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TECHNOLOGIES FOR THE AUTONOMOUS RAIL OPERATION

D4.4– Stability and headway analysis

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REPORT CONTRIBUTORS

Name	Company	Details of Contribution
Merve Nalbant	DB	Leading the study and writing the outcome
Benoît BIENFAIT	ALSTOM	Reviewing
Marcus Fischer	KB	Contributing (chapter 4.4 and 4.5) & Reviewing
Paul Bretos Loidi	CAF	Reviewing
Javier Goikoetxea	CAF	Quality check

Table 1 – Scope of work splitting among contributors

DISCLAIMER

CONTEXT AND OBJECTIVES

To improve the efficiency of the railway sector, the automatic train is the goal - without driver or any human assistance.

The next step of railway evolution is the operation of an automatic train regardless of the type of the line, and even of its equipment.

To enable such a function even on non-ETCS area means that the GOA3/4 specifications need to be upgraded and a new model provided. Interfaces between ATO and TMS will have to be reconsidered. The main reason is that GOA3/4 specifications lie on assumptions about the TMS behaviour. If an automatic train operated without driver or human assistance is the objective, then those assumptions can lead to instabilities and even to failure.

The focus of WP4 is on bridging the gap to enable ATO operations on no-ETCS area. To do so, WP4 has been divided into three sub-tasks:

- An upgrade of the GOA3/4 specifications
- A semi-formal model of the GOA3/4 specifications along with the use of a model to validate the new concepts by simulations
- A report about the validation of the interaction between ATO and TMS.

These tasks will ascertain the migration to ATO over ETCS and guarantee the safety of the use of ATO in aeras devoid of ETCS.

The operations that are currently operator related need to be reshaped so they can be replaced by automatic procedures, meaning that more autonomous operation will be incorporated.

The objective of WP4 is to operate with ATO in non-ETCS areas. To do so, this task focuses on the possibility to instead use lineside signalling to give the Movement Authority to the on-board ATO.

The main activities are the following:

- Define the generic requirements so this function can be implemented in an interchangeable way – following the signalling principles.
- Define the transition processes from ETCS area to non-ETCS area
- Define addendum to the current interface supported by both subset 130 and 126

These activities are complementary to the development of ATO in class-B area (= non ETCS area) and refer to all the systems the rolling stock is composed of.

The subject of this document is the stability and the headway analysis.

The main goal is to find the parameters that can be modulated to reduce the headway to minimum braking distance.

The definition of these parameters is linked with:

- Train performances (speed of calculation, braking performances under various conditions)
- Timetable management (specific drivers, robustness management)

- Network performances (more precisely the GSMR and the localisation)

Several parameters can play a strong role in the headway performance. If the consideration of the parameters is implemented, it can not only help to reduce the headway to minimum braking distance but also improve the capacity of the line. If trains are more performant and their performance is less situation-dependent, less headway is required and hence the capacity can be increased. Or the same number of trains can be run at improved quality of the service.

The present document D4.4 has the objective to analyse those parameters and determine to what extent they will have an impact on the headway. Use cases will be generated for the analysis process.

METHODOLOGY

An investigative approach is used to answer the problematic.

We realized a state of the art of the current situation and looked for what could be improved to have a positive impact on the headway – to reduce it.

Parameters impacting directly and non-directly the headway are identified and an approach is developed to evaluate their impact. Each parameter is analysed through a study with the goal to determine whether it achieves the objective to reduce the headway to the minimum braking distance.

Finally, a direct comparison of the actual situation and the improved one is realized, allowing to determine the impact of the study considered.

MAIN CONCLUSIONS

The work done gave an interesting contribution thanks to a structured and repeatable process, based on

- Investigative approach
- Common analysis result for each parameter considered
- Clear study to evaluate the impact of each parameter
- State of the art analysis/current situation analysis
- Analysis of the study to evaluate the parameter considered

The work accomplished allowed to find strategies to both quantitively and qualitatively improve the capacity of railway lines.

The analysis conducted evidenced that:

- New research should be led to develop creative ways to improve the capacity of railway lines

Use cases to manage the parameters using GOA3/4 specifications are defined and new technologies are identified.

The main contribution are:

- Analysis method and criteria definition
- New functions and technologies to be developed to improve the headway and consequently the capacity of railway line

The document contributes effectively to the next generation ATO and TCMS system development.

ABBREVIATIONS AND ACRONYMS

ATO	Automatic Train Operation
ATP	Automatic Train Protection
CTA	Connecta
TMS	Time Management system
EN	European Norm
ETCS	European Train Control System
TAURO	Technologies for the AUtonomous Rail Operation
TCMS	Train Control and Monitoring System
THR	Tolerable Hazard Rate
TSI	Technical Specification of Interoperability

TABLE OF CONTENTS

1 INTRODUCTION

The objective of the document is to identify the different parameters that we can already modulate in the current situation, with GOA3/4 implemented, in order to reach minimum braking distance.

The tests are executed on non-autonomous main line.

The document investigates on which extent these parameters can play a role in reducing the headway – and increasing the capacity of the line or the quality.

The document is organized as follow:

- Chapter 2: the context of the study will be defined, including the critical analysis of the methodology used, the current situation on the railway lines, and the impact of the research performed. The methodology applied at each parameter will be detailed. The method consists in describing the current situation, in explaining the contribution of the study performed, and in evaluating the impact of the study. All the studies will be realized under the form of use cases, which will allow an optimized and synthetic evaluation.
- Chapter 3: The different parameters studied under the scope of TAURO D4.4 will be introduced.
- Chapter 4: Critical analysis of every function defined in chapter 2 in accordance with the method described in chapter 3 will be collected. The output for each function is a collection of test use case.
- Chapter 5: Concluding the effect of the analysed parameters on the GoA ¾ specification and functions exported to TMS.
- Chapter 6: References to be introduced.

2 CONTEXT

We know that ATO performance is highly correlated to its interaction with TMS. Both systems lie on strict criteria and include regulations loop that cope with different parameters. For instance, traffic fluidity, punctuality, and energy consumption.

To validate the GOA3/4 specifications and functions exported to TMS, we need to demonstrate the stability of the regulation loop.

To do so, the report must include simulation activities that stress the TMS/ATO system. These simulations shall be based on use cases close to reality.

The headway performance strongly depends on the communication between TMS and ATO. This report will be based on simulations that demonstrate the level of headway performance achievable with the TMS/ATO based on GOA3/4 specifications and the functions exported to TMS.

The headway performance simulation is performed on existing line, trains, and operation schemes.

Hence, to provide the most complete answer to the study, we have first started with a state of the art of the current situation of railway line, and we worked backward from the result expected to be obtained: improved headway performance. We considered the situation of a non-ETCS area and a class-B line – as stated by the requirements of D4.4.

A list of parameters has been compiled to provide a clear understanding of the aspect that can be modulated to improve the headway performance.

The impact of each of the parameters has been tested and a comparison between the current situation vs the improved one has been conducted.

You can find the list of the parameters in the section number 3.

3 LIST OF PARAMETERS

From the requirements of TAURO D4.4, a list of the most relevant parameters has been made.

1. Interlocking processing time: This parameter directly impacts the occupation time of the train and, if improved, can lead to an increase of the capacity of the line. This parameter's unit is the number of second. It can be easily measured through the number of seconds that are spared when the calculation time or the execution time of commands is reduced.
2. Communication time and ETCS processing time: We know that to work properly the ETCS needs to receive all the keys from the RBC. The unit is the number of seconds.
3. Localisation accuracy: We need to have an accurate information about localization. Nowadays, the margin is around 5 meters. If we have a more accurate information, we will improve the headway performance. The reason is that the more accurate and reliable information the on-board ATO has, the better the headway performance will be. The unit of this parameters is the number of seconds.
4. Digital Automatic Coupler (indication time): In rail freight, when the engine brakes, the wagons of the train, for example wagon 1 and 8, do not brake at the same time. The consequence is that we will have a prolonged braking distance. If we use the DAC device, the use of a network-based EP-brake is enabled. Using this, a simultaneous application (not necessarily release) of the brakes in all the cars is possible without big delays. Thus, this will result in a significant gain in braking performance (reducing the stopping distance) and therefore in the distance between two trains can be reduced and if we go further, even in the capacity of the line can be increased. This effect relates to freight traffic only. For passenger coaches already today a simultaneous EP brake control is possible. Modern passenger trains use the concept of multiple units. A DAC device does not make any difference for those. The improvements is in the range of several seconds.
5. Wheel/ rail adhesion situation and adhesion management system performance: in the current class B systems' infrastructure layout, but also in the ETCS braking curves definition, the influence of low wheel/rail adhesion situations is considered. This is done by either establishing overlap distances or additional factors which reduce the considered braking performance, just as for example Kwet. There is the possibility to improve the situation if on the one hand the current adhesion situation is known and reported, but on the other hand also available adhesion management systems are considered during the braking. This way overlap distances can be reduced, and the safe braking deceleration can be increased. Both means can be used to reduce the headways between trains and therewith increase line capacity or operational stability.

4 STUDIES TESTING THE PARAMETERS

The study is part of DB-internal research. It was agreed to share partially the results of the relevant parameters for the TAURO analysis. The study defined a detailed model for occupancy times of trains on the track to analyze the capacity effects. Simulation was performed to schedule trains on microscopic level with the occupancy times of DB model. Simulation allows you to set of corridors to be analysed that covers the range of today‘s technologies and traffic mixes The study reduces headways drastically because it affects most elements of the occupancy time. Internal study claims to increase capacity by up to 35%.

List of 8 corridors of the analysis cover a range of different traffic mixes and reference technologies:

Corridor	**no of tracks**	**traffic mix**	**Current CCS technology**
Wunstorf-Minden, inkl. Knoten Wunstorf	2	all types, speed range 100…200	optical signals+ PZB and LZB
Würzburg – Nürnberg inkl. Knoten Fürth	2	all types	optical signals+ PZB and LZB
Donautalbahn	1	Regional and freight	optical signals+ PZB
S-Bahn München Stammstrecke	2	homogenous S-Bahn	LZB-CIR-ELKE
Rosenheim - Kufstein	2	Regional and freight	optical signals+ PZB
Offenburg - Freiburg	2	all types, speed range 80…160	LZB-CIR-ELKE
Rechter Rhein	2	Regional and freight	optical signals+ PZB
Köln Hbf – Köln-Deutz	node	all passeger types	optical signals+ PZB

4.1 INTERLOCKING PROCESSING TIME

4.1.1 Current situation

The current situation includes interlocking processing times from 9 sec (relay interlocking) to typically 16 sec (electronic interlocking, if up to 4 points are involved). More points and certain level crossings will require longer times.

4.1.2 Contribution of the studies

Processing time TMS (set route)

The time TMS needs to create the set request for the drive protection section(s).

This element is fixed duration, independent from the properties of the involved trains.

Value optimistic:0,25 sec

Value conservative: 0,5 sec

Remark: Assumption for expected high-performance non-safe operation

Switching time Interlocking Elements

The time the movable infrastructure element(s) need to set and lock the requested position, incl. processing in object controller.

This element is fixed duration, independent from the properties of the involved trains

Value optimistic: 1 point to switch: 6 sec 2-4 points to switch: 7 sec others: individual values

Value conservative: 1 point to switch: 6 sec 2-4 points to switch: 7 sec others: individual values

Remark: Standard values for DB Netz. SBB uses 4s. In general, slower switch times result in a better reliability.

4.1.3 Analysis and evalutation

the interlocking itself does not necessarily cause differences between ETCS levels 2 and 3, i.e., the same interlocking may serve both and again time could ascend.

4.2 COMMUNICATION TIME AND ETCS PROCESSING TIME

4.2.1 Current situation

The corresponding processing time of well performing Radio Block Centres is expected to be 1 sec today. However, this omits other times.

4.2.2 Contribution of the studies

Processing ETCS L3

The time ETCS needs to process the set request for the drive protection section (s), from receiving it at the inbound socket to sending a set request to the object controller at the outbound socket

This element is fixed duration, independent from the properties of the involved trains

Value optimistic:0,5 sec

Value conservative: 1 sec

Remark: derived from current target value for processing a MA in a RBC = 0,5 s; not achieved by actually installed RBCs

4.2.3 Analysis and evaluation

According to result of the analysis, 0,5 sec could be beneficial by using ATO and ETCS L3

4.3 LOCALISATION ACCURACY

4.3.1 Current situation

Today’s systems rely on axle counters.

4.3.2 Contribution of the studies

The time needed between the actual measurement of the location and the sending of the train position report to trackside.

This element is fixed duration, independent from the properties of the involved trains.

Value optimistic:0,75 sec

Value conservative: 1,5 sec

4.3.3 Analysis and evaluation

This is a feature of onboard odometry, i.e. there is no systematic advantage of ETCS level 3 + ATO.

4.4 DIGITAL AUTOMATIC COUPLER

4.4.1 Current situation

Electro-Pneumatic Brakes are currently used, especially for passenger coaches and multiple units. For freight trains, brake pipe based, purely pneumatic, brake systems are used.

4.4.2 Contribution of the studies

Digital automatic coupler will enable to use of network based EP brake systems in Freight Trains. Therefore, a higher performance would be possible due to faster brake application.

4.5 CONSIDERATION OF WHEEL/RAIL ADHESION SITUATION

4.5.1 Current situation

Currently low adhesion situations are already considered during operation. This is on the one hand done “statically” by integration of overlap distances in the signalling system/ infrastructure. This way, when missing the target braking distance due to low adhesion conditions, still no dangerous situation occurs.

"Dynamically", the actual situation can be respected by operational rules, such as the reduction of maximum decelerations or maximum speeds to be used for the current train run. As input information rough and very objective messages from train drivers are used, who report for example WSP activity or prolonged braking distances during operation. This information is then used for the subsequent train. There is no accurate information related to the current condition.

Besides, currently adhesion management systems are not yet considered during operation. Especially when looking at for example ETCS braking curves, the consideration of the performance of sanding or adhesion management systems could make a huge difference for the braking curves to be used during low adhesion situations.

4.5.2 Contribution of the studies

At KB simulations/ railway operational studies have been conducted in order to quantify the advantages, especially related to the braking curve parameters Kwet and Kdry, that can be achieved by consideration of the performance of adhesion management systems and further brake system functions, e.g. a deceleration control function.

In this consideration it is assumed that a possible deceleration control function which compensates brake system internal deviations and tolerances has a major influence on the Kdry parameter of the ETCS braking curves.

Beyond, adhesion management functions are incorporated as a major influence on the Kwet parameter as it is already done for the WSP function today.

In parallel to the consideration in the ATP, the adhesion management as well as the other brake system functions could also be considered within the ATO system with a similar effect. Furthermore, the best would be to consider it for both the ATP and the ATO curves to get the optimum effect, independently of which braking curve is the relevant and limiting one in the current situation.

Within the studies, a certain improvement of the parameters Kwet and Kdry effected by new adhesion management and deceleration control functions was supposed. Both improvements were based on experiences from actual measurements that were performed using test trains. As a result using the formula for A_brake_safe defined in UNISIG Subset026-3 (3.13.6.2.1.4), the available safe deceleration and therewith the safe braking distance of the trains in the simulation could be improved. The same approach was used for the ATO braking curves.

4.5.3 Analysis and evaluation

Following an estimation of the possible adaptation (improvement) of the Kwet and Kdry factor by use of the new functions, a railway operational study and corresponding simulations were performed. The simulation study is based on the real suburban railway network of the citiy of Hamburg, Germany. At this point it shall be mentioned that the results of such a study are strongly dependent on the considered operational environment, represented by the signalling system, the infrastructure or the vehicles that are used. The study included the compilation and analysis of two reference scenarios: the operation with ETCS L2 and ATO at "dry" conditions (unrestricted wheel/rail adhesion conditions) and the one at "wet" conditions (reduced wheel/rail adhesion). The scenarios to be examined and rated were based on “dry” and “wet” conditions at use of ETCS L2 and ATO as well but included a potentially improved braking performance based on the use of enhanced brake and adhesion management functions.

The idea is that by reduction of the train approach time, the headway could be reduced, which can then be used to increase the capacity of the track.

Based on the study, the introduction of ETCS and ATO enabled to reduce the signal headway by 9%. Under consideration of a possible adaptation of the safe decelerations/ braking distances of the whole fleet, on dry rail additional reductions of 3% can be realised. Looking at wet rails, additional 9% can be realised compared to the reference scenario. The uncompensated delays can be reduced by 18% on dry rails and the 3-minute-punctionality can be increased by 1 percentage point, whereas on wet rails the uncompensated delays can even be reduced by 57% and the 3-minutes-punctionality can be increased by 7% percentage points. Using this concept, especially the breakdown of punctuality at degraded wheel/rail adhesion conditions can be avoided.

Looking at the theoretically possible performance, the introduction of ETCS and ATO leads to an increase of 13%. The consideration of new braking distance/ deceleration relevant functions leads to another increase by 4,2% whereas the nominal capacity can be increased by 9,5% at the same time. At wet rail conditions the theoretical performance can be increased by 10% and the nominal capacity by 26% leading to conditions almost equal to the ones experienced at dry rail conditions.

As a conclusion we can state that block length for ETCS do have an influence on capacity, but beyond also the braking curves/ decelerations shall be considered which can be influenced by adhesion management and other brake system functions and lead to improved reproducibility/ reduced variations of braking distances. Their consideration in the EBI and the ATO braking curve immediately leads to a reduced train approaching time.

With respect to current Class B systems, there is less potential that can be raised since due to the already fixed conditions related to infrastructure and signalling (fixed block length etc.), rather only the braking curves of the ATO system can be influenced.

5 REFLECTION ON THE GOA3-4 SPECIFICATION AND FUNCTIONS

List of the TMS Functions	List of analysed parameters
• Authorize SR movements • Authorize shunting movements • Dispatch orders • Ensure the monitoring of running trains • Manage possession • Manage temporary speed restriction • Manage track adhesion • Request catenary power shutdown • Request protection against high voltage switch on • Set routes • Solve conflicts • Take initial actions in case of emergencies	• Interlocking processing time • Communication time and ECTS processing time • Localisation accuracy • Digital automatic Coupler • Consideration of wheel/Rail adhesion situation

The listed functions are exported from X2Rail4 Capella model. Those define the interface data exchange logical functions from TMS to ATO. Analysed parameters have direct effect on the functions used in TMS. Hence, some of the functions are crucial for specific parameters researched. For instance, localization accuracy is sensitive parameter for set the route function, if the route is set late, localization will be delayed which occurs lack of efficiency as well as solve conflicts is going to have negative impact. Or if localization accuracy is not correct, all functions stated above going to be affected negatively. Depending on the parameters stated in the research, all functions defined in TMS are going to be affected accordingly including TMS-ATO stability.

6 REFERENCES

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