etc.). Namely, vibration effects are generated by the static axle loads moving along the track and by the dynamic forces which arises in the presence of harmonic or non-harmonic wheels and rails irregularities. The second technique, developed and tested within T4.2, is based on an axle box acceleration (ABA) system which is installed in a passenger train. Based on the accelerations generated by the track irregularities, the most critical locations can be detected, which provides a valuable decision making support in terms of maintenance and safety. For instance, the developed technique and field test validation of the detection of welds that need special attention and corrugation. The third technique is based on mobile apps and their corresponding services that take advantage of smartphone low cost sensors (accelerometer, gyroscope, etc.) and allow for measuring linear and angular accelerations on-board trains in relation with ride comfort.

These techniques address different and complementary issues pertaining to track (and rolling stock) health monitoring and ride comfort, and allow for detecting various defects on both the track (linear sections and switches & crossings) and rolling stock. They generate large amounts of data that need to be handled to extract valuable monitoring information. In this deliverable, we will recall the main features of the techniques and will provide a detailed description of the data produced, while specifying its organisation, and discuss the way to perform monitoring based on the generated data. In fact, the aim of T4.5 task is to define a data management framework that ensures a homogeneous and harmonized treatment of the produced data. Namely, adequate data structures are developed and specified to encode the various monitoring data produced. The standard meta-data established...
allows interoperability of the whole data produced by the tools developed within T4.1, T4.2 and T4.3 and offers a documented and reference basis that makes it possible to integrate the various monitoring data and extract the relevant monitoring information as a support for decision making.

The extraction of useful monitoring information is based on adequate data filtering and analysis that fulfil the relevant standards and guidelines and allow for distinguishing the urgent situations that need a prompt reaction to prevent safety issues, and long term tracking of the infrastructure status and defects toward optimizing infrastructure operation and maintenance, in line with the high level targets of NeTIRail-INFRA. We have deliberately chosen to de-corrrelate between the encoding of monitoring data and its analysis to infer monitoring information. Such a choice offers various benefits, that will be discussed in the relevant sections of the report.

As specified in the grant agreement, this task contributes to the standardization of monitoring. Thereby, from that point of view, the established framework has been developed elaborated while targeting RailTopoModel (RTM) standard that is currently under development. RTM is a generic railway infrastructure data model that aims to support current and future business usages and needs. The underlying idea behind targeting RTM is twofold: 1) to bring a contribution to this development regarding monitoring and measuring activities in general, and 2) to ensure interoperability with further monitoring techniques. The latest, being also an objective of WP6. Thus, with this task, we create synergies between different efforts in the NeTIRail-INFRA project.

The report is organized as follows: In Chapter 1, we introduce some preliminary concepts and notations that are needed in the sequel to discuss the contribution. Chapter 2 is dedicated to the development of our monitoring data model. Namely, after recalling the underlying motivation and the main objectives through such a model, we discuss the formalism used to set up the model and then progressively discuss the model features. Then chapters 3, 4 and 5 review the three monitoring techniques developed within T4.1, T4.2 and T4.3, respectively. Let us recall that these techniques are subject to our work in task T4.5. Namely, besides recalling the major features of each technique, we shall focus on the monitoring data generated by the developed tools. In particular, we will establish a detailed specification of these data and provide the logical architecture that supports their organisation. In addition, we will iteratively discuss the way to perform the monitoring based on the produced data. In Chapter 6, we discuss the integration of the various monitoring data and how valuable management information can be derived on the basis of the developed framework. Finally, some concluding remarks are given in Chapter 6.

The work completed in Task 4.5 has been carried out as described in the NeTIRail grant agreement without deviation and is presented in this deliverable.
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## Abbreviations and acronyms

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<td>Axle box acceleration</td>
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<td>DB</td>
<td>Data base</td>
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<td>GUI</td>
<td>Graphical User interface</td>
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<td>IT</td>
<td>Information Technology</td>
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<td>OCL</td>
<td>Object Constraint Language</td>
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<td>Object Oriented Software Engineering</td>
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<td>RMS</td>
<td>Root mean square</td>
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<td>RailTopoModel</td>
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<tr>
<td>SQL</td>
<td><strong>Structured Query Language</strong></td>
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1 Preliminaries

In this section we will introduce some preliminary concepts that will be useful in the sequel to explain the motivation of this task and discuss the developed framework. These concepts are mainly pertaining to data structuration, modelling and analysis.

1.1 Data vs. Information

From an etymological point of view, on one hand "Data" comes from "datum", which is a singular Latin word that means "something given". Its early usage dates back to the 1600s. Then, later on, "data" has been introduced to designate the plural of datum. On the other hand, "Information" is an older word that dates back to the 1300s and finds its origin in Old French and Middle English. It designates "the act of informing". The classical usage is often in regard to education, instruction, or other knowledge communication.

In fact, there is a subtle difference between data and information. Data can be referred to as some original facts or details from which information is derived. Individual pieces of data are rarely useful alone. Data needs to be put into some context to become information. Such a context gives the circumstances in which data has been generated/gathered, the items concerned by the data, etc. Phrased differently, data is raw, unorganized facts that need to be processed. Data can be something simple and seemingly random, it is often useless until it is organized in some intelligible way. When it is processed, organized, structured or presented in a given context it becomes useful, therefore called information since it brings some knowledge on some items.

Let us take the example of squat and corrugation detection and monitoring along a railway section. The isolated values of the vertical and longitudinal acceleration correspond to raw data. However, when the context (speed of measurement, track characteristics, traffic type/density, etc.) is defined and the data gathered is organized (location, time, etc.), information can be inferred regarding the existence of some track defects (squats, corrugation, under-quality welds, etc.), and also regarding the evolution of the defects in time according to various parameters (traffic, weather, etc.). It is clear here that the raw values of acceleration without adequate organization and adequate correlation with further factors do not bring valuable knowledge about the status of the concerned track section.

1.1 Data fusion / Data integration / Data aggregation

In some applications such as, for instance, railway monitoring, data are generated by more than one data source and need to be integrated to produce more consistent, accurate and useful information than that provided by any individual data source. This process is called Data fusion.

Depending on the processing stage at which fusion takes place, data fusion processes can be classified as low, intermediate, or high (Klein et al., 2004). In general, low-level data fusion combines several
sources of raw data to produce new raw data. The expectation is that fused data brings more information in more synthetic way compared to the original inputs.

For example, if we refer to the NeTIRail-INFRA context, fusion of data generated by an accelerometer that measures the vibrations induced by wheel/track contact and the location generated by a GPS/GNSS sensor is a sort of multi-sensor data fusion.

The term Data integration is sometimes used to mean data fusion, typically in the geospatial domain where, often, diverse data sets need be combined in a unified (fused) data set. However, in some applications, differences in the usage of the two terms apply. For instance, in business intelligence data integration is used to describe the combining of data, whereas data fusion is integration followed by reduction or replacement. Data integration might be viewed as set combination wherein the larger set is retained, whereas fusion is a set reduction technique with improved confidence.

Finally, Data aggregation is the compiling of information from databases with intent to prepare combined datasets for data processing (Stanley et al., 2003), (Pierce et al., 2005), (Ledig et al., 2007).

1.2 Data model

Information systems have to manage large amounts of data that could be more or less structured. Data models offer an abstract description/formalization that explicitly specifies the structural organization of data, their manipulation and how they relate to one another and to properties of the real world entities. Therefore, data models are main artefacts that underlay information systems. In practice, data models are specified in a data modelling notation, which is often graphical in form, such as, for instance, UML (Unified Modelling Language) which is a standard modelling formalism that is widely used in various domains (UML).

According to ANSI (ANSI, 1975), data model can be of three types:

- Physical data models: that focus on the physical means used for data storage. Basically, this involves HD partitions, tablespaces, CPUs, etc.

Conceptual data model: describes the semantics of the domain concerned by the model, such as, for instance, railway infrastructure, health monitoring, warehouses, and so on. This consists of entity classes, representing types of significant items in the domain, and relationship assertions about the associations between entity classes. A conceptual schema specifies the kinds of facts or propositions that can be expressed using the model. In that sense, it defines the allowed expressions in an artificial formalism while limiting the scope to the domain concerned by the model.

Logical data model: that describes the semantics, as represented by a particular data manipulation technology. A logical data model gives a detailed description of the data, without caring about the way in which they will be physically implemented in the database. Features of a logical data model include: all entities and relationships among them, all the associated attributes for each entity, the primary key for each entity, foreign keys.
1.3 Meta-Data

In Greek, Meta prefix means "after" or "beyond", but its meaning in epistemology is rather "about". In most information technology usages Meta prefix means "an underlying definition or description." Accordingly, Metadata is data that describes and/or provides information about other data, regarding some aspects. Metadata can be categorized in three distinct types:

- Descriptive metadata describes a resource for purposes such as discovery and identification. For example, it can include elements such as title, abstract, authors, and keywords.

Structural metadata is metadata that provides description about containers of data and indicates how compound objects are put together, for example, for a book the number of pages that form chapters. It describes the types, versions, relationships and other characteristics of digital materials.

Administrative metadata provides information that can be useful for managing a resource, such as the creation date, the creation way, the access rules to some information, etc.

In the context of railway monitoring data, associated Metadata can include, for instance, the location where the (sensing) measure was made, its date and time, the used tool/mean to perform the measurement, the relevant standard or guidelines followed, the file size, etc.

1.4 Data interoperability

At a general level, systems’ interoperability refers to the ability of two or more systems to communicate with each other. We say that they exhibit syntactic interoperability when using specified data formats and communication protocols.

At a more operational level, data interoperability addresses the ability of systems and services that create, exchange and consume data to have clear, shared expectations for the contents, context and meaning of that data. In other terms, it refers to the exchange of information that preserves the meaning and relationships of the data exchanged.

1.5 RailTopoModel (RTM)

RailTopoModel is a logical object model that is being developed to standardize the representation of railway infrastructure-related data. The design process involves various stakeholders from railway and IT domains and aims to cope with more and more facets of railway infrastructure (architecture/structure, traffic management, maintenance, etc.). The aim being to have a generic railway standard (IRS 30100 published by UIC) that can be applied to various different use cases in the railway domain. Successive versions for RTM have been developed, and the project progress is regularly published in the official RTM website (RTM).

Concretely, RTM is often evoked together with railML (RailML), which defines the schema for the exchange of data. Used jointly, they will allow an interoperable sharing of information in the railway industry.
Beyond the NeTIRail-INFRA context and with the aim to ensure interoperability with external and future monitoring techniques and tools, in the current NeTIRail-INFRA task (T4.5), we consider RTM as a target when we develop our framework to structure and analyse the monitoring data produced by the tools developed in tasks T4.1, T4.2 and T4.3. Besides the interoperability desire, we also intend to provide a contribution to the RTM development project as a starting basis for the monitoring activities. In this regard, as will be discussed along this deliverable, we strive to develop a generic framework to formalize and specify railway monitoring activities that can be used beyond the NeTIRail-INFRA context.
2 Developing a generic-model for managing railway monitoring data

2.1 Introduction & Motivation

The aim behind developing a model for monitoring data is to set up a generic framework that allows for structuring the data generated by the monitoring techniques developed within the previous tasks of WP4, and a harmonised management of this data. As mentioned earlier in this report, beyond the NeTIRail-Infra context, our aim is to prepare a basis for integrating monitoring data that may be produced by further sources. With that objective in mind, we strive to establish a generic and standard reference model for handling monitoring data. This is the reason why we have identified RTM as a target and, this way, our developed model will serve as an input for the RTM standard development coordinated by UIC (also partner of task T4.5).

In line with the work description in the grant agreement, besides the specification of data structures and their organization, we shall also implement techniques for deriving monitoring information according to different management horizons, i.e. operational level, long term management, etc. Namely, the induced monitoring information shall allow for detecting and identifying critical safety situations (defects) for which corrective actions need be taken promptly before further analysis can be made, versus mid and long-term inspection and supervision aspects such as, for instance, the impact of various rolling stocks in terms of track fatigue and defect creation. Overall, such management information will offer a valuable support to optimize the operation choices and business planning, in line with the lean philosophy.

2.2 Model description

To develop our data model, we used the UML formalism (Unified Modeling Language) which is a graphical modelling notation developed under the frame of the Object Management Group (OMG) with the aim to set up a standard, intuitive and highly expressive notation that allow for describing various points of view of a system. In fact, UML is the result of merging three main object-oriented methods, namely OMT (object modelling technique (Rambaugh, 1991)), Booch (Booch, 2004) and OOSE (Object Oriented Software Engineering (Jacobson, 1992)). Besides, UML is the result of a broad consensus involving numerous stakeholders (software companies, modelling experts, etc.). As a consequence, the notation is widely adopted in different domains as a design and communication mean, as it allows an intuitive representation of object-oriented solutions. In addition, it is worth noticing that UML has been adopted by OMG group as a standard since 1997. The main features of UML are:

- It offers a graphical intuitive representation of the solution, which allows for comparing and evaluating various alternatives.
- It has semi-formal semantics that allows for eliminating certain ambiguity and helps for clarifying design aspects.

- It is independent from the programming language that is actually used for the implementation, and from the application domains and processes, which makes the notation generic and universal.

- It allows for representing the system from different perspective, while offering a number of specialized diagrams that can be deployed according to the considered point of view.

As mentioned earlier, UML offers a set of diagrams that can be used depending on the addressed aspects of the system. Before presenting the data model we developed, we firstly introduce the UML class diagram that will be used to set up our data model. A UML class diagram is a static model that describes the structure of a system and clearly maps out its structure by showing the system's classes (templates for creating actual objects), their attributes, operations (or methods) and the relationships among objects. The benefits of using a class diagram is that it illustrates data models for information systems, no matter how simple or complex, and allows for better understanding the general overview of the schematics of an application. In fact, it provides an implementation-independent description of types used in a system that are then later passed between its components. It is worth noticing that this diagram is the most used model among UML diagrams. Below, we give the main features of a class diagram (non-exhaustive list):

- Class: this is the central item of this diagram. It can be seen as a template for creating objects, providing initial values for state through member variables, and specify the behaviour of the object through member functions or methods. The class shape consists of a rectangle with three rows. The top row contains the name of the class, the middle row has the attributes of the class, and the bottom section expresses the methods or operations that the class may utilize (cf. Figure 1). A class can also a specialization of a super-class. Such a relationship is called Inheritance, also known as generalization. this is the process of a child or sub-class taking on the functionality of a parent or superclass. It's symbolized by a straight connected line with a closed arrowhead pointing towards the superclass.

- Class attribute: it is a specification that defines a property of the objects of the class. It can be seen as a metadata that describes a property of the class instances (type, access, etc.), (cf. Figure 2.1)

- Class operation/method: A method is a procedure associated with a message and an object and specifies some behaviour of the class instances (cf. Figure 2.1).
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Figure 2.1: An illustration of class diagram

- Association: an association represents a family of links between two or several classes. A binary association (with two ends) is normally represented as a line. An association can have a name, and the ends of an association can be specified with role names, ownership indicators, multiplicity, visibility, and other properties (cf. Figure 2.2).

- Aggregation: it is type of associations that expresses a "has a" association relationship; i.e., it is an association that represents a part-whole or part-of relationship or a relationship between two classes that have different “hierarchy” level within this relationship. It is represented by an empty diamond (cf. Figure 2.2).

- Composition: a composition relationship expresses a “composed of” relationship between objects. Graphically, it is depicted as a filled diamond shape on the containing class end of the lines that connect contained class(es) to the containing class (cf. Figure 2.2).

Figure 2.2: Various types of associations

Below, we introduce and comment the data model that we’ve developed for railway infrastructure monitoring. Namely, we report a UML class diagram that offers a static overview of the monitoring data organisation.
The corresponding script file (.UML) generated by Papyrus tool is given in Appendix 1.
2.3 Description of the developed Meta-model

Classes:

- MeasurementCampaign: this class allows for creating the instances in terms of measurement campaigns, that are characterized by the area concerned by the measures, the climatic conditions during the campaign, and the dates of the campaign.

- Measurement: a measurement campaign can contain a set of measurements, each of which can be specified through a set of unitary measures and/or measure sets (instance of MeasureSet class) and may be assigned to some climatic conditions.

- UnitaryMeasure: a measurement holds zero or more unitary measures, each of which is characterized by the climatic conditions, one or more sets of measures (instance of MeasureSet class), the method used (instance of Method class) and the tool used (instance of the Tool class).

- Meteo: this class serves to encode the climatic conditions related to the measurements achieved. Some constraints need be added to the model to encode the fact that if the climatic conditions related to a unitary measure (instance of UnitaryMeasure class) are not set, they can be derived from those assigned to the holding measurement (instance of Measurement class). In the same way, if the climatic conditions related to a measurement (instance of Measurement class) are not set, they can be derived from those assigned to the holding measurement campaign (instance of Measurement Campaign class). Such constraints can be encoded using the Object Constraint Language (OCL). OCL is a declarative language describing rules applying to UML models developed and is now part of the UML standard.

- MeasureSet: a measurement (instance of Measurement class) holds zero or more measure sets that can be characterized by a name and a description (strings).

- Tool: this class allows for describing the measurement tools used to get the measure (instance of UnitaryMeasure).

- Method: this class allows for describing the method used to get the measure (instance of UnitaryMeasure).

- Standard: this class allows for encoding the standard related to the measurement method used (instance of Method class).

- Guideline: this class allows for encoding the guidelines followed to implement the measurement method used (instance of Method class). Typically, they can be issued by UIC.

- UncertainValue: is a super-class of UnitaryMeasure. It is characterized by the accuracy of the measure and has a dependency relationship with AccuracyType class.

- PhysicalValue: is a super-class of UncertainValue class and is characterized by a data attribute which indicates the physical unit of the measure value (exp. m/s², °C, etc.). This class has a dependency with PhysicalUnit class.
Later on in this report, we discuss how the developed data model will be actually used to encode the monitoring data produced by the techniques developed within T4.1, T4.2 and T4.3. Moreover, we will explain how such information can be integrated with monitoring data generated through future external monitoring tools.

3 Low cost track based monitoring modules for plain line and S&C

3.1 General presentation of the technique

The system developed under Task T4.1 is designed to make acquisition of the vibrations values for track rails over a long time. The technical solution could be used equally for plain lines, but also for turnouts with S&C components.

The system is designed to contain the next three types of devices, working together, but having distinctive functionalities:

- WSDR (Wireless Sensor Device for Rail).

WCDR (Wireless Concentrator Device for Rail).

WLRCD (Wireless Long Range Communication Device).

The devices developed should support restrictions provided by the real field implementation and long-time functioning. In this regard, the devices have to function in outdoor conditions and isolated locations; the system has to work 24 hours / 7 days, in real conditions, with total autonomy.

One of the most challenging restriction is the environmental conditions that the devices, completing the system, should function in. These requests are represented by the outdoor placement, in open air and isolated field locations, with harmful weather and climate influences and also harsh mechanical conditions.

The developed solution should be in the low-cost category and was a very important objective in designing stage. The component with the highest value is the photovoltaic cells area, the cost of which is comparable with all the other components and materials composing the devices.

3.1.1 WSDR - Wireless Sensor Device for Rail

From the three types of devices that will be installed in the field, the WSDR will be the most affected by the working environment. It will have to work with direct mechanical contact with the rail and withstand all negative influences (e.g. water and snow covering, extreme temperature conditions) To these requirements are added the mechanical ones, encountered only in this type of device, which result out of the strong vibrations from the train passage.

Main functionalities: make acquisition data from accelerometer; local storage of data for short time; sending data using radio short range protocol to the WCDR as concentrator device.
This type of device could be used in a number of points of interest, where necessary. For every needed point of measurement one WSDR device will be provided.

For collecting rail vibrations values, WSDR device uses a three-axis accelerometer with selectable full scales in area of: \((\pm 2g/\pm 4g/\pm 8g/\pm 16g)\) and working with sampling rate from 1 Hz to 5.3 kHz, also selectable. The firmware of the device will filter out only useful data: all values above the normal “no train” range will be saved and transmitted. In this way, the device hardware core will stay in very low power mode almost the entire time.

The device has the possibility to store data locally for a few minutes, which is necessary when the train blocks the visibility of the RF signal. Nevertheless the device should send the acceleration samples as fast as possible to the concentrator device.

One of the most performant functions of this system is the capability of sending acquisitioned data in real time from the rail level, over a short distance to the WCDR type device, using IEEE 802.15.4 RF standard as sub 1 GHz protocol stack (ISM 868 Band for Europe).

As a solution to reduce the influence of noise on the measurements and to protect electronics against severe environmental conditions, the entire WSDR device is encapsulated in a special transparent resin. Further the noise category component can be removed by a numerical filter in the analysis and modelling process.

### 3.1.2 WCDR - Wireless Concentrator Device for Rail

WCDR (Wireless Concentrator Device for Rail) – has main role to collect data from WSDR devices. The WCDR device has to comply following requirements:

- Collect data from WSDR's.
- Send sensor data to the device acting as a transceiver, having data logger function and long-range communication capability (WLRCD).
- Serve as a Gateway device of the external settings and commands, for WSDR.
- Provide total autonomy using battery and photovoltaic cells.
- Provide a sealing class of at least IP65 by its Housing box.

For this development stage, the WCDR device accepts a maximum of seven simultaneous WSDR devices, which could get a RF link with WCDR.

### 3.1.3 WLRCD - Wireless Long Range Communication Device

WLRCD (Wireless Long Range Communication Device) – acts as a transceiver data and will send accelerations values to a Control Centre Application for storing and analysing.

Due to the range of Wi-Fi communication of few hundred meters, the system should be placed near the train stations, where, in almost all cases Wi-Fi and Internet support are available.

The WCDR device has to comply following requirements:
• Receive data from WCDR, through a cable link, using RS485 full duplex standard.

• Data Logger function using own memory, for collecting sensors data when the long range communication is missing.

• Default version for Long Range Communication is Wi-Fi Ethernet solution. Secondary solution could be GSM communication.

• Provide total autonomy using battery and photovoltaic cells.

• Provide a sealing class of at least IP65 by its Housing box.

The chosen RS485 full duplex protocol, as communication link between WCDR and WLRCD gives optimum balance between fast baud rate and high-level protection against electrostatic and electromagnetic negative influences.

3.2 Generated data

3.2.1 Description

Data collected by the system are automatically transmitted by WSDR devices. The current version of the firmware makes acquisitions of the acceleration values with a sampling rate of 400 SPS for each of the three axes: 0X, 0Y, 0Z. The measurement range is variable and is set in the current firmware version to +/- 4g. The acquisition value is on one byte with sign, there are values from -128 to +127.

After the first experiments it was found that the transmission of the values acquired, during the passage of the train, causes many transmission errors and consequently the loss of messages. The later version of the firmware keeps the data in its own WSDR memory and transmits it approx. 1 second after vibration produced by the train has ceased. In fact, it is assumed that the train has left the measuring area in this case.

Acceleration values begin to be acquired after a trigger represented by an acceleration value, on any axis, greater than +/- 2.5g. The values are then collected and saved in the WSDR local memory as long as there are higher values than the trigger value.

If there are no more accelerations above threshold value for approx. 1 second, we consider the acquisition session as terminated and, according to the allocated time interval, the recorded data are transmitted to the WCDR in a succession of messages. Note that the data messages also contain the values acquired in the last second, with values below the threshold.

In one measurement system, all devices work in the same frequency bandwidth. Therefore, each WSDR has a waiting time period before the data is transmitted, so that the transmitted data does not overlap with those transmitted by the other devices. This time buffer is dependent on own code (WSDR Code). The waiting time frame is modifiable and must be longer than the maximum length of transmission of the collected data, for a train crossing the measurement area.
3.2.2 Data structure/organisation

The message data is exemplified below:

```
20180126-144145,6568,0,1,-1,0,32,-1,0,33,-1,134,-1,-1,33,-1,0,33,-1,0,33,-1,133,0,-1,33,-1,0,33,0,0,32,-1,0,33,-1,133,-1,134,-1,-1,33,-1,0,33,-1,0,34,-2,1,33,-1,2,34,-1,1,33,-1,0,33,0,1,41,5,115,-3,-5,127,-2,-7,127,-6,-1,127,-8,-11,97,5,-1,103,-7,11,26,14,3,3,1,-7,14,-3,12,-30,-2,10,-54,1,12,-106,-2,15,-122,2,-8,-75,1,1,-55,-2,-21,25,0,-16,11,
```

The definitions of the fields are described as following:

**Date-Time, Message Header, WCDR Code, WSDR Code, Message Type, 0X, 0Y, 0Z, 0X, 0Y, 0Z ...**

- **Date-Time:** Date and Time of saving message on the file
  - Date as (yyyymmdd);
  - Time as (hhmmss);

- **Message Header:** Automatic Data (AD);

- **WCDR Code:** Always 0;

- **WSDR Code:** 0...7;

- **0X, 0Y, 0Z:** acceleration values for the three axes; values are represented as one byte with sign.

3.3 Extraction of monitoring information

When receiving the acceleration data, the user interface (GUI) application will display the values in real time and will save the received message.

Acceleration information is saved in .csv file format. The name is made up of the Date/Time of the creation of the file.

A file contains the values acquired in a measurement session. A measurement session contains the values from the moment of triggering the amplitude and ends when the values have fallen below the trigger level, for a period of time sufficient to consider that the train has left the measurement area.

The data files are then processed with MatLab or Excel programs. With these programs, graphics are created and represented with the following measures of interest:

- * Graphical representation of all collected values, on the three axes.
- * Determination and representation of the minimum, maximum, average values for the amplitude of the signals.
- * Determination and representation of minimum, maximum, average values for the signal frequency.
4 ABA-based technique

4.1 General presentation of the technique

There are different methods to diagnose the condition of rail defects, including ultrasonic measurements, eddy current testing, image recognition and guided-wave based monitoring among other technologies. Each of them has different advantages and disadvantages. To detect defects in an early stage, Li et al. (2015) investigated the feasibility of detecting early-stage squats using an ABA prototype. It is reported that squats could be detected by analysing the frequency content of the ABA signals in the wavelet power spectrum. In practice, the useful frequency band for early detection of squats ranges from 1000-2000 Hz and 200-400 Hz (Molodova et al. 2014). It has been reported that ABA systems can be employed to detect surface rail defects like corrugation, squats and welds in poor condition.

The ABA-based rail condition monitoring offers the advantages of

(1) having a lower cost than other types of detection methods,
(2) being easy to maintain and
(3) allowing to be implemented in-service operational trains.

Other significant advantages that ABA offers compared to similar measurement systems are

(4) the ability to detect small defects with the absence of complicated instrumentation and
(5) the ability to indicate the level of the dynamic contact force (Molodova et al. 2015).

In the Dutch railways, ABA measurement has been successfully used for the detection of rolling contact fatigue (RCF) (Li et al., 2011; Molodova et al. 2011; Molodova et al., 2014; Li et al., 2015), degradation monitoring of insulated rail joints (Oregui et al., 2015; Molodova et al., 2016), and for monitoring of railway crossings (Wei et al., 2017). In other countries like Korea (Lee et al., 2012), Japan (Sunaga et al., 1997), Poland (Massel, 1999), Italy (Bocciolone et al., 2007), ABA systems have also been implemented for analysis of railway track defects.

A track irregularity like a squat, corrugation or a damaged weld causes an impact to the train wheel, which induces forced vibration of the wheelset. The vibrations caused by the impact are then transmitted from the wheel-rail interface to the axle. In the case of longitudinal and vertical acceleration, axial symmetry of the wheel permits users to analyse some correlation between them and the local irregularity (Li et al., 2015). The principle of the ABA measurements is that the vibrations induced by track irregularity will be transmitted to the wheel and can be measure at the axle box. Accelerometers mounted on the axle boxes of the bogies can reliably measure the ABA. When the wheel passes over a defect, the vibration is much different than when it is passing through smooth rail. The differences between the responses can be employed to detect where the different sorts of
defects are located and their severity. Based on ABA measurements, these differences can be quantified by using predefined thresholds or frequency energy extracted by the Fourier transform, wavelet transform etc.

For the monitoring of the entire Romanian railway, data is collected from accelerometers, a GPS receiver, either a tacho or a speed sensor for positioning. For ABA measurements, a number of accelerometers are mounted on the axle boxes of at least one bogie. Sensor cables are routed from the bogie frame to the measurement box in the train. GPS data is obtained from a receiver that is placed in the measurement box. The GPS antenna is placed on the roof of the train and mounted via a baseplate containing a strong magnet. The GPS antenna cable is routed through an open window or, if available through a cable entry to the measurement box. For accurate positioning measurements, either a tacho signal or a speed signal is employed when available. Figure 4.1 shows the train SNCF Class X 4500, that operates on the line Bartolomeu-Zarnesti Figure 4.1(a) is in the workshop of RCCF, Romania. Figure 4.1(b) is during the measurement campaign in September 2016. The magnitude of the ABA signal is dependent on train speed.

In normal operation, the higher the speed, the higher the impact of the dynamic forces and thus the energy of the ABA signal. Thus, the actual operation conditions are reflected by different severity of detected defects conditions over the defects. To consider this factor, multiple measurements are normally performed.

### 4.2 Generated data

#### 4.2.1 Description

The generated data from several rounds of measurements in Romania are introduced below in detail. In the implementation on a passenger train in operation, the speed varied from 0 km/h at stations to up to 80 km/h. The signals collected at nearly 0 km/h do not contain the necessary excitation for analysis of defects, while the ones around 70 km/h will have the more valuable information. Figure 4.1(a) shows the map of the railway track measured, and Figure 4.1(b) shows the speed profile at various measurement rounds (from Brasov to Zarnesti). Figure 4.1(b) indicates in green the areas where the signals will have the most information usable for detection of defects. The coverage is around 80% of the infrastructure. For the remaining rails (most of them at stations or near them), quantitative
relationships with the signature tunes and maximum ABA can be later incorporated using a regression model, to make full use of the data collected.

For each of the measurements, there is a set of values recorded before and after the measurement for general information of measurements. It includes the date of the measurement performed, the number of the measurement, the starting time of the measurement, the total number of samples recorded, the sampling time interval (sampling frequency), the initial value of tacho sensor and so on.

From each of the measurements, there are 20 different data series measured and recorded synchronously. An example of the data is depicted in Figure 4. Each column in the data set represents a data series with the second row denoting the meaning of the data series. The first column is the serial date number that can be transformed to the date and time when the sample point is recorded. The 16 columns from column 2 to 17 are ABA signals measured in the unit of meter per second squared (m/s^2).

The abbreviations on the second row of these columns have the same format that denotes the source channel of ABA. Concretely, the first digit in the abbreviations represents the number of axle on which the sensor is installed. The letter next to the digit is ‘L’ or ‘R’ that denotes the left and right side of an axle, respectively. The last letter is ‘V’ or ‘H’ that denotes the vertical and horizontal direction of acceleration, respectively. For instance, the abbreviation ‘5LV’ means that the ABA signal in this column is the vertical acceleration measured by the sensor mounted at the left side of axle number 5. Column 18 is the value of tacho sensor. Column 18 and 19 are the latitude and longitude of the train, respectively, where the sample point is recorded.

![Figure 4.2 (a): Map of the railway track between Brasov and Zarnesti, Romania. (b): Speed of the train during the measuring campaign (various rounds).](image-url)

![Figure 4.3 An example of measurement data set.](image-url)
With the full set of data, the vertical and horizontal ABA signals measured from both sides of different axle are available for further analysis. The time and location of sample points helps to calculate the train speed, obtain the running trajectory and trace the locations of rail defects.

4.2.2 Data structure/organisation

The data generated by the ABA monitoring technique are basically .CSV files that record the following data:

- Session ID
- Rail unit ID
- Smartphone ID
- Route
- Location (latitude, longitude, altitude)
- Accuracy
- Speed
- Vertical acceleration
- Longitudinal acceleration
- Lateral acceleration

4.3 Extraction of Monitoring information

The feature extraction of ABA signals is realized by the wavelet transform. The wavelet coefficients of a ABA data series decomposed by wavelet transform (Mallat, 1999).

The corresponding wavelet power spectrum or the so-called scalogram is defined as the square of the wavelet power spectrum signal.

The Morlet function is selected as the mother wavelet for the wavelet transform of ABA signals. Some examples of rail defect detection are shown in the following.

Figure 4. shows three different welds, labelled as W3, W7 and W11. Side and top views are shown. In Figure 4., the ABA responses on the welds and the detection signal are presented. The wavelet power at low frequency band is used to detect the welds.

In the figure, 5 different measurements for the same welds are shown. They were all obtained at a similar speed, so it is possible to estimate the severity of the welds based on the energy values or the maximum peak of the ABA signal in the time domain.
W11 would be the healthier weld, while W7 the one where the highest impact and the most energy are concentrated among the three welds. This example shows that it is possible to create a ranking of the welds that will need more attention in the coming period. Visually inspected they might seem to be in a similar condition. However, by using their dynamic response it is possible to estimate in which ones the most energy is being dissipated during the wheel-weld-track interaction. In the example, the ranking sorted by the healthier weld would be first W11, second W3 and third W7.
Figure 4.4: Three different welds, W3, W7 and W11.

Figure 4.5 ABA signals in the time domain and wavelet energy for the welds W3, W7 and W11.

Figure 4. shows the photo of a segment of rail with corrugation, the corresponding ABA signal and the wavelet scalogram of ABA. The scalogram at the frequency range from 0 to 400Hz shows the continuous impact caused by the corrugation along the rail.
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

For a long-term data series from a continuous measurement, an automatic defect detection algorithm is used to identify defect based on the wavelet energy at different frequency level. As an example, Figure 4.6 shows the detections results from a segment of rail.

Each row starting from the third row represents a detected defect. The columns from 1 to 3 show the midpoint, start and end locations (km) of the defect, respectively. The columns from 4 to 19 provide the detected energy peak values or zero.

In a similar way to measurements, the abbreviation, for example ‘A3H_LF’ represents the amplitude of wavelet energy of horizontal ABA measured from axle number 4 (A3H) within the low-frequency (LF) range. With the help of these results, it is possible to diagnose the type and severity of defects based on the defect duration, the amplitude of energy and the indicative frequency band.

Figure 4.7: Detection results from a segment of rail.
5 Smartphone technology for track and ride quality monitoring

5.1 General presentation of the technique

The monitoring tool developed within Task 4.3 is based on the development of a smartphone-based technology for vehicle and infrastructure monitoring from within passenger vehicles, i.e. crowdsourced data collection, to increase the regularity and granularity of the monitoring data available.

The results of this task are:

- An app to gather data from the smartphone GPS sensor and its accelerometer. This considers conservation of battery life as a priority to ensure viability of the app.
- A gateway to which the data is transmitted using the phone 3G or WiFi connection.
- An interface for querying of available data, namely a relational database.

The developed system architecture is presented in the Figure 5.1 underlying the different physical tiers (system applications) and connection points.

![Figure 5.1: Architecture of the developed system](image)

At the rail unit level (Application for low cost smartphone) the different physical layers of the system consist of:

- Android application service for sensor acquisition data.
5.2 Generated data

5.2.1 Description

Vibrations in trains can be mainly caused by welding and rolling defects, rail joints, poor track alignments, various defects/roughness in the track or wheel surfaces, etc. Another factor is related to the traveling speed of the train that can also magnify the amplitude of the vibrations as the train goes faster.

The combinations of these parameters affect the passengers’ perception of ride comfort (see Figure 5.2).
The data collected through the Application for low cost smartphone is in compliance with the standard ISO 2631-1:1997. In fact, ISO 2631-1:1997 provides basic evaluation methods based on the crest factor. The standard defines the total vibration value of weighted r.m.s. (root mean square) acceleration for all directions in respective position.

Perception of ride comfort according to ISO-2631-1:1997 is presented in the table below.

<table>
<thead>
<tr>
<th>r.m.s vibration level</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0,315 m/s²</td>
<td>Not uncomfortable</td>
</tr>
<tr>
<td>0,315 m/s² to 0,63 m/s²</td>
<td>A little uncomfortable</td>
</tr>
<tr>
<td>0,63 m/s² to 1 m/s²</td>
<td>Fairly uncomfortable</td>
</tr>
<tr>
<td>1 m/s² to 1,6 m/s²</td>
<td>Uncomfortable</td>
</tr>
<tr>
<td>1,6 m/s² to 2,5 m/s²</td>
<td>Very uncomfortable</td>
</tr>
<tr>
<td>Greater than 2 m/s²</td>
<td>Extremely uncomfortable</td>
</tr>
</tbody>
</table>

A smartphone’s coordinate system is a relative coordinate system depending on the smartphone’s screen. When the mobile phone is placed horizontally and the screen is upward, smartphone’s screen center is the origin of this coordinate, the direction parallel to the short side of the screen is the x-axis, the direction parallel to the long side of screen is the y-axis, and the direction vertical up to the screen is the z-axis (see Figure 5.3).

The inertial coordinate system in which the rail unit vibration comfort will be calculated can be regarded as an intermediate status between the smartphone and the world coordinate system, while its origin is identical with the origin of the smartphone’s coordinate system and its axes are parallel to the axes of the world coordinate system. Transformation from the smartphone’s coordinate system to the inertial system coordinates only needs a rotating operation, while transformation from the world coordinate system to inertial coordinate system only needs shift operation.

Figure 5.3: Android coordinate (2,3), and Vibration model of human body (4)[CITATION Hon16 \l 1033]
The parameters of acceleration and orientation sensor built-in smartphone are listed in the table below.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration sensor</td>
<td>A_values[0]</td>
<td>Acceleration along the x-axis (including gravity)</td>
</tr>
<tr>
<td></td>
<td>A_values[1]</td>
<td>Acceleration along the y-axis (including gravity)</td>
</tr>
<tr>
<td></td>
<td>A_values[2]</td>
<td>Acceleration along the z-axis (including gravity)</td>
</tr>
<tr>
<td>Orientation sensor</td>
<td>O_values[0]</td>
<td>Azimuth, the angle between x-axis and the magnetic North Pole (0° to 360°)</td>
</tr>
<tr>
<td></td>
<td>O_values[1]</td>
<td>Pitch, the angle between y-axis and horizontal plane (−180° to 180°)</td>
</tr>
<tr>
<td></td>
<td>O_values[2]</td>
<td>Roll, the angle between z-axis and horizontal plane (−90° to 90°)</td>
</tr>
</tbody>
</table>

Table 5.1: parameters of acceleration and orientation of smartphone sensor(2,3)

5.2.2 Data structure/organisation

Data is collected in the system in two different formats, specific to each subsystem, namely:

- at the smartphone application level, data is structured in .csv format
- at the control centre level, data is collected and stored in a relational database

At the smartphone application level, the data is collated into 2 types of csv files:

- A file that characterizes the registration session.
  - A file with data collected from acceleration and GPS sensors.

The file that characterizes the registration session records the following information.
Because the data volume collected from the sensors is very high, and to transmit these data in real time, a separate .csv file is generated for each time-slot of one minute.

The smartphone application sends these files to the control centre via a web service. At the control centre level, data is automatically extracted and inserted into the real-estate database structure.

The database structure is presented below.

![Database Structure](image)
5.3 Extraction of Monitoring information

Registration sessions are made in intervals of one minute in order to allow graphical representation of the results (one session contains an average of 60000 registrations). Illustrations of the monitoring facilities are given in Figure 5. to Figure 5.
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

Figure 5.7: Display of max/min values of information for Vibration and Comfort

Figure 5.8: Function for filtering information for Vibration and Comfort

The following figures show the most significant diagrams, in which the vibration and comfort records are presented in parallel.
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

Figure 5.9: Illustration of the vibration graph Session 29/04/2017 9:55:19

Figure 5.10: Illustration of the comfort graph - Session 29/04/2017 9:59:19
6 Data monitoring integration

6.1 Description of the interface

The meta-model developed to store and organize the monitoring data, which was discussed in Section 2 serves as a reference for the development of the actual interface to encode the generated data.

The technical choice we have taken to implement the interface is a relational database in such a way to store and organize the generated data in various tables linked with each other through defined associations. The motivation underlying this choice can be explained as follows:

- Such encoding of the data is in line with the deliberate choice we have explained earlier in the report, regarding the separation between monitoring data storing and the generation of monitoring information. In fact, the monitoring information can be derived from the relational data base by means of parametrisable queries according to the monitoring rules/criteria that one defines.

- In terms of tooling, numerous free database management systems are available.

- From a practical point of view, the encoding of monitoring data generated by the tools developed in T4.1, T4.2 and T4.3 has been achieved by means of relational databases. Hence, although the architectures of the developed databases are not fully compliant with the data model developed within the correct task (T4.5), such a translation can be done through some adhoc scripts and remains workable with fairly reasonable effort.

The script that has been developed (by ADS) to define the SQL architecture of our database is given in Appendix 2. The tables of the database need be adopted according to the recorded measures. In particular, as specified in the UML class diagram presented earlier in this report, the developed data model allows recording measures in shape of individual values, but also “vectors” of measures that are linked to each other by some parameters: same location, simultaneous captured measures, etc.

6.2 Monitoring management

The developed monitoring data model that was discussed in Section 2 of the current report only considers the encoding and organisation of the produced data while taking care of interoperability issues in view of integration with further monitoring tools/techniques. In fact, the developed framework does not consider the analysis/filtering of the recorded data. This choice is deliberate and offers important advantages in terms of flexibility. For the sake of illustration, the following aspects can be highlighted:

- **From a comfort point of view:** such a distinction allows for a flexible analysis of the recorded monitoring data. Indeed, depending on the operational context (type of traffic: passenger vs. freight, high speed vs. conventional traffic, etc.) and/or the requirements in terms of ride comfort, the appropriate criteria to filter the data (thresholds, etc.) can be defined.

To better illustrate these aspects, let us consider the ride quality point of view: depending on the traffic type (passenger vs. freight typically), the requirements in terms of comfort are potentially
significantly different. Consequently, the monitored thresholds in terms of vibration (namely linear and radial accelerations) have to be adapted accordingly. Namely, it is obvious that for passenger traffic, the quality on terms of ride quality is much higher than the case of freight traffic.

- **From a safety point of view:** although for any operational context circumstances, certain circumstances that may give raise to critical scenarios such as, for instance train derailment, have to be carefully monitored and prevented by means of various maintenance and operational actions, the actual implementation in terms of monitoring has to take into consideration various parameters related to the traffic (speed, density, weight, axle load, etc.), to the climatic conditions (snowy weather for example) or also to the location concerned by the monitoring.

For instance, let us consider the Low cost track based monitoring technique developed for plain line and S&C within task T4.1, depending on the measurement location, i.e., on the location where the monitoring modules (WSDRs namely) are installed (curve, slope), the acceleration thresholds that need be monitored can be very different. Hence such monitoring “parameters” should not be hard-coded in the data-model, but instead defined adequately according to the actual context.

- **From a management point of view:** following the detection of some minor defects on the track for instance, several alternatives can be envisaged in terms of maintenance. For example, let us consider the case of S&C, depending on various economic and operational aspects, this may vary from some light maintenance operations to the replacement of some components on the S&C or even the complete replacement of the whole S&C.

In fact, apart from the extent and the severity of the defect in relation with safety, some other considerations can enter into play. Namely, depending on the labour costs, the availability of maintenance operators, the traffic type and density, the decision can be considerably different. It may be for instance a speed limitation until future planned maintenance operations are performed, or in opposite a complete replacement of the S&C being given a foreseen renewal plan of the line, etc.

Hence, the monitoring parameters should be adapted to the management plan. As a side note, it is worth noticing here that, on the opposite, the extracted monitoring information also serves as an input for decision making and management in general. I.e., the appropriate decisions in terms of maintenance and operation management but also in terms of business planning (judging the marginal cost of particular traffic types for exp.) have to take into account the inferred monitoring information appropriately.

In practice, the extraction of monitoring data is made by means of SQL queries that can be parametrised with the adequate values of parameters in a way to make the targeted filtering of data, the identification of potentially defective locations or also to trace the degradation of the track in time according to traffic volumes, etc.

As specified in the grant document, besides filtering which aims to remove insignificant and spurious data, we can distinguish two types of monitoring information:

- **Short term monitoring information** regarding the line under consideration: by raising alarms some measures indicate abnormal values that potentially mean the existence of specific defects in some
given locations. Namely, this can be performed in an easy way by surveying some threshold values. These values can be defined with regards to safety requirements or also regarding comfort.

Depending on the case, it is possible that in some situations the detection of isolated abnormal values in terms of safety or comfort (exceeding some defined thresholds) needs confirmation by further detection occurrences. In fact, due to imprecision in the measured values or to noise inferred by environment, some measures exceeding the defined thresholds may not reflect the reality. In other terms, such “aberrant” values may be just the result of incorrect measures. Hence, confirmation by means of additional measures is needed to gain enough reliability of the measurements.

In practice, such information can be inferred by very simple queries. Since it is meaningless to try to cope with all the possibilities in this respect, we just give some examples of the types of requests one can make:

Example:

“Find all the locations (at a given area) for which at least N VERTICAL_VIBRATION measures are bigger than a GIVEN_VALUE.”

- **Long term monitoring information** regarding the line under consideration: compared with the short term monitoring, it is not about the detection of punctual defects along the track, but rather allows for following the evolution of the track condition on time. This can serve, for instance, to assess the formation of some specific defects (and thus the degradation of the track) due to some specific type/density of traffic. Also, this kind of monitoring information can target the identification of correlation between some defect formations and specific parameters (traffic, climatic conditions, maintenance operations). Such information can be very valuable to optimize maintenance operations or also to help decision making in terms of business planning.

In practice the implementation of such monitoring tasks may give raise to complex SQL queries depending on the information sought for. To illustrate this aspect, let us consider the following example:

Example:

“Find all the locations (in a given area) for which a quick increase of VERTICAL_VIBRATIONS is detected within a short time interval (1 week for instance)”.

- Perform some statistics on the recorded monitoring values to assess the impact of some particular maintenance operations.

It should be noted that some queries may result in the computation of some “joining” operations, involving big tables. Therefore, such queries should be handled with care to ensure scalability.
7 Conclusions

In this deliverable, we have recalled the main features of the monitoring techniques & tools that were developed within WP4 and provided a detailed description of the generated monitoring data. Then a generic data model has been elaborated in order to define a standardized basis to encode and structure the monitoring data. This basis has served as a reference for the actual implementation of the interface. For the various advantages it offers, UML notation was adopted to specify all the features related to the generated data (types, relations, etc.).

Besides the NeTIRAil-INFRA context, the developed metamodel targets the RailTopoModel (RTM) standard which is the standard that aims to encode all the date related to railway infrastructure, railway operation and in the future additional types of railway data. The underlying objective is twofold:

1) is to prepare integration of the monitoring data with future monitoring application and tools, and
2) to provide a contribution that can serves to cope with monitoring data for RTM project.

The developed UML class diagram has served as a reference for the implementation of the interface that will actually serve to store the monitoring data and perform activities. From a technical point of view, a relational data base system was targeted to implement the system and provide a support for monitoring. This choice is argued as follows:

- Such encoding of the data is in line with the deliberate choice we have explained earlier in the report, regarding the separation between monitoring data storing and the generation of monitoring information. In fact, the monitoring information can be derived from the relational data base by means of parametrisable queries according to the monitoring rules/criteria that one defines.

- In terms of tooling, numerous free database management systems are available.

- From a practical point of view, the encoding of monitoring data generated by the tools developed in T4.1, T4.2 and T4.3 has been achieved by means of relational databases. Hence, although the architectures of the developed databases are not fully compliant with the data model developed within the correct task (T4.5), such a translation can be done through some adhoc scripts and remains workable with fairly reasonable effort.

As for the monitoring activity, we have made the deliberate choice to rigorously separate between data storage and monitoring itself. This choice offers several advantages in terms of flexibility of the monitoring activity which, this way, can be adequately adapted to the context and to the goals one can define for the monitoring activities. We have discussed and illustrated how monitoring activities can be performed on the basis of the relational database the encodes the monitoring data. As explained in the report, monitoring activities can be performed with regards to various perspectives: short-term monitoring that allows for detecting urgent situations that need prompt actions to prevent safety issues, and long-term monitoring that allows for monitoring degradation of the track according to given parameters: traffic types/density, weather, etc.
It should be noted that the investigation capabilities through the queries that can be performed on the relational database offer support not only in terms of short-term and long-term monitoring but also offers valuable support in terms of decision making. One important aspect to take care of is the traceability. In fact, to ensure an efficient tracking of the track status and make efficient choices in terms of maintenance, operation, it is important to ensure a precise recording of the monitoring investigation in time so as to have enough material to derive statistics and know short and long term variations of the track health.
8 References


11. RTM: www.railtopomodel.org


13. OMG: www.omg.org


D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

NeTIRail-INFRA

H2020-MG-2015-2015 GA-636237

2018/03/1

APPENDIX 1

UML-CLASS-DIAGRAM.uml generated through Papyrus

```xml
<uml:Model xmi:version="20131001" xmi:id="_7MZBIAWSEifco9b3hINiw" name="RTM_Measure"><packageImport xmi:type="uml:PackageImport" xmi:id="_7d9SQAWSdEifco9b3hINiw"><importedPackage xmi:type="uml:Model" href="pathmap://UML_LIBRARIES/UMLPrimitiveTypes.library.uml#_0"/></packageImport><packagedElement xmi:type="uml:Class" xmi:id="_6W_0wAWTEifco9b3hINiw" name="MeasurementCampaign" visibility="public"><ownedAttribute xmi:type="uml:Property" xmi:id="_8DJ_IQWUEifco9b3hINiw" name="measure" type="_BgQWcAWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJ_IgWUEifco9b3hINiw" value="0"/></ownedAttribute><ownedAttribute xmi:type="uml:Property" xmi:id="_BDQWcAWUEifco9b3hINiw" name="measureregion" type="_8DJIgWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJ_IgWUEifco9b3hINiw" value="0"/></ownedAttribute></class><packagedElement xmi:type="uml:Class" xmi:id="_81q4gWVVeifco9b3hINiw" name="Meteo"><ownedAttribute xmi:type="uml:Property" xmi:id="_A81q4gWVVeifco9b3hINiw" name="date" type="_8DJIgWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJIgWUEifco9b3hINiw" value="0"/></ownedAttribute><ownedAttribute xmi:type="uml:Property" xmi:id="_A81q4gWVVeifco9b3hINiw" name="time" type="_8DJIgWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJIgWUEifco9b3hINiw" value="0"/></ownedAttribute></class><packagedElement xmi:type="uml:Class" xmi:id="_81q4gWVVeifco9b3hINiw" name="Measurement"><ownedAttribute xmi:type="uml:Property" xmi:id="_A81q4gWVVeifco9b3hINiw" name="date" type="_8DJIgWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJIgWUEifco9b3hINiw" value="0"/></ownedAttribute><ownedAttribute xmi:type="uml:Property" xmi:id="_A81q4gWVVeifco9b3hINiw" name="time" type="_8DJIgWUEifco9b3hINiw" aggregation="shared" association="_8DJIgWUEifco9b3hINiw"><lowerValue xmi:type="uml:LiteralInteger" xmi:id="_8DJIgWUEifco9b3hINiw" value="0"/></ownedAttribute></class></model>
```

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Appendix 2

DROP TABLE IF EXISTS "Guideline" CASCADE;
DROP TABLE IF EXISTS "Standard" CASCADE;
DROP TABLE IF EXISTS "PhysicalValue" CASCADE;
DROP TABLE IF EXISTS "PhysicalUnit" CASCADE;
DROP TABLE IF EXISTS "UncertainValue" CASCADE;
DROP TABLE IF EXISTS "AccuracyType" CASCADE;
DROP TABLE IF EXISTS "Tool" CASCADE;
DROP TABLE IF EXISTS "Method" CASCADE;
DROP TABLE IF EXISTS "MeasureSet" CASCADE;
DROP TABLE IF EXISTS "UnitaryMeasure" CASCADE;
DROP TABLE IF EXISTS "Meteo" CASCADE;
DROP TABLE IF EXISTS "Measurement" CASCADE;
DROP TABLE IF EXISTS "Documentation" CASCADE;
DROP TABLE IF EXISTS "Delete" CASCADE;
DROP TABLE IF EXISTS "Replace" CASCADE;
DROP TABLE IF EXISTS "Add" CASCADE;
DROP TABLE IF EXISTS "XMI" CASCADE;
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

DROP TABLE IF EXISTS extension CASCADE;
DROP TABLE IF EXISTS documentation CASCADE;
DROP TABLE IF EXISTS guideline CASCADE;
DROP TABLE IF EXISTS standard CASCADE;
DROP TABLE IF EXISTS data CASCADE;
DROP TABLE IF EXISTS accuracy CASCADE;
DROP TABLE IF EXISTS tool CASCADE;
DROP TABLE IF EXISTS method CASCADE;
DROP TABLE IF EXISTS measureset CASCADE;
DROP TABLE IF EXISTS unitarymeasure CASCADE;
DROP TABLE IF EXISTS meteo CASCADE;
DROP TABLE IF EXISTS measure CASCADE;
DROP TABLE IF EXISTS target CASCADE;
DROP TABLE IF EXISTS "Difference" CASCADE;
DROP TABLE IF EXISTS container CASCADE;
DROP TABLE IF EXISTS "Extension" CASCADE;
DROP TABLE IF EXISTS difference CASCADE;
DROP TABLE IF EXISTS "MeasurementCampaign" CASCADE;

--
-- No annotation is available
-- xmlns: http:///RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: root, content: true, list: true, bridge: false, virtual: false
--
CREATE TABLE "MeasurementCampaign" (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
  document_id TEXT,
  -- PRIMARY KEY
  "MeasurementCampaign_id" BIGINT CHECK ( "MeasurementCampaign_id" >= 0 )
  PRIMARY KEY,
  -- NESTED KEY : measure ( measure_id )
  measure_id BIGINT CHECK ( measure_id >= 0 ),
  -- NESTED KEY : meteo ( meteo_id )
  meteo_id BIGINT CHECK ( meteo_id >= 0 ),
  -- ATTRIBUTE
  label TEXT,
  -- ATTRIBUTE
  uuid TEXT,
  -- ATTRIBUTE
  href TEXT,
  -- ATTRIBUTE
  idref TEXT,
  -- ATTRIBUTE
  type TEXT,
  -- ATTRIBUTE
  "Area" TEXT NOT NULL,
  -- ATTRIBUTE
  "startDate" TEXT NOT NULL,
  -- ATTRIBUTE
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

```
"endDate" TEXT NOT NULL,
-- ATTRIBUTE
measure TEXT,
-- ATTRIBUTE
meteo TEXT
);

--
-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMLSchema
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE difference (
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
-- PRIMARY KEY
difference_id BIGINT CHECK ( difference_id >= 0 ) PRIMARY KEY,
-- NESTED KEY: "Difference" ( "Difference_id" ), PARENT NODE: difference container
"Difference_id" BIGINT CHECK ( "Difference_id" >= 0 )
);

--
-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMLSchema
-- type: admin child, content: true, list: false, bridge: false, virtual: false
--
CREATE TABLE "Extension" (
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
"Extension_id" BIGINT CHECK ( "Extension_id" >= 0 ) ,
-- ANY ELEMENT
any_element XML,
-- ATTRIBUTE
id TEXT,
-- ATTRIBUTE
label TEXT,
-- ATTRIBUTE
uuid TEXT,
-- ATTRIBUTE
href TEXT,
-- ATTRIBUTE
idref TEXT,
-- ATTRIBUTE
type TEXT,
-- ATTRIBUTE
extender TEXT,
-- ATTRIBUTE
```
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--
-- No annotation is available
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE container (  
   document_id TEXT,
   container_id BIGINT CHECK ( container_id >= 0 ),
   "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 )
);

--
-- No annotation is available
-- type: admin root, content: true, list: true, bridge: false, virtual: true
--
CREATE TABLE "Difference" (  
   document_id TEXT,
   "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 ),
   FOREIGN KEY : difference ( difference_id )
   difference_id BIGINT CHECK ( difference_id >= 0 ) CONSTRAINT FK_Difference_difference REFERENCES difference ( difference_id ),
   FOREIGN KEY : container ( container_id )
   container_id BIGINT CHECK ( container_id >= 0 ),
   FOREIGN KEY : target ( target_id ), PARENT NODE : difference container
   target_id BIGINT CHECK ( target_id >= 0 ),
   FOREIGN KEY : "Extension" ( "Extension_id" )
   "Extension_id" BIGINT CHECK ( "Extension_id" >= 0 ),
   ATTRIBUTE
   id TEXT,
   ATTRIBUTE
   label TEXT,
   ATTRIBUTE
   uuid TEXT,
   ATTRIBUTE
   href TEXT,
   ATTRIBUTE
   idref TEXT,
   ATTRIBUTE
   type TEXT,
   ATTRIBUTE
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

CREATE TABLE target (  
    document_id TEXT ,  
    target_id BIGINT CHECK ( target_id >= 0 ) ,  
    FOREIGN KEY : "Difference" ( "Difference_id" )  
        "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 ) ,  
    ANY ELEMENT  
        any_element XML ,  
    ANY ATTRIBUTE  
        any_attribute XML  
    );

CREATE TABLE measure (  
    document_id TEXT ,  
    measure_id BIGINT CHECK ( measure_id >= 0 ) ,  
    NESTED KEY : "Measurement" ( "Measurement_id" )  
        "Measurement_id" BIGINT CHECK ( "Measurement_id" >= 0 )  
    );

CREATE TABLE meteo (  
    document_id TEXT ,  
    meteo_id BIGINT CHECK ( meteo_id >= 0 ) ,  
    NESTED KEY : "Meteo" ( "Meteo_id" ), PARENT NODE : unitarymeasure  
        "Meteo_id" BIGINT CHECK ( "Meteo_id" >= 0 )  
    );
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

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CREATE TABLE unitarymeasure (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
unitarymeasure_id BIGINT CHECK ( unitarymeasure_id >= 0 ) ,  
-- NESTED KEY : "UnitaryMeasure" ( "UnitaryMeasure_id" ), PARENT NODE : measure  
"UnitaryMeasure_id" BIGINT CHECK ( "UnitaryMeasure_id" >= 0 )
);

CREATE TABLE measureset (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
measureset_id BIGINT CHECK ( measureset_id >= 0 ) ,  
-- NESTED KEY : "MeasureSet" ( "MeasureSet_id" ), PARENT NODE : measure unitarymeasure  
"MeasureSet_id" BIGINT CHECK ( "MeasureSet_id" >= 0 )
);

CREATE TABLE method (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
method_id BIGINT CHECK ( method_id >= 0 ) ,  
-- NESTED KEY : "Method" ( "Method_id" ), PARENT NODE : unitarymeasure  
"Method_id" BIGINT CHECK ( "Method_id" >= 0 )
);

CREATE TABLE tool (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
tool_id BIGINT CHECK ( tool_id >= 0 ) ,  
-- NESTED KEY : "Tool" ( "Tool_id" ), PARENT NODE : unitarymeasure
"Tool_id" BIGINT CHECK ( "Tool_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE accuracy (  
    document_id TEXT,  
    accuracy_id BIGINT CHECK ( accuracy_id >= 0 ) ,  
    "AccuracyType_id" BIGINT CHECK ( "AccuracyType_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE data (  
    document_id TEXT,  
    data_id BIGINT CHECK ( data_id >= 0 ) ,  
    "PhysicalUnit_id" BIGINT CHECK ( "PhysicalUnit_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE standard (  
    document_id TEXT,  
    standard_id BIGINT CHECK ( standard_id >= 0 ) ,  
    "Standard_id" BIGINT CHECK ( "Standard_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin child, content: false, list: true, bridge: true, virtual: false
--
CREATE TABLE guideline (  
    document_id TEXT
)
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

document_id TEXT,
guideline_id BIGINT CHECK ( guideline_id >= 0 ),
-- NESTED KEY : "Guideline" ( "Guideline_id" ), PARENT NODE : method
"Guideline_id" BIGINT CHECK ( "Guideline_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMI.xsd
-- type: admin root, content: false, list: false, bridge: false, virtual: true
--
CREATE TABLE documentation (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
-- PRIMARY KEY
documentation_id BIGINT CHECK ( documentation_id >= 0 ) PRIMARY KEY
);

-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMI.xsd
-- type: admin root, content: false, list: false, bridge: false, virtual: true
--
CREATE TABLE extension (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
-- PRIMARY KEY
extension_id BIGINT CHECK ( extension_id >= 0 ) PRIMARY KEY
);

-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMI.xsd
-- type: admin root, content: true, list: false, bridge: false, virtual: true
--
CREATE TABLE "XMI" (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
-- PRIMARY KEY
"XML_id" BIGINT CHECK ( "XML_id" >= 0 ) PRIMARY KEY,
-- ANY ELEMENT
any_element XML,
-- ATTRIBUTE
id TEXT,
-- ATTRIBUTE
label TEXT,
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

-- ATTRIBUTE
    uuid TEXT ,
-- ATTRIBUTE
    href TEXT ,
-- ATTRIBUTE
    idref TEXT ,
-- ATTRIBUTE
    type TEXT
);

--
-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMI.xsd
-- type: admin root, content: true, list: false, bridge: true, virtual: true
--
CREATE TABLE "Add"
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT ,
-- PRIMARY KEY
    "Add_id" BIGINT CHECK ( "Add_id" >= 0 ) PRIMARY KEY ,
-- NESTED KEY : "Difference" ( "Difference_id" )
    "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 ) ,
-- ATTRIBUTE
    position INTEGER ,
-- ATTRIBUTE
    addition TEXT
);

--
-- No annotation is available
-- xmlns: http://www.omg.org/spec/XMI/20131001 (default), schema location:
http://www.omg.org/spec/XMI/20131001/XMI.xsd
-- type: admin root, content: true, list: false, bridge: true, virtual: true
--
CREATE TABLE "Replace"
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT ,
-- PRIMARY KEY
    "Replace_id" BIGINT CHECK ( "Replace_id" >= 0 ) PRIMARY KEY ,
-- NESTED KEY : "Difference" ( "Difference_id" )
    "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 ) ,
-- ATTRIBUTE
    position INTEGER ,
-- ATTRIBUTE
    replacement TEXT
);
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

CREATE TABLE "Delete" (  
  document_id TEXT ,  
  "Delete_id" BIGINT CHECK ( "Delete_id" >= 0 ) PRIMARY KEY ,  
  "Difference_id" BIGINT CHECK ( "Difference_id" >= 0 )  
);  

CREATE TABLE "Documentation" (  
  document_id TEXT ,  
  "Documentation_id" BIGINT CHECK ( "Documentation_id" >= 0 ) ,  
  contact TEXT ,  
  exporter TEXT ,  
  "exporterVersion" TEXT ,  
  "longDescription" TEXT ,  
  "shortDescription" TEXT ,  
  notice TEXT ,  
  owner TEXT ,  
  timestamp TIMESTAMP ,  
  "Extension_id" BIGINT CHECK ( "Extension_id" >= 0 ) ,  
  id TEXT ,  
  label TEXT ,  
  uuid TEXT ,  
  href TEXT ,  
  idref TEXT ,  
  type TEXT  
);
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

CREATE TABLE "Measurement" (  
  DOCUMENT KEY is pointer to data source (aka. Entry ID)  
  document_id TEXT ,  
  "Measurement_id" BIGINT CHECK ( "Measurement_id" >= 0 ) ,  
  FOREIGN KEY : measure ( measure_id )  
  measure_id BIGINT CHECK ( measure_id >= 0 ) ,  
  NESTED KEY : unitarymeasure ( unitarymeasure_id ), PARENT NODE : measure  
  unitarymeasure_id BIGINT CHECK ( unitarymeasure_id >= 0 ) ,  
  NESTED KEY : measureset ( measureset_id ), PARENT NODE : measure  
  measureset_id BIGINT CHECK ( measureset_id >= 0 ) ,  
  NESTED KEY : meteo ( meteo_id ), PARENT NODE : measure  
  meteo_id BIGINT CHECK ( meteo_id >= 0 ) ,  
  ATTRIBUTE  
    label TEXT ,  
  ATTRIBUTE  
    uuid TEXT ,  
  ATTRIBUTE  
    href TEXT ,  
  ATTRIBUTE  
    idref TEXT ,  
  ATTRIBUTE  
    type TEXT ,  
  ATTRIBUTE  
    meteo TEXT  
);  

CREATE TABLE "Meteo" (  
  DOCUMENT KEY is pointer to data source (aka. Entry ID)  
  document_id TEXT ,  
  "Meteo_id" BIGINT CHECK ( "Meteo_id" >= 0 ) ,  
  FOREIGN KEY : meteo ( meteo_id )  
  meteo_id BIGINT CHECK ( meteo_id >= 0 ) ,  
  ATTRIBUTE  
    label TEXT ,  
  ATTRIBUTE  
    uuid TEXT ,  
  ATTRIBUTE  
    href TEXT ,  
  ATTRIBUTE  
    idref TEXT ,  
  ATTRIBUTE  
    type TEXT ,  
  ATTRIBUTE  
    meteo TEXT  
)
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CREATE TABLE "UnitaryMeasure" (  
  DOCUMENT KEY is pointer to data source (aka. Entry ID) 
  document_id TEXT, 
  "UnitaryMeasure_id" BIGINT CHECK ( "UnitaryMeasure_id" >= 0 ), 
  FOREIGN KEY : unitarymeasure ( unitarymeasure_id ) 
  unitarymeasure_id BIGINT CHECK ( unitarymeasure_id >= 0 ), 
  NESTED KEY : "UncertainValue" ( "UncertainValue_id" ) 
  "UncertainValue_id" BIGINT CHECK ( "UncertainValue_id" >= 0 ), 
  ATTRIBUTE  
  meteo TEXT, 
  ATTRIBUTE  
  measureset TEXT, 
  ATTRIBUTE  
  method TEXT, 
  ATTRIBUTE  
  tool TEXT 
);
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

CREATE TABLE "Method" (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
"Method_id" BIGINT CHECK ( "Method_id" >= 0 ) ,  
-- FOREIGN KEY : method ( method_id )  
method_id BIGINT CHECK ( method_id >= 0 ) ,  
-- NESTED KEY : standard ( standard_id ), PARENT NODE : method  
standard_id BIGINT CHECK ( standard_id >= 0 ) ,  
-- NESTED KEY : guideline ( guideline_id ), PARENT NODE : method  
guideline_id BIGINT CHECK ( guideline_id >= 0 ) ,  
-- ATTRIBUTE  
label TEXT ,  
-- ATTRIBUTE  
uuid TEXT ,  
-- ATTRIBUTE  
href TEXT ,  
-- ATTRIBUTE  
idref TEXT ,  
-- ATTRIBUTE  
type TEXT ,  
-- ATTRIBUTE  
standard TEXT ,  
-- ATTRIBUTE  
guideline TEXT
);

CREATE TABLE "Tool" (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)  
document_id TEXT ,  
"Tool_id" BIGINT CHECK ( "Tool_id" >= 0 ) ,  
-- FOREIGN KEY : tool ( tool_id )  
tool_id BIGINT CHECK ( tool_id >= 0 ) ,  
-- ATTRIBUTE  
label TEXT ,
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

-- ATTRIBUTE
    uuid TEXT,
-- ATTRIBUTE
    href TEXT,
-- ATTRIBUTE
    idref TEXT,
-- ATTRIBUTE
    type TEXT
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin root, content: true, list: false, bridge: false, virtual: true
--
CREATE TABLE "AccuracyType" (  
    -- DOCUMENT KEY is pointer to data source (aka. Entry ID)
    document_id TEXT,
    "AccuracyType_id" BIGINT CHECK ( "AccuracyType_id" >= 0 ),
-- FOREIGN KEY : accuracy ( accuracy_id )
    accuracy_id BIGINT CHECK ( accuracy_id >= 0 ),
-- ATTRIBUTE
    label TEXT,
-- ATTRIBUTE
    uuid TEXT,
-- ATTRIBUTE
    href TEXT,
-- ATTRIBUTE
    idref TEXT,
-- ATTRIBUTE
    type TEXT
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin root, content: false, list: true, bridge: false, virtual: true
--
CREATE TABLE "UncertainValue" (  
    -- DOCUMENT KEY is pointer to data source (aka. Entry ID)
    document_id TEXT,
    "UncertainValue_id" BIGINT CHECK ( "UncertainValue_id" >= 0 ),
-- NESTED KEY : "PhysicalValue" ( "PhysicalValue_id" )
    "PhysicalValue_id" BIGINT CHECK ( "PhysicalValue_id" >= 0 )
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
CREATE TABLE "PhysicalUnit" (  
document_id TEXT ,  
"PhysicalUnit_id" BIGINT CHECK ( "PhysicalUnit_id" >= 0 ) ,  
data_id BIGINT CHECK ( data_id >= 0 ) ,  
label TEXT ,  
uuid TEXT ,  
href TEXT ,  
idref TEXT ,  
type TEXT ) ;

CREATE TABLE "PhysicalValue" (  
document_id TEXT ,  
"PhysicalValue_id" BIGINT CHECK ( "PhysicalValue_id" >= 0 ) ,  
data_id BIGINT CHECK ( data_id >= 0 ) ,  
label TEXT ,  
uuid TEXT ,  
href TEXT ,  
idref TEXT ,  
type TEXT ) ;

CREATE TABLE "Standard" (  
label TEXT ,  
uuid TEXT ,  
href TEXT ,  
idref TEXT ,  
type TEXT ) ;
D4.10: Tailored decision support for track and vehicle maintenance through conversion of data to information.

```
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
   "Standard_id" BIGINT CHECK ( "Standard_id" >= 0 ),
-- FOREIGN KEY : standard ( standard_id )
   standard_id BIGINT CHECK ( standard_id >= 0 ),
-- ATTRIBUTE
   label TEXT,
-- ATTRIBUTE
   uuid TEXT,
-- ATTRIBUTE
   href TEXT,
-- ATTRIBUTE
   idref TEXT,
-- ATTRIBUTE
   type TEXT
);

-- No annotation is available
-- xmlns: http://RTM_Measure.ecore (RTM_Measure), schema location: RTM_Measure.xsd
-- type: admin root, content: true, list: false, bridge: false, virtual: true
--
CREATE TABLE "Guideline" (  
-- DOCUMENT KEY is pointer to data source (aka. Entry ID)
document_id TEXT,
   "Guideline_id" BIGINT CHECK ( "Guideline_id" >= 0 ),
-- FOREIGN KEY : guideline ( guideline_id )
   guideline_id BIGINT CHECK ( guideline_id >= 0 ),
-- ATTRIBUTE
   label TEXT,
-- ATTRIBUTE
   uuid TEXT,
-- ATTRIBUTE
   href TEXT,
-- ATTRIBUTE
   idref TEXT,
-- ATTRIBUTE
   type TEXT
);
```