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System Architecture for a Data-Based, Automated ETCS L2 Data Point Plan Review

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Abstract

To support the rapid rollout of the European Train Control System Level 2 across Germany's railway network, this paper outlines a step towards automating the data point plan review process. It includes gathering requirements and subsequently developing a system architecture, applying design strategies of the Attribute Driven Design method for architectures, for a data-based, automated data point plan review. In accordance with the gathered requirements, the developed system architecture supports an automated review of the completeness and correct location of the data points in any given plan. The modular structure of the system architecture allows for easy updates and reusability of its modules. Further details of the system are specified in deeper layers of the system architecture. The layers allow covering the underlying rules and regulations in full, hence all functionalities for an automated data point plan review are included. Relationships between the derived modules form a control algorithm, guiding the high-level automated plan review process. The implementation of the developed system architecture will provide support for human plan reviewers, leading to an acceleration of the planning and rollout process of the European Train Control System in Germany, contributing to interoperability and thus increasing railway capacity in Europe.

Keywords: European Train Control System, planning processes, data point, plan review, automation, system architecture

1 Introduction

This chapter presents the initial situation and motivation for this paper, followed by a research on the state of the art. Based on the state of the art, a gap in research is identified and the objective of this paper is defined. Lastly, the structure of this paper in the following chapters is laid out.

1.1 Initial Situation

The search for a fast, reliable and effective means of transport that presents higher energy efficiency and less impact on the environment has resulted in renewed interest and rapid development of railway technology. Two of the central elements that ensure the safe movement of rolling stock through the infrastructure are signalling and communications.

For an efficient and effective railway traffic in Europe, the European Commission introduced the European Railway Traffic Management System (ERTMS) as a standard in Europe. ERTMS makes railway traffic safer and more competitive through a uniform and standardized system, facilitating interoperable railway traffic. Some of the main components of the new ERTMS are the European Train Control System (ETCS), communications through the Global System for Mobile Communication - Railway (GSM-R) and the European Traffic Management Layer (ETML) [1].

The objective of introducing a standardized train control system that enables cross-border railway operations without the use of additional national safety systems was given further emphasis within the European Deployment Plan ((EU) 2017/6).

1.2 Motivation

The national ETCS-implementation plan for Germany published in October 2017 [2] has set the target of adding 1,818 kilometres of lines equipped with ETCS by the end of 2023. A comparison (see Figure 1) between the lines planned to be equipped with ETCS L2 by 2023 (left side) and the lines actually equipped with ETCS L2 at the end of 2023 (right side) shows, that by the end of 2023 only 557km of lines could be equipped with ETCS [3]. As of the latest update of the migration strategy for ETCS in the German railway infrastructure, 4,399 kilometres of lines are now planned to be equipped with ETCS L2 by the end of 2028 [3].

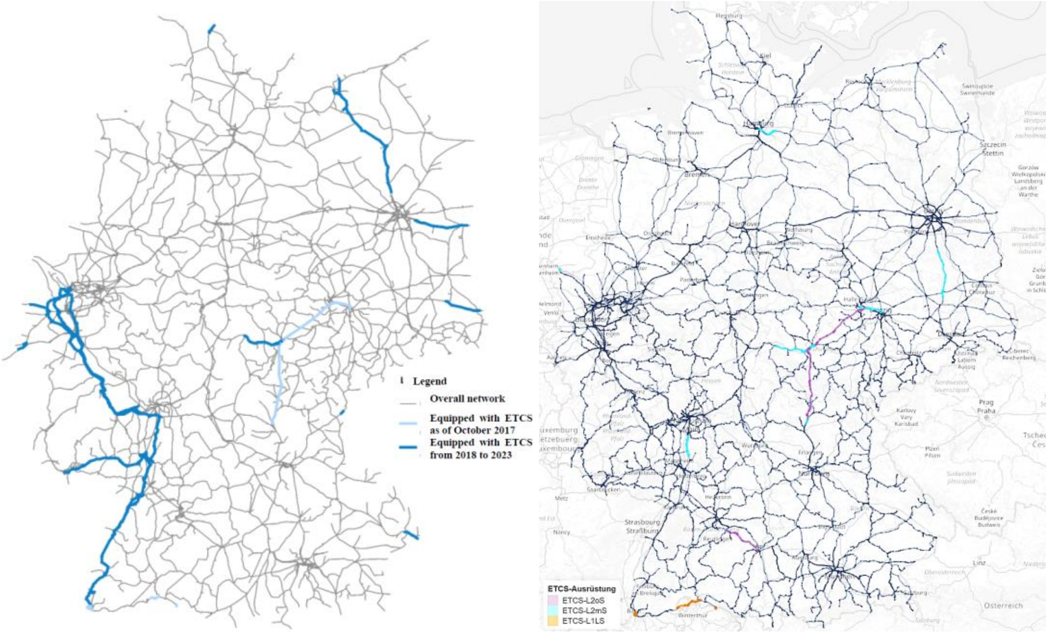

Figure 1: Lines planned to be equipped with ETCS by 2023 on the left side [2] vs. Lines actually equipped with ETCS by the end of 2023 on the right side [3].

The slow progress in the rollout of ETCS in the national railway network of Germany may lead to delays in timelines with neighbouring countries and the realization of a safer and more competitive, interoperable railway traffic in Europe. A rapid rollout of ETCS L2 in Germany among others depends on the available planning capacities. Support for the human experts, working in ETCS planning, can help to accelerate the planning processes [4].

1.3 State of the art

As of [3], ETCS Level 2 (L2) is the preferred ETCS level to be rolled out in Germany. ETCS L2 planning processes for the German railway network are based on the rules and regulations 819.1344: Principles for the planning for ETCS L2 [5]. Responsible authorities in Germany require a dual control in planning processes through the separation of plan creation and plan review [6]. In order to provide the needed support for human experts, accelerating the ETCS L2 planning processes, the state of the art of (separate parts of) ETCS L2 planning processes, with special regards to data-based and automated planning, is investigated.

In praxis, ETCS L2 plan creation on the one hand is carried out by human experts, supported by planning tools. On the other hand, plan review is carried out manually by human experts, sometimes with the support of own, unsystematic calculation tools, mainly spreadsheet based.

A review of the literature and industry research on automation of ETCS planning processes shows research efforts on data-based planning, among others on the digitalization in the planning process of signalling facilities [7–9] and the formalization of railway signalling planning processes [10].

With regard to ETCS planning, there is literature on data-based ETCS L2 plan creation [11]. Some of the central findings discussed in these articles refer to the time saving potential by creating an AutoCAD based layout plan for ETCS L2 DP plan manually and in a subsequent step generate the summarizing DP tables automatically. Further time saving potential has been identified in the formalization of planning rules and (partly) automation of the planning processes.

A review of the industry leading developmental activities within the field of ETCS L2 plan creation and plan review leads to tools for data-based ETCS L2 plan creation. These tools are developed by different software companies and feature different approaches The approaches include for example more graphical, data supported plan creation (CAD-/BIM-based tools), among others used in ProSig (see also [11]), e.g. as part of PlanPro toolbox [12] or more numerical, data supported plan creation (table-based tools), such as in [13].

The PlanPro toolbox, on top of that, already provides some plan review functionalities for railway signalling planning processes [13]. However, these functionalities support other areas of the signalling planning but fail to include ETCS L2 plan review. Existing literature provides with initial research on the automation of ETCS L2 plan review. Currently, the scientific efforts are limited to initial research and a feasibility proof for the automation of the ETCS L2 plan review through formalization of the rules and regulations [14].

1.4 Identified research Gap and objectives and structure of this paper

The literature and industry research shows that various activities within the field of automating the process for ETCS L2 plan creation are taking place. However, within the context of ETCS L2 plan review, only a feasibility proof for automation has been carried out. In this context, the derivation and development of the process towards a data-based and automated, ETCS L2 plan review has not yet been addressed within scientific literature.

In order to address the above-describe gap in research, a data-based, automated ETCS L2 plan review needs to be developed. The development of an approach for the automation of any process as per standard involves gathering all functional and non-functional requirements at an early stage. After the requirements have been gathered, the system architecture, representing a bridge between the requirements and implemented code, can be derived [15]. The objective of this paper is twofold. First, the requirements for a data-based, automated ETCS L2 plan review are to be systematically gathered. Second, a system architecture for a data-based, automated ETCS L2 plan review, meeting the gathered requirements, as a base for the implementation, is to be derived. In the context of this paper, the system corresponds to the entirety of functionalities (=algorithms) needed for an automated ETCS L2 plan review, the system architecture includes the functionalities and how they interact (=behaviour of the system).

After the introduction to the initial situation and motivation for the overall topic, as well as an investigation of the state of the art and definition of the objectives in chapter 1, this paper is structured in three more chapters to achieve the defined objective: Subsequent to this chapter, the Chapter 2 focuses on the requirements and methods. As an initial step, the requirements are gathered. Following, methods to achieve the defined objective are derived and the approach, how the methods are applied to develop the results, is described. The following Chapter 3 focuses on the results, namely the derivation and development of a system architecture for a data-based, automated ETCS L2 plan review, using the approach described in Chapter 2, and presents the developed results. The last Chapter 4 focuses on the conclusions of this paper, including the new and important aspects and conclusions that can be drawn from them.

2 Requirements and Methods

This chapter presents the gathered requirements for the development of an automated ETCS L2 plan review. In addition the methods to on the one hand address the overall problem of automating the ETCS L2 plan review in brief and on the other hand to develop a system architecture as a step towards automation are described.

2.1 Requirements

The requirements are mainly derived from workshops and interviews with future users, namely, technical experts from the field of ETCS L2 plan review. Due to the small number of experts in this field, further interviews with experts from the fields of ETCS L2 plan creation as well as interlocking plan review and acceptance testing of plans (from the infrastructure manufacturer) have contributed to complement the list of requirements with expertise from adjacent domains. In addition to the workshops and interviews, a systematic analysis of the applicable rules and regulations for ETCS L2 planning in Germany [16] has allowed to further enhance the level of detail of the gathered requirements and to crosscheck and complement the list of resulting requirements.

The requirements have been categorized into functional requirements and non-functional requirements. In the context of this paper, functional requirements are those that directly must be fulfilled through functionalities of the automated ETCS L2 DP plan review, and non-functional requirements those that must be fulfilled through an adequate structure of the system architecture.

The functional requirements can be clustered into four main functional requirements:

- process relevant data-based inputs automatically,
- review the completeness of the ETCS L2 DP plan,
- review the correct location of the DP in accordance with DP-specific rules and
- review the correct location of the DP in accordance with the basic principles for DP locations.

These four main functional requirements contain further detailed requirements, e.g. on the relevant inputs or the output of a report containing the results of the plan reviews of completeness and correctness. In addition, four non-functional requirements are identified:

- be exhaustive, i.e. consider the German rules and regulations for ETCS L2 DP planning in full,
- be expandable, e.g. when DP types are added or removed,
- be modifiable, e.g. when a new/updated version of the rules and regulations is published and
- if possible, be reusable, e.g. for use in other countries.

An overview of all architecturally relevant functional requirements for a data-based, automated ETCS L2 plan review, consolidated after the workshops and interviews with experts from the field, is shown in Figure 2.

2.2 Overall problems to be solved for the development of a data-based, automated ETCS L2 plan review

The data-based, automated ETCS L2 plan review has to fulfil functional as well as non-functional requirements (Sub-chapter 2.1). The non-functional requirements correspond to characteristics, which need to be fulfilled through a fitting structure of the system architecture. The functional requirements demand functionalities for data processing and reviewing the ETCS L2 plan. Data processing functionalities are mainly to be achieved during implementation, subsequent to the development phase discussed in this paper. Therefore, this paper sets its focus on the problems that need to be solved to perform the plan review itself.

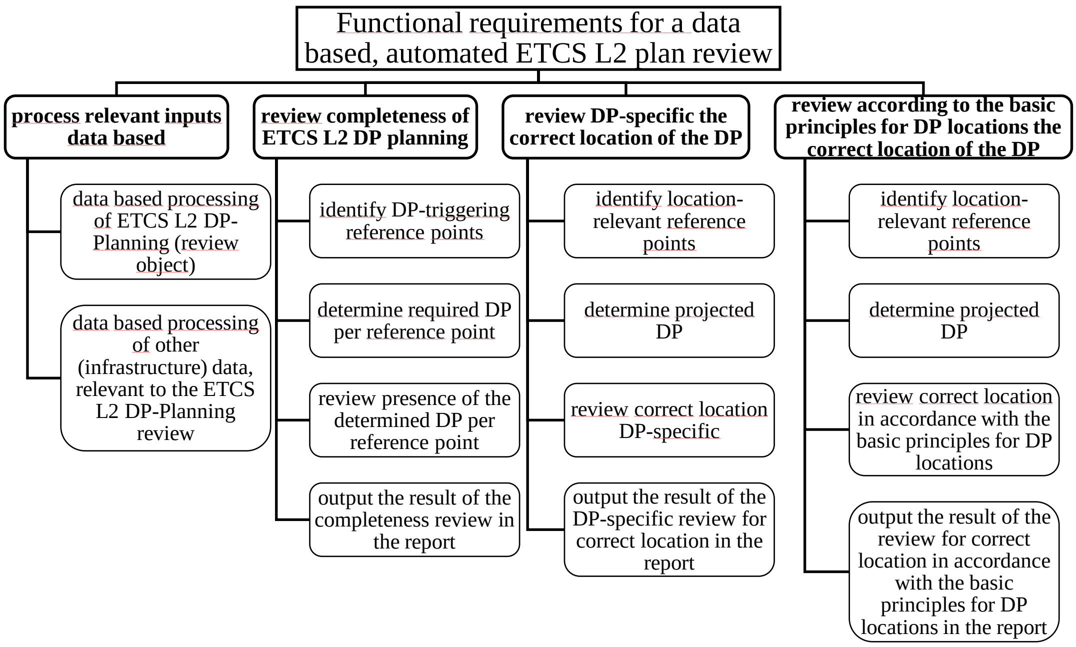

Figure 2: Overview of the functional requirements for a data-based, automated ETCS L2 plan review (own figure).

The automated plan review process entails the process of investigating if the ETCS L2 plan to be reviewed complies with a set of conditions. The conditions are derived from Germany's underlying ETCS L2 planning rules and regulations [5]. The output generated at the end of the automated plan review process is delivered as report, which provides detailed insight regarding whether the reviewed plan complies with the conditions or not.

Furthermore, according to the requirements (Sub-chapter 2.1), decisions are needed on the completeness and correctness of the ETCS L2 DP plan (DP-specific and according to basic principles for DP planning). Hence, the generated output must provide with solutions to a set of decision problems. Carrying out the entire ETCS L2 plan review in an automated manner requires to connect and control the small decision problems, to construct a coherent automated process. .

Initial attempts to formalize the rules and regulations into an automated process (see [4]) indicate that the digital database is not consistently complete. Moreover, it has become evident that the rules and regulations only include conditions to be met. Yet, these do not include a description of the entire ETCS L2 plan review process. In addition, the rules and regulations involve a set of exceptions that may not be suitable for their modelling as binary (e.g yes/no) answers. In few instances, resolving such exceptions may even require a context-specific consultation with the authors of the rules and regulations. Consequently, a purely mathematical solution of the review problem might be particularly difficult to implement.

To address the complexities brought by a comprehensive assessment of completeness and correctness of an ETCS L2 plan, a heuristic and rule-based decision-making approach, is recommended. Heuristics serve to formalize mainly knowledge-based activities, traditionally performed by human plan reviewers. Heuristically formalized activities can include e.g. a control algorithm, guiding the overall process of the automated plan review and ensuring a systematic evaluation or algorithms to review the completeness of the ETCS L2 plan. Rules and regulations, mainly regarding the location of ETCS L2 DP, can be formalized as rule-based algorithms. The explicit rules are to be complemented with heuristic elements that would allow for the formalization of more complex cases, such as instances involving an incomplete database or requiring consultation with authors.

2.3 Methods to achieve the described objective of this paper

In [17] it is stated, that designing an architecture is essential since it

- manifests early design decisions,
- functions as an abstraction of reality that is reusable and
- serves as a means of communication among stakeholders.

The architecture of a program or computing system comprises the software components, their externally visible characteristics, and the relationships between the components. This means, that the architecture must consider function and scope of each of the components as well as their interaction [18, 19].

For designing a system architecture, a vast number of methods exists. Currently, there is no available overview in literature that provides a description and a systematic or comprehensive comparison of methods for the general design of system architectures. This is also the case for designing system architectures for plan review or verification purposes. Frequently cited work have, among others, been published by [15], [17], [18] and [19].

Since the architecture must be designed such that it corresponds with the above-listed functional requirements, a method that supports the requirement-based development of a system architecture is needed. Methods, supporting a requirement-based development of architectures are among others The Open Group Architecture Framework (TOGAF) [20]or the matrix-based Zachman Framework [21], which are focused on the development of enterprise architectures. A more software development suited approach is the Attribute-Driven Design (ADD) method, proposing an iterative approach to develop a requirement based system architecture [19].

As the design strategies of the ADD method allow to derive a system architecture based on the main requirements of a system, it is selected to achieve the described objective of this paper. The three design strategies of the iterative ADD method include:

1. the decomposition of the system,
2. the design of architecture components according to significant requirements and
3. testing if the design satisfies the requirements.

The three strategies must be repeated until all significant requirements are satisfied. Each iteration helps to select a part of the system, gather all significant requirements for that part and design and test the respective design.

A benchmark of well-established design structures, which can be utilized as a complement to the above-chosen method for designing a system architecture, can be found in architectural patterns. A pattern or a combination of patterns can be used to make the architecture fit with a specific context and requirements. Common patterns according to [19] are among others Module Patterns (e.g. layered pattern or decomposition pattern), and Component-and-Connector Patterns (e.g. Broker Pattern), to which the service-oriented architecture (SOA) belongs.

Like many other systems, the automated ETCS L2 plan review requires a combination of various different functionalities. In order to ensure that the system is updatable and reusable (see requirements from Sub-chapter 2.1), the use of a pattern, supporting the separation into modules with little interaction between each other, is suggested. This not only supports the representation of the required functionalities but also non-functional advantages like portability, e.g. to a different operating system, modifiability, e.g. in case of changes in the underlying rules and regulations and reuse, e.g. in other countries with different constraints and rules and regulations.

In order to achieve the separation into mostly independent modules, a layered pattern, which divides the system into units called layers, can be used [19]. Each layer represents a group of modules that provide a set of functionalities. The relations between the layers are unidirectional and allow using the related layers. One downside regarding the use of different layers resides in the fact that it may result in slightly weaker system performance. The reduced performance is due to the resulting complexity of the system, as it needs to switch between contexts. Nonetheless, such ability to switch between contexts would allow to capture and represent the complexity of the system, thus, he layered pattern is chosen for this purpose. At the same time, it must be considered that the performance in terms of computing speed is not crucial for the developed system since it is not to be used in real-time operations but in the phase of infrastructure planning. Therefore, the layered pattern stands as the chosen alternative to design a complex system such as the automated ETCS L2 plan review.

To present and document the resulting system architecture, a formal (e.g. mathematical), semi-formal (e.g. UML) or non-formal notation [19] can be used. Since the addressed problem requires a solution that combines heuristic functions and rule-based decision-making (see Sub-chapter 2.2) and standard semi-formal notations, such as UML, do not support the documentation of layered pattern, the derived system architecture is documented in a non-formal notation, based on UML.

2.4 Approach to achieve the described objective of this paper, applying the method and pattern described in the previous subsection

A combination of a bottom up and top down approach is followed while applying the above introduced design strategies. The heterogenic nature of the identified requirements led to a slightly modified application of the method, such that all three design strategies are carried out for all the components of the system from bottom up. After that, the next iteration is started, carrying out all three design strategies for all the components of the system from top down, instead of going through the iterations with one single component. The approach is realized as follows:

1. the decomposition of the system, in order to derive the modules that are needed to meet the requirements
   - 1.1. bottom up: deriving the (sub-)functionalities from the rules and regulations
   - 1.2. top down: deriving further (sub-)functionalities which are needed in the system to meet the requirements
2. the design of architecture components according to significant requirements and
   - 2.1. bottom up: grouping (sub-)functionalities in sets of functions, which form the modules of the system architecture, and assign them to layers
   - 2.2. top down: deriving the relations within and between the layers; the relations and functions in the top layer represent the heuristic control algorithm, which guides the automated plan review process (behaviour / overall strategy of the system)
3. testing if the design satisfies the requirements
   - 3.1. bottom up, testing if requirements as per rules and regulations are met
   - 3.2. top down, testing if additional functional requirements are met

3 Results

This chapter presents the development of the results achieved through the application of the method and pattern, using the approach described in chapter 2. Concluding, the results are presented.

3.1 Decomposition of the system – bottom up

Following the above-described approach, initially the system is decomposed to derive the necessary modules. The first part of the decomposition is conducted bottom up, based on the German rules and regulations for ETCS L2 DP planning [16]. The largest part of the rules and regulations corresponds to text sections, which describe the conditions for the planning of each specific DP type. There are text sections with rules for 37 specific DP types (numbered from 1 – 63, however not each number is occupied). These include, in which case(s) a specific DP type needs to be projected, using a reference point already existing in the infrastructure, which triggers the planning of the specific DP type, and where this specific DP needs to be located. To define the location of the specific DP type, a reference point is used as well, however this can, but does not necessarily have to be the same reference point like the one that triggered the planning of the specific DP type. In addition to that, the rules and regulations describe the basic principles for DP locations, including eight rules concerning DP locations in general, e.g. the projection of DP in the area of switches or metal masses.

The text sections with rules for the 37 specific DP types can be considered in the development of the system architecture as follows: The review of the correct location of each specific DP can be included in the system by a sub-function for each specific DP type. These include a rule based DP-specific algorithm, developed through systematic formalization of the respective text section of the rules and regulations. This algorithm reviews the correct location according to the rules and regulations of each specific DP, using information about the location-relevant reference point and the location this DP is actually projected, and adds an entry to the report with the result of the review of the correct location of the specific DP.

The review of the presence of a required DP type needs to be initiated coming from the triggering reference point. Triggering reference points, such as main signals, trigger different DP types, depending where in the infrastructure, e.g. at level crossings or on free tracks inside ETCS L2, the reference point is located. The risk of ambiguity of reference points in different parts of the area can be solved by dividing the area to be reviewed in independent “functional sections”, within which the completeness of the DP required in the functional section can be reviewed algorithmically, based on the rules and regulations. The functional section specific algorithm, like DP-specific algorithms, adds an entry to the report with the result of the review of the completeness of the DP planning in the functional section.

The text sections with basic principles for DP locations can be considered in the development of the system architecture as follows: The review of the correct location of each DP in accordance with the basic principles for DP locations can be included in the system by a sub-function for each basic principle. These include a rule based algorithm per basic principle, developed through systematic formalization of the respective text section and add an entry to the report with the result of the review.

In order to review correct locations of DP, there is the need for support functions, which can be used by every DP-specific function. These should provide functionalities, such as to calculate distances, e.g. between a specific DP type and the location-relevant reference point. The reference distances are given either as a determined value, or as a formula, depending on the speed. The formulas employ the unit m/s, whereas the allowed speed in the railway sector mostly is given in km/h. Therefore, a further useful functionality is a reusable function, providing the service to convert between the two speed units.

The above described sub-functions and functions, derived bottom up from the rules and regulations, show unequal granularity. To derive the necessary layers and modules of the system architecture, a grouping of the functions, is needed, which is conducted in the following sub-chapter.

3.2 Design of architecture components – bottom up

As described in Sub-chapter 3.1 the review of the presence of a required DP type needs to be initiated through the triggering reference point. The proposed solution requires a function for completeness review for each independent functional section. Independent functional sections at the same time enable the system to conduct parallel reviews of the functional sections. Therefore, the DP-specific sub-functions to review the correct locations of all DP-types, assigned to a functional section, are grouped into a function for the correctness review for each functional section. The completeness review and the DP-specific correctness review for each functional section can be considered in the same and deepest layer (L3), considered in this paper. Together, they can be grouped to a higher layer (L2) function for the review of each functional section. From the German rules and regulations, four independent functional sections can be derived and be reviewed in parallel. These can again be grouped in a higher layer (L1) function for the review of the functional sections. The L1-L3 functions, derived bottom up from the rules and regulations, and how they are included in deeper layers of the system architecture, is shown in Figure 3.

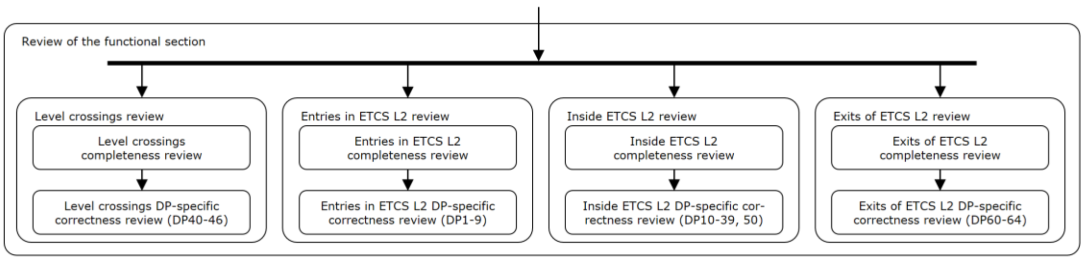

Figure 3: L1-L3 functions for an automated ETCS L2 DP plan review, derived bottom up from the rules and regulations (own figure).

The sub-functions to review the correct location of each DP in accordance with the basic principles for DP locations review can be grouped in a function to review the basic principles for DP locations (L1 function, corresponding to the review of the functional sections).

In order to output the result of the completeness review, DP-specific correctness review and review of correct location according to the basic principles for DP locations, a plan review report must be systematically generated from all entries added to the report. Therefore, a further L1 function to generate the report must be included in the system, subsequently to the review steps. The three bottom up derived L1 functions "review of the functional sections", "review of basic principles of DP locations" and "generation of the review report" can be grouped to the system architecture module "**Review process**" on the top layer (L0). The "**Output**" of that process, the plan review report, is to be included in the system as the terminating top layer (L0) module.

In order to perform the plan review process in an automated manner, the functions for distance calculation and conversion are used. These can be grouped to "**Shared Services**" which form a second system architecture module on L0. All bottom up derived modules and functions (L0 and L1), as parts of the resulting system architecture, are presented in Figure 4.

3.3 Testing – bottom up

The bottom up derived architecture components (modules and functions) can be related to three main functional requirements "review completeness", "review DP-specific the correct location" and "review in accordance with the basic principles for DP locations the correct location" of the requirements. From the more detailed functional requirements, consolidated under these main functional requirements, the above-derived modules fulfil the requirements to review and output each of the three categories. Consequently, the functional requirement of "data-based processing of relevant inputs", the detailed functional requirements to identify reference points and required and projected DP, as well as the non-functional requirements still need to be fulfilled. To ensure these are included in the system, in the subsequent steps the second part of the decomposition of the system is needed.

3.4 Decomposition of the system – top down

Following the approach described in Sub-chapter 2.4, the second part of the decomposition is conducted top down, based on the gathered requirements (see Sub-chapter 2.1), which are not fulfilled yet (see Sub-chapter 3.3). The functional requirements which are open until now, are concerning the "data-based processing of inputs" and preparation of this data to be processed by the bottom up derived functions (see Sub-chapter 3.2).

In order to perform the ETCS L2 DP plan review in an automated manner, the inputs have to be included in the system. The inputs have to contain all the information on the ETCS L2 DP plan as well as all other relevant infrastructure related information, which is mainly results from previous planning steps such as interlocking planning, locally allowed speed and slope.

To make the input data useful for the automated plan review process, among others, the detailed functional requirements to identify reference points and required and projected DP, as described in Sub-chapter 3.3 still need to be fulfilled. Therefore, a functionality to analyse the entire area to be reviewed needs to be included in the system. In order to do so the entire area to be reviewed has to be identified first. To facilitate the review of the functional sections, another functionality, which identifies the functional sections, needs to be included in the system, before the actual plan review can start.

The above described inputs and functions, derived top down from the requirements rules and regulations, need to be assigned to layers and modules of the system architecture, which is conducted in the following sub-chapter.

3.5 Design of architecture components – top down

The data bases "ETCS L2 DP-planning" and "relevant railway infrastructure data" can be derived from the above described relevant input data. They can be seen as L1 data and which is grouped in the module "**Inputs**", representing the initializing L0 module in the system architecture.

The steps, which are necessary to facilitate the automation of the plan review process, require functions to identify the entire area, identify functional sections inside the area and analyse the area to be reviewed. These are L1 functions in the system architecture, which contain further functionalities (e.g. identification of reference points), which can be solved by standard search and sort algorithms and therefore are not detailed further here. The three top down from the requirements derived L1 functions can be grouped in the L0 module "**Pre-Processes**" to be included in the system architecture between the inputs and the actual plan review process.

3.6 Testing – top down

The decomposition of the system top down, coming from the requirements, made it possible to include all functionalities to fulfil the functional requirements that have not been fulfilled by the bottom up decomposition. Further, decomposing the system in a top down approach complementing the bottom up approach ensures that the non-functional requirement of representing the German rules and regulations for ETCS L2 DP planning in full is met and fulfilled. The layered module pattern with hierarchical relations, avoiding recursions between and within modules, allow the system to be expandable or modifiable easily. In addition to that, this structure also makes the system reusable, as the functionalities, ensuring that the German rules and regulations for ETCS L2 DP planning are represented in full, are encapsulated inside deeper layers (layer 2 and deeper). Consequently, only the functionalities in layer 2 and deeper need to be modified or replaced in order to make the derived system useful, e.g. in other countries with different national rules and regulations for ETCS L2 DP planning, respecting constraints of the respective national infrastructure. The derived system architecture, as shown in Figure 4 therefore fulfils the non-functional requirements of expandability, modifiability and reusability.

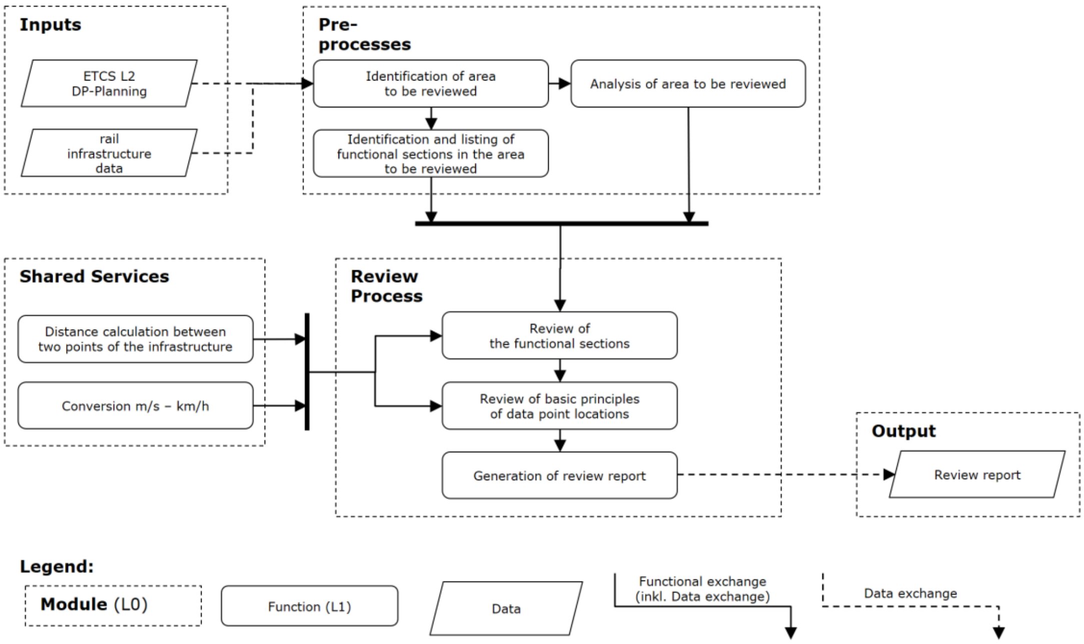

Figure 4: L0-L1 of the system architecture for an automated ETCS L2 DP plan review, derived bottom up and top down (own figure).

4 Conclusions and Contributions

The feasibility of conducting an automated review of ETCS L2 DP plans was presented in [14]. Based on the proof of concept presented in [14], this article derived the requirements and a system architecture for a data-based, automated ETCS L2 DP plan review. The proposed system architecture was derived through a bottom-up and top-down decomposition approach, ensuring a comprehensive consideration of the rules and regulations for ETCS L2 DP planning in Germany as well as the requirements.

A total of five modules constitute the resulting system architecture. The relations between modules and their respective functions define the system's behaviour, presenting a control algorithm that guides the automated plan review. The developed modular system architecture allows not only reviewing single aspects of the ETCS L2 DP plan, e.g. the correct location of a DP, automatically but is also an approach to automate the entire ETCS L2 DP plan review process.

Additionally, due to its modular nature, the proposed system architecture it is expandable, modifiable and reusable. These features allow the architecture to be updated, e.g. in case of updates of the underlying rules and regulations. Furthermore, single modules or the whole system can be used not only in the context in which they were developed(for equipping Germany's railway network with ETCS L2) but also in different railway networks by deriving the functionalities of the deeper layers of the system architecture (beyond L1) from the respecting rules and regulations

The resulting benefits for practical applications include the support and thereby acceleration of the ETCS L2 DP plan review process, which is currently carried out by human experts. The acceleration in the planning processes can support a faster rollout of ETCS L2 in the German railway network, involving the earlier replacement of older national train control systems and contributing to interoperability in Europe. Thereby, the proposed system may contribute to increasing usable railway capacity. In addition, an increase of the planning quality through data-based, automated planning processes can be achieved, harmonizing planning results and decreasing the risk of human errors.

The development of the system has shown that current research does not provide an overview with a systematic and comprehensive comparison of methods for deriving system architecture. This might be an interesting topic to address for researchers in this domain. Furthermore, the analysis of the German rules and regulations for ETCS L2 DP plan review has shown that the contents of the rules and regulations are not suited for full automation of its process. This challenge arises due to, among others, exceptions that require consultation with the authors. Further development of the contents of the rules and regulations may facilitate an increase of the degree of automation of the DP plan review process.

Next steps to make the developed system architecture for a data-based and automated ETCS L2 DP plan review usable for practical applications is the specification of the deeper layers of the system, e.g. the development of algorithms to review the completeness and correct DP locations according to basic principles as well as DP-specific rules. The system architecture for a data-based, automated ETCS L2 DP plan review serves as a framework and base for all further development in this domain and for the implementation of the system.

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