Rail to Digital automated up to autonomous train operation

D32.2 – DATO business case outline & required inputs specifications and scheme

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EXECUTIVE SUMMARY

Digital Automated up to Autonomous Train Operation (DATO) concepts are innovative technological developments for railway systems. These technologies can be used to automate the operation of trains which has the potential to make rail transport more competitive and improve energy efficiency. The adoption of such new and innovative technologies by decision-makers is challenging due to the uncertainty and lack of a generic method for evidence based and transparent decision making.

The aim of this document is to provide a structured outline that provides guidelines and methods to ensure a successful development of a business case for DATO.

The use of business cases in the railway sector is an established practice, as is academic research on the functionality and applications of DATO technology. The development of a concise and generalisable business case for DATO is, however, an innovation for which this D32.2 deliverable is the starting point. It is the basis on which we will build our D32.1 deliverable, the DATO business case.

The first action to be taken when endeavouring to construct a business case format is scientific research on the current best practices for building business cases in general, especially those where technological developments are involved. Based on best practices from literature and innovative modelling methods (as discussed in chapter 2), business cases for technological developments such as DATO can be built using four building blocks: a clear goal and scope, a business case model, a presentation, evaluation of the results and an interpretation of the results. These four building blocks will, therefore, also be used for the DATO business case.

To be able to contribute to the efficient deployment of DATO, the DATO business case will need to adopt an operational definition of ‘DATO’ since it entails various concepts. There are also dependencies between the different DATO concepts that must be taken into account.

WP32 receives its qualitative and quantitative input for the DATO business case from other R2DATO work packages (e.g.,17,18,37,39). WP32 states requirements and specifications for these data supplying work packages regarding rail traffic and human factors simulations. We do this to make sure that the data will attribute to a business case that will in the most optimal way facilitate fast and cost effective deployment of DATOThis, in turn, requires a look ahead and first abstract idea on relevant business impacts, including human factors (which is a novelty) and a rather more developed idea on several use cases of DATO applications. It also requires alignment and monitoring with the relevant work packages especially since the due dates of their deliverables are not always attuned to the WP32 timeline as defined in the Grant Agreement.

By defining a best practice approach towards a DATO business case, a novel state-of-the-art tool for facilitating the deployment of DATO will be developed. Other requirements to that extent, are a more extensive study of relevant business impacts, their quantification and of the use of innovative modelling methods such as Formal Methods. Together with the aligned output from other work packages such as simulation results and use cases, this will result in an innovative tool for decision/policy making.

ABBREVIATIONS AND ACRONYMS

ATC	Automatic Train Control
ATO	Automatic Train Operation
BAMS	Brake Adhesion Management System
CAPEX	Capital Expenses
C-DAS	Connected Driver Advisory System
DAC	Digital Automatic Coupling
DATO	Digital Automated up to Autonomous Train Operation
DMU	Diesel Multiple Unit
DSR	Design Science Research
EMU	Electric Multiple Unit
ETCS	European Train Control System
ER	Europe's Rail
ERTMS	European Rail Traffic Management System
HITL	Human in the loop
HTD	Hybrid Train Detection
HL3	Hybrid Level 3
FP	Flagship Project
GoA	Grade of Automation
LCC	Life Cycle Costing
LCP	Life Cycle Profit
NG brake	New Generation brake system
OPEX	Operational Expenses
R2DATO	Rail to Digital automated up to autonomous train operation
RBC	Radio Block Centre
RTO	Remote Train Operation
TMS	Traffic Management System
TSI	Technical Specifications for Interoperability
WP	Work Package

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1 INTRODUCTION

The European Union has set objectives to achieve sustainable and smart mobility. To meet these goals as well as the increasing demand for transportation of both passengers and freight, Europe's Rail's Flagship Project 2 R2DATO will take the advantages of digitalisation and automation to develop the Next Generation Automatic Train Control (ATC) and deliver scalable Digital and Automatic (up to Autonomous) Train Operation (DATO) capabilities in order to enhance the capacity of the existing rail networks and more attractiveness of rail in mobility.

Within Flagship Project (FP) 2, work package 32 (WP32) falls within the cluster Fast and Effective Deployment. Its Deliverables D32.2 and D32.1 are aimed at providing an attractive concise business case (format) for future DATO projects with a selection of decisive parameters and guidelines to obtain them. This business case (format) will attribute to a smooth, fast and efficient deployment of DATO technology in European networks as it will assist in the justification of DATO projects by means of a management tool for evidence based and transparent decision making.

'DATO business case outline & required inputs specifications and scheme'

The present document constitutes the Deliverable D32.2 'DATO business case outline & required inputs specifications and scheme'.

It presents:

- scientific research on the most effective business case (format) and best-practices in that field,
- an outline of the structure of the DATO business case (format),
- an overview of work package 32's interconnectedness with other R2DATO work packages, regarding input and output requirements for the upcoming Deliverable D32.1 'DATO business case' with a main focus on FP1 MOTIONAL work packages 8,9,15 and 16,
- ways of alignment with these work packages.

Business case (format)

A DATO business case (format) is an innovation for there is currently no best practice business case (format) for this specific technology. Therefore, as a starting point, scientific research will be done on the most effective business case (format) and best-practices. This will lead to insights and eventually an outline for the DATO business case (format). Chapter 2 will address this business case methodology.

For an effective business case (format), scoping is of course of the essence. There is no set definition of DATO. So which DATO concepts should be considered and why? Chapter 3 of this Deliverable aims at defining DATO concepts, their relevance for the business case and how they correlate.

Interconnectedness other work packages

Data for the business case will be provided to WP32 by multiple other work packages in R2DATO and MOTIONAL. Alignment with these work packages is important and to make sure that the data meets the needs of the business case, WP32 issues requirements and specifications for simulation studies to these work packages. This Deliverable contains said requirements and specifications (chapter 5).

In order to be able to compile efficient and effective requirements and specifications, it is necessary to know which data is relevant for the business case. For this purpose, a first assessment of business impacts as a result of implementing DATO concepts needs to be made early on as well as a set of application scenarios. This will provide insight into which data is needed and will thus in turn lead to an efficient and thought out set of requirements and specifications.

Chapter 4 will address this first assessment and provide a high-level overview of potential business impacts. In chapter 5 a set of application scenarios is included.

For the work towards the D32.1 business case, WP32 will build on the outline of the business case format included in chapter 2 of this Deliverable. Challenges lay ahead regarding timely receipt of necessary data from other work packages and how to approach future technologies such as for instance operation under Grade of Operation (GoA) 4 with a lack of real-world data. In those cases when no operational output information is at hand, modelling of future behaviour will be emulated by simulation or serious gaming.

2 BUSINESS CASE METHODOLOGY

This chapter is aimed at explaining and motivating how a successful business case for DATO can be developed. It provides an overview of what is relevant for the development of the DATO business case based on relevant knowledge, latest developments, and best practices from academia. It provides an overview of considerations and requirements that are recommended for successfully developing a DATO business case and concludes by outlining an approach for building the R2DATO business case itself

2.1 BUSINESS CASE DEVELOPMENT

2.1.1 Business case development for technological change

Business case development on its own is not a new discipline. Many of the generalizable recommendations for building business cases have already been established in hundreds of academic articles [1]. For business cases related to technological development, attention is given to several areas [1] such as (i) justification for actions related to organizational goals [2]; (ii) providing well-reasoned arguments for convincing and educating audiences [3]; (iii) Shaping the decision-making process employing building blocks [4][5]; and (iv) Providing recommendations for the best course of action supported by analysis [6]. At a basic level, any business case can be described using only five “building blocks” consisting of (1) an introduction; (2) Methods & Assumptions; (3) Business Impacts; (4) Sensitivity, Risks, and Contingencies; and (5) Conclusion & Recommendations (see Table 1).

Table 1: Business case structure, amended from [5]

“Building block”	Brief description
A. Introduction	Title, subject, purpose, situation, summary, disclaimer
B. Methods and assumptions	Metrics, assumptions, scope/boundaries, scenarios, cost model, rationale
C. Business Impacts	Financial model, financial & non-financial results
D. Sensitivity, Risks, and Contingencies	Testing assumptions and robustness, investigating sensitivities, what needs to be in place?
E. Conclusion & Recommendations	Motivating business decisions or, and recommending courses of action

2.1.2 Railway business cases

Academic publications (e.g., conference and Journal publications) where a railway business case is the main focus are not widespread, as exemplified in Figure 1.

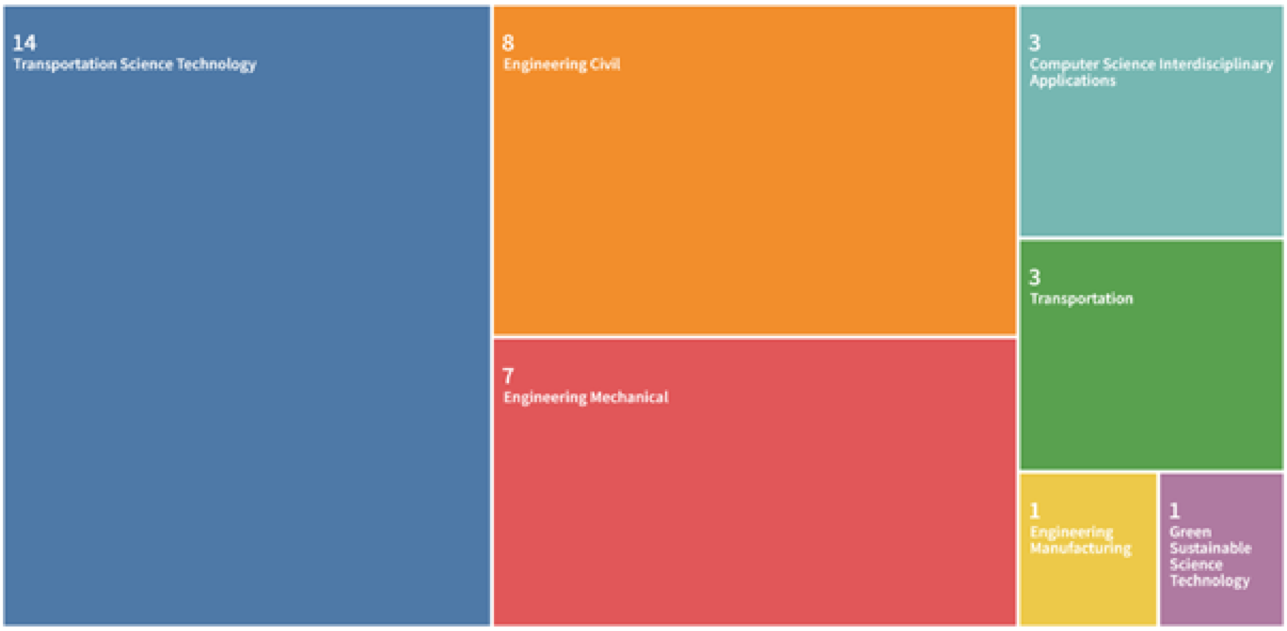


Figure 1: Web of Science results for the query ["business case" AND rail] (www.webofscience.com)

Among the available articles where this is the case are best practices for public-private partnership business cases [7]. There is also growing attention to railway business cases related to better understanding and explaining the main drivers of sustainability in the railway sector [8][9]. An investigation into 16 public infrastructure projects in Australia draws attention to the prevalence of cost underestimation in business cases for railway projects [10]. Based on the review of 21 business cases on major public transport projects in Canada [11], it is recommended to (1) assess if a business case provides an improvement for users and the public, (2) make business cases publicly available before resulting decisions become final, and (3) prioritize the creation of (public) value creation that best captures the interest of the public. The credibility and robustness of business cases for public sector rail projects can be undermined by underestimations of costs and overestimations of benefits [12]. In such cases, credibility in business case development can be addressed through (1) benchmarking, (2) challenge sessions, (3) independent reviews, and (4) sensitivity analysis [12].

Railway investments have been studied in a project management perspective, where the Business Case is an instrument in the start of a project, encompassing both quantitative and qualitative facets [A][B][C][D][E]. One example which includes several railway related investments is the quality assurance of major public investments [F][G]. The purpose is to give government officials and parliament decision support structured as business cases for a proposed investment, including cost, benefits, and societal implications.

Rather than the business case being the focal point of articles, the development and applications of specific technological developments and implementation of DATO technologies is much more common. Examples include but are not limited to (1) Automatic Train Operations for Mainline [13]; (2) Efficiency improvement of automated transit systems [14]; (3) Self-driving freight train taxonomy [15]; And feasibility studies and challenges of ATO for specific countries such as Sweden [16][17]; Overall, there appears a wide availability of many different documents, reports, and research on specific elements and applications of ATO in various countries. The challenge in developing a business case for DATO is to collect the somewhat fragmented knowledge into a concise, attractive, and generalizable business case.

2.2 BEST PRACTICES AND STATE-OF-THE-ART FOR BUSINESS CASE DEVELOPMENT

This section dives into seven specific best practices and state-of-the-art knowledge required for developing a business case.

2.2.1 Goal and Scope

As indicated earlier, the introduction forms the first building block of the business case. A business case can be defined as “*a justification for pursuing a course of action in an organizational context to meet stated organizational objectives or goals*” [2]. As such, business case approaches typically start with making the goal of the business case explicit. Purposes for business cases that use public funding may include (i) Economic cases (is an investment worthwhile?), (ii) Value for Money cases (do the benefit outweigh the costs?), or (iii) Financial cases (is an investment affordable?) [7].

The benefits of an investment are often a function of the values of an organization and will inherently have a significant degree of subjectivity associated with it [2]. As such, business cases are even likened to legal cases presented in court because of the freedom to structure arguments, select and ignore evidence, and package the formal presentation [5]. As such, good business case needs to be based on clear rules and boundaries on what is included [5] as well as a clear framing of the expected value for the stakeholders [18]. By defining the purpose and scope, the viewpoint that is taken in the business case can be clarified [19]. Good business cases therefore need to present rules for deciding what is included and stipulate the boundaries of the analysis [5].

2.2.2 Modular business case models

Good business cases are not only meant to acquire funding but also to show how benefits depend on (technological) business changes in an objective manner [20]. To do this robustly and transparently, a model of the costs and benefits is needed [5]. In Life Cycle Costing (LCC) - a technique that can be used to model and evaluate the cost of a system over the entire lifespan - this can be done by linking costs explicitly to functional activities, system elements, or classes of common items [21][22][23]. To enable this insight for benefits, it is necessary to identify and structure the links between objectives, measures, and benefits as explicitly as possible [24]. Especially for investments in digital technology, including automation, it is important to clearly show the dependencies between various technologies, the business benefits, and overall organizational objectives [25] (see Figure 1). In some sense, business case models can be seen as the ‘centrepieces’ of the business cases and can vary widely from simple individual financial statements (e.g., spreadsheets) to multiple interdependent complex models [5]. In cases where the context of these models is changeable (e.g., for different applications or countries), the use of flexible or re-usable models is advised [26].

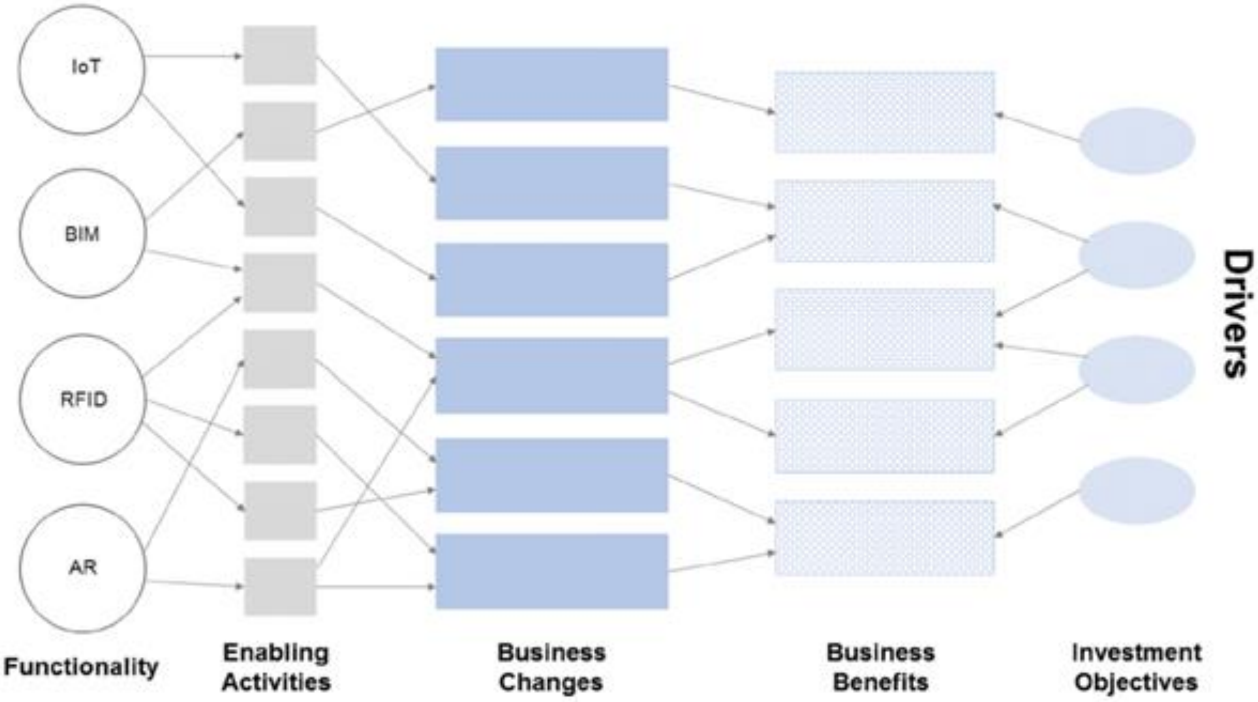


Figure 2: Dependencies between technology and business case benefits [25]

2.2.3 Stakeholder Costs & Benefits

Business cases assess the costs, benefits, and risks associated with a certain decision or action. At first glance, costs and benefits may seem like two sides of the same coin, but to build business cases, there are some important differences between the two. Within infrastructure systems and networks, value is rarely provided by individual assets, but is derived from the cost, risk, and performance of the entire system for various stakeholders [27]. This is especially the case for complex systems such as electricity networks, manufacturing processes, and transport systems [28]. The difference between costs and benefits is also reflected in the existence of different types of analyses for costs and benefits such as Life Cycle Cost (LCC) and Life Cycle Profit (LCP) analyses respectively [29], indicating that value can be gained from both lowering costs as well as increasing benefits. Furthermore, it is generally easier to break down the costs of complex systems into individual components than it is to attribute the benefits of a system in a similar manner. It is even said that cost and benefits are so different from each other that they may well be from 'different planets' [30]. The perception of costs and benefits also depends on the interests of the involved stakeholders that carry the burdens and experience the benefits. Infrastructure organizations often aim to serve society as a whole, which involves creating value for a broad range of stakeholders. How societal (or public) value is perceived by society therefore depends on the perception and interests of the constituencies and often involve political aspects [H].

2.2.4 Using qualitative & quantitative factors

A business case depends on the accumulation of many different costs and benefits for various stakeholders using different technologies. The knowledge, information, and data needed to build a business case model need to be collected and combined from different sources, each with its own original purpose, scope, and level of detail. When objects can only be described and compared using several characteristics, aggregation becomes a major issue [31]. A common practice in these situations is to include business case elements in a qualitative and/or quantitative manner and to distinguish between financial and non-financial impacts [19][27][26]. There are several degrees to which benefits can be made explicit, ranging from observable, measurable, quantifiable, and financial benefits [20] (see Table 2).

Table 2: Degrees of explicitness of benefits, amended from [20]

Degree of benefit explicitness	**Explanation**
Financial	Benefits that can be expressed in financial terms.
Quantifiable	Is measurable and allows for determining the size or magnitude of the benefit.
Measurable	Benefit has an identifiable measure. Can be used to establish (baseline) performance, but not size or magnitude.
Observable	Can only be measured by opinion or judgment. E.g., subjective, intangible, or qualitative benefits.

Overall, the elements of a business case can be developed and made explicit by first making an inventory of elements that can be observed and are deemed to be relevant for use in the business case. These elements serve as recognizable and sensible 'building blocks' to create and present business cases. Business case elements that have relevant costs and/or benefits associated with them will be included in the business case scope. Other elements will be excluded from the scope.

In the second step, all relevant business case elements (that fall within the scope) are first named and described qualitatively. This step involves explaining the logic and relevance of each business case element. This way, 'what' is included in the business case, and 'why' it is included can be easily understood at a glance. This document (the business case outline) already contains an overview of several business case elements that are expected to be relevant to the business case.

To support the measurability and accountability of the business case elements, the elements are preferably included in a quantitative manner where possible and sensible. For non-financial quantities, this should include a description of how the size or magnitude of the impact can be determined. A key step in many business cases that account for quantifiable costs or benefits that are not immediately expressed in cost is monetary valuation. This is the practice of converting measures of social and biophysical impacts into monetary units to determine the economic value of non-market goods [32]. As such, it can be used to translate quantifiable impacts into equivalent financial terms. This practice is commonly used to express environmental impact in financial terms [32] but is also commonplace in societal cost-benefit analysis such as the Dutch "*Maatschappelijke kosten-batenanalyse (MKBA)*" [33]. Business case elements that can be translated into direct or indirect financial impacts should be translated into equivalent financial impact where possible (e.g., # min of travel time is equivalent to X €)

This monetary valuation allows for the aggregation and comparison of the magnitude of the costs and benefits for different stakeholders as they use the same unit (e.g., €). This process is illustrated in Figure 3.

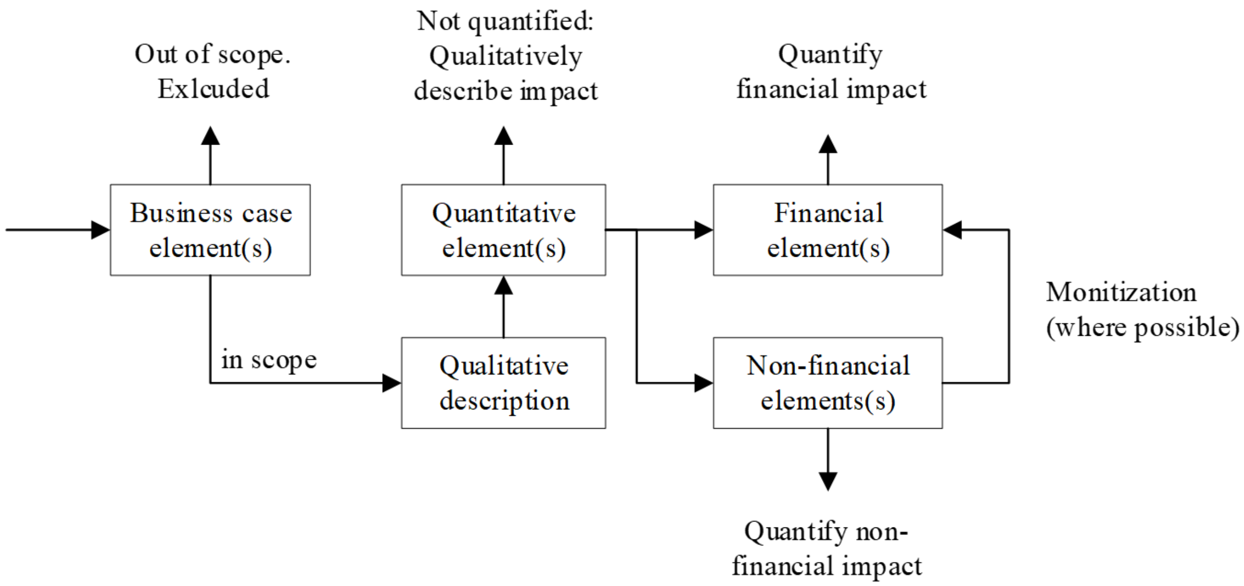


Figure 3: Selection of business case elements

2.2.5 Making sense of business case results

"*In complex, ambiguous, multileveled situations it is necessary to allow and foster a sensemaking interaction associated with communication and representation*" [34]. This sensemaking is something that should be seen as an ongoing process that runs in parallel with business model development and is performed by individuals as well as groups [35]. Iterations to the goals, scope, and model are likely to be necessary, especially when dealing with larger and more complex business cases. For the outcome business cases, a phased delivery of the results is recommended over a 'big bang' delivery of all results in one go [2]. There are several reasons for recommending this phased delivery. Firstly, this allows for formative evaluation and review of intermediate results that can inform changes that may be needed at an early stage [2]. For example, preliminary results may inform changes to the goal, scope, assumptions, or model of the business case itself at an early stage. Secondly, it can help in early shifting the focus to the most important or sensitive elements of the business case by means of a 'Gravity analysis' or 'Pareto analysis', drawing attention to the model inputs or outputs that have the most impact on the business case results [36]. This focus-shifting towards the most important elements may be used to simplify the business case which in turn improves the communication and clarity of the results [29][26].

Overall, a phased and iterative approach is recommended as it leads to increased acceptance of the outcome through understanding costs, benefits, participation, building trust, judging efficacy, and alignment with values and goals [37] (see Figure 4). In cases where business cases are concerned with enterprise-wide transformation, a continuous "living" business case may even be considered which is continuously updated over the life of the project, including implementation [24].

2.2.6 Dealing with sensitivity risk and uncertainty

When dealing with innovative topics, uncertainty is an important factor in interpreting the outcome of the business case. There are internal sources of uncertainty that are part of the business case model such as uncertainty or sensitivity or specific parameters or assumptions. There are also external sources of uncertainty that may or may not be included quantitatively in a business case [39]. A risk assessment can be performed to assess whether risks and uncertainties are tolerable, as low as reasonably possible, or intolerable [38].

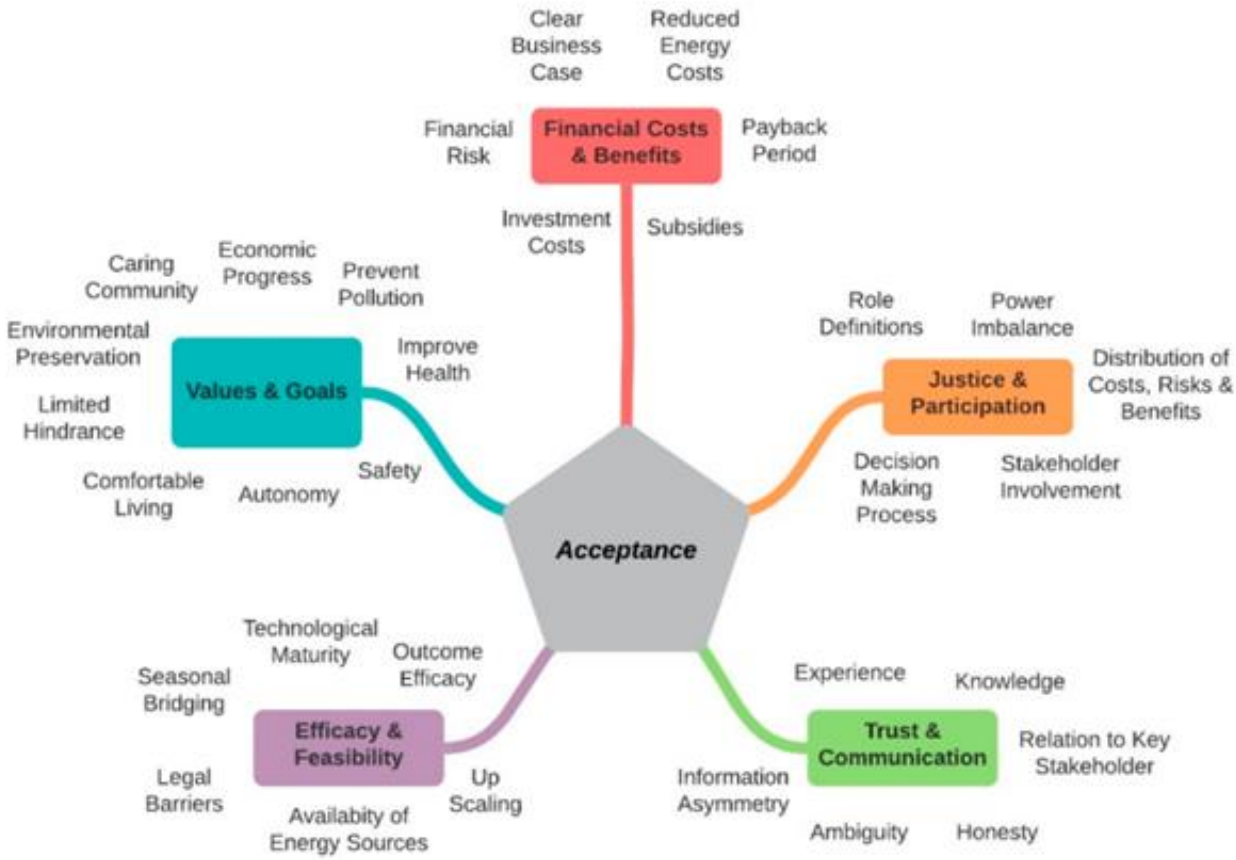


Figure 4: Key concepts affecting different types of acceptance of transitions [37]

2.2.7 Participatory & collaborative business case development

Advanced or specific knowledge or technical skills may be required to correctly develop and evaluate the business case, necessitating the involvement of experts [3]. The management of complex and large systems such as the railway system often depends on bringing together and collaborating with multiple different disciplines [40][41]. Furthermore, the information also needs to be understood by laymen without losing essential information [42]. This collaborative integration of multidisciplinary knowledge, combined with the aforementioned phased approach needed for sensemaking and acceptance means that the development of the business case itself is likely to benefit greatly from a formal process of facilitation.

Design Science Research (DSR) [43] is a useful research strategy in this regard as it involves the construction of a wide range of socio-technical artifacts such as decision support systems, modelling tools, governance strategies, evaluation methods, and change interventions [44]. It also allows the research to be grounded in the state-of-the-art and best practices as indicated in this document and enables future development to continue to align with potential changes in the goals, needs, and challenges in the business case.

2.3 DATO BUSINESS CASE OUTLINE

Based on the best practices and state-of-the-art knowledge, several recommendations can be made about the process and choices needed to develop a business case (format) for DATO. This approach can be summarized by four main building blocks, as indicated in Figure 5. These building blocks are the fundament of the outline and structure of the DATO business case (format).

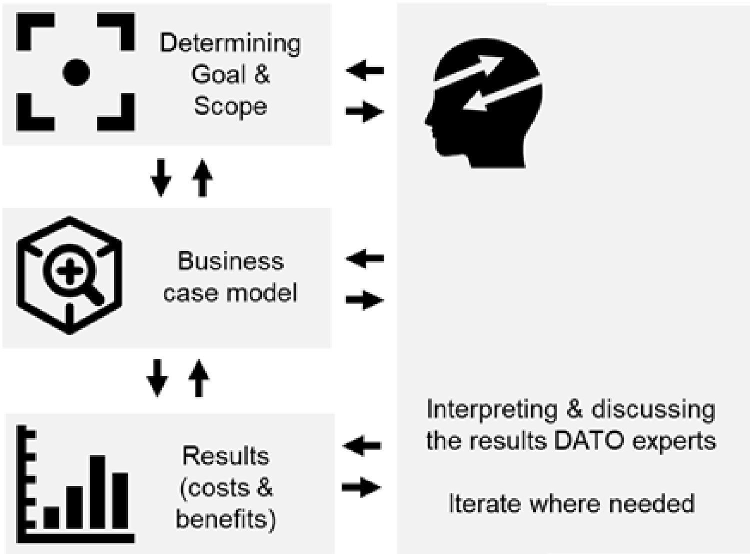


Figure 5: Four building blocks of R2DATO business case development, amended from [26]

Building block 1: Goal & Scope

The first building block states the goal, scope, and boundaries of the business case. The main business objectives and stakeholder value are elaborated on. In the scope section the DATO technologies are scoped as well as the business impacts.

Building block 2: Business case model

The second building block describes the (flexible) business case model, as a result of a collaborative approach. This model contains the most relevant business case costs and benefits. This part will show how DATO leads to certain costs and benefits in a manner that is as explicit as reasonably possible. This means that elements of this model are first described qualitatively but are made quantitative and/or expressed in financial terms where possible. For this, the relation between the different DATO concepts and generic DATO costs and benefits is made.

Building block 3: Results

The third building block involves presenting and evaluating the results of the business case model including the testing of assumptions, risks, and sensitivities. The business case will be tested and evaluated based on examples from real-world case studies. These case studies are also used to improve and expand the business case model.

Building block 4: Discussion of the results

Lastly, the fourth building block is to interpret the results and discuss the results to provide clear, well-understood, and well-motivated courses of action. The DATO business case is preferably developed in a phased and iterative manner to allow for a focused and concise assessment of the main costs and benefits and allows for early knowledge exchange with other work packages.

As part of the business case development for DATO, academic research will be performed on how the process of developing business cases can best be facilitated. The intended academic result is the creation of new and generalizable knowledge and understanding of how business cases such as the one for DATO can be best developed and facilitated for DATO. 'Field testing' of the designed artifacts [45] and participatory collaborative development [46] (see Figure 6) with DATO experts is part of the approach.

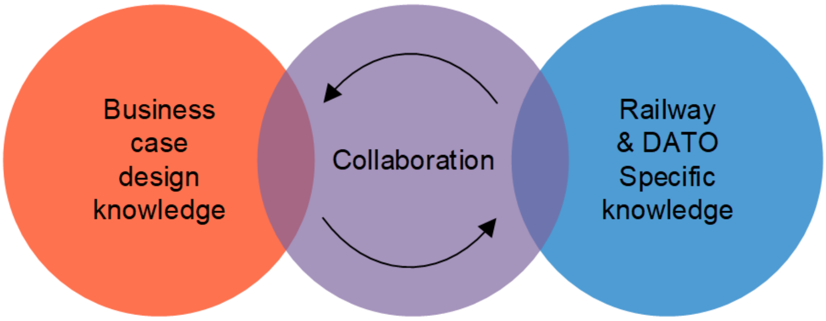


Figure 6: Participatory design collaboration system model, amended from [46]

3 DATO CONCEPTS

This chapter provides an overview of the definitions and motivations for the DATO concepts that are considered for the DATO business case. For each of the DATO concepts, the main motivations (assumed benefits) are summarized to explain their relevance for the business case but will touch on the main prerequisites or costs. These elements are discussed in Chapter 3 on Business case impacts.

3.1 DATO

As described in the previous chapter, we are working towards a framework for a business case for DATO concepts. Before we delve into describing the various DATO concepts within the scope of this framework, it is important to clarify our understanding of the term DATO.

By DATO, we mean: Digital Automated up to Autonomous Train Operation concepts. This encompasses significant leaps in railway systems, ranging from the automation of (parts of) train operation to fully autonomous train operation.

To determine which DATO concepts are relevant to the business case (format), we have examined the concepts being developed within R2DATO. The identified concepts are ATO GoA2, ATO GoA4, C-DAS, TMS, ERTMS HL3, ERTMS Moving Block, NG Brake, Digital Automatic Coupling, and Remote Train Operation. These concepts will be elaborated upon in the following paragraphs.

3.2 ATO

The term "ATO" stands for Automatic Train Operation, which is an overarching concept. There are four different levels of automation referred to as GoA levels (Grades of Automation) defined in the international standard IEC 62290-1:

- GoA1: The train driver operates the train manually, possibly with the assistance of driving advisory systems.
- GoA2: Acceleration, deceleration, and stopping are automated. The train driver remains responsible, monitors the ATO system, and intervenes if necessary.
- GoA3: The ATO system operates the train independently. The train driver does not need to be in the cab and can perform other tasks.
- GoA4: The ATO system operates the train independently and intervenes in case of (potential) incidents. No train driver is present on the train. Disruptions are managed through remote control and/or by a maintenance team.

The GoA levels are also illustrated in Figure 7.

GoA1 represents the current manual train operation, which serves as the reference point against which the benefits of higher GoA levels are evaluated. The addition of a C-DAS to GoA1 (sometimes referred to as GoA1.5) is treated as a distinct DATO concept in chapter 3.5.

In this study we consider GoA3 out-of-scope as a separate concept and take a more in-depth look at GoA4. As such, the business case includes the two extremes of DATO implementation levels in sense of estimated benefits and costs. The scoping for the baseline is GoA level 1, which represents a minimal level of automation. On the other end of the scope, GoA level 4 is included representing the most advanced technical level for DATO in which the full benefits of DATO can be realised. GoA level 2 is included in the scope as an intermediate level, representing the highest level from which empirical data is available at the time of writing.

Grade of Automation		Door closure	Setting train in motion	Stopping train	Degraded operation in case of disruption
GoA1	Non-automated train operation	Driver	Driver	Driver	Driver
GoA 2	Semi-automated train operation	Driver	Automatic	Automatic	Driver
GoA 3	Driverless train operation	Attendant	Automatic	Automatic	Attendant
GoA 4	Unattended train operation	Automatic	Automatic	Automatic	Automatic

Figure 7: Overview of ATO concepts

3.3 ATO GoA2

3.3.1 Concept overview

In essence, ATO GoA2 consists of two systems: ATO trackside and ATO onboard. ATO trackside serves as a mailbox. It constructs a journey profile and segment profile based on the train's current status, timing points, and the timetable and route planning from the TMS. This constructed plan is then delivered to the ATO system on the train. ATO onboard influences the train's traction and braking. This system takes into account various factors such as the timetable, infrastructure characteristics, train characteristics, safety limits, comfort limits, current time, speed, and train position. It uses this information to determine the desired speed profile, translating it into brake/acceleration/coasting commands for the train.

The standard ATO solution within the European Rail Traffic Management System (ERTMS) framework was developed by a European working group under the Shift2Rail partnership. The objectives were to create an interoperable ATO extension for the ERTMS/ETCS system, establish a common standard, and become the primary solution for ATO on mainlines in the EU. This effort resulted in the ATO GoA2 over ETCS specification in the Technical Specifications for Interoperability (TSI) 2022. Please refer to the picture below for further details.

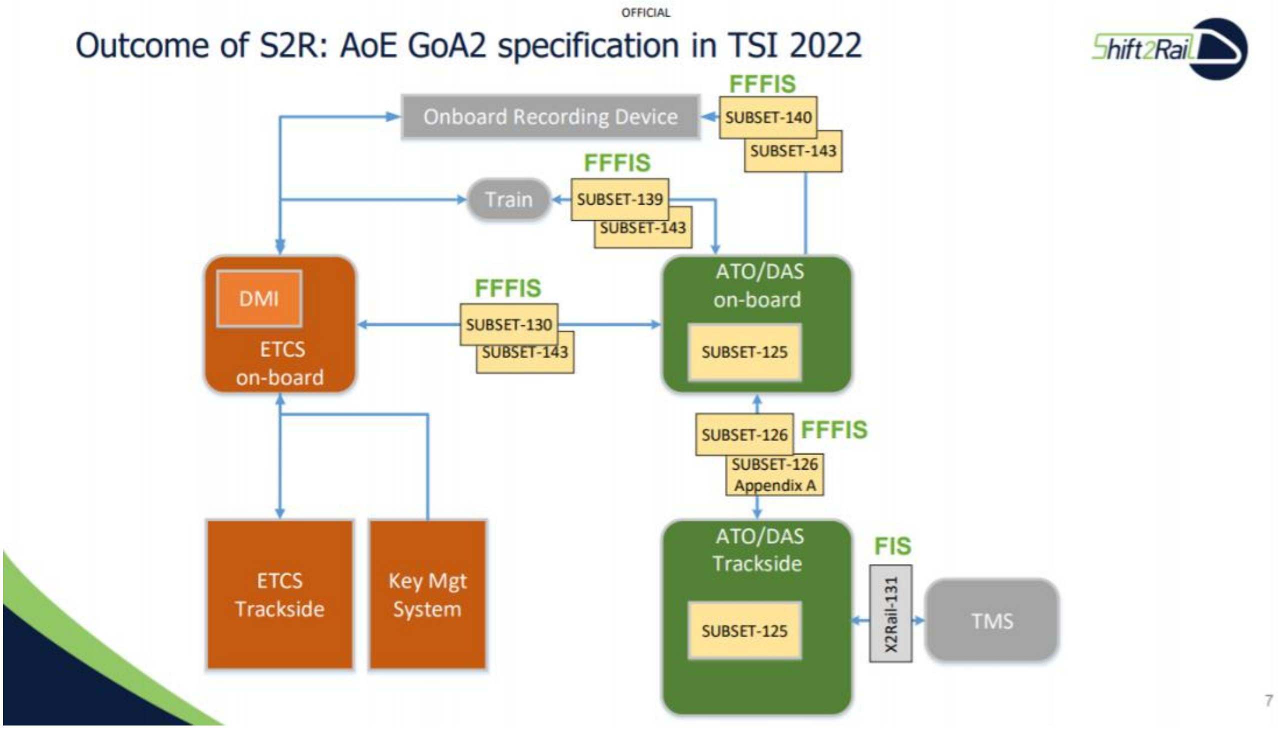


Figure 8: Outcome of Shift2Rail

3.3.2 Motivation

- Reduced variance in driving behaviour
- Increased punctuality and faster response times to timetable updates
- Enhanced train capacity, allowing more trains on the same infrastructure
- Reduced travel time from A to B through shorter travel times
- More energy-efficient operation by closely following an energy-optimized driving profile
- Highly precise stopping at the desired stopping location

3.4 ATO GoA4

3.4.1 Concept overview

In contrast to ATO GoA2, ATO GoA4 operates without a train driver present in the train cab and no personnel on board the train. The most significant difference is that ATO GoA4 has to fulfil additional functions, requiring the incorporation of extra systems. These functions include monitoring and responding to hazards on and around the track. For ATO GoA4, an obstacle detection system must be added, comprising sensors on the train (such as camera, lidar, etc.) and an image recognition model to detect and respond to obstacles. In the event of disrupted situations, the system must be capable of handling them autonomously. Persistent disruptions can be addressed by deploying a mobile maintenance team or by taking remote control of the train from a remote operation centre.

3.4.2 Motivation

- Lower staffing costs due to autonomous driving
- More flexible planning and control of rolling stock and personnel
- Elimination of travel time and cost for personnel to and from trains

- Reduced dwell times for turning, reversing, and changing direction
- Space savings, without the need for onboard driver facilities, there is potential for more efficient train design and utilization of interior space

3.5 C-DAS

3.5.1 Definition

As described in deliverable 15.1 from flagship project 1 C-DAS (Connected Driver Advisory System) is a driver advisory system with a communication link to external control systems in each controlled area in which the train operates. This enables the provision of schedule, routing, and speed-restriction updates to trains in near real time, and also receipt of information from trains to these systems to improve regulation decisions.

3.5.2 Concept overview

C-DAS consists of two main systems: the Trackside (TS) system and the Onboard (OB) system. These systems work together to provide real-time information and advisory recommendations to train drivers. The OB subsystem of a C-DAS is installed on the train itself or it can be a hand-held equipment (tablet). It receives the recommendations generated by the TS system and provides them to the train driver in real-time, displaying the recommendations on the driver's interface, typically through visual displays or audio alerts. The OB system may also collect onboard data, such as train performance metrics, and transmit it back to the TS system for further analysis.

The system can give advice for example on punctual execution of the timetable and energy optimal driving. However, the system is dependent that the train driver follows the output from the C-DAS.

3.5.3 Motivation

- Optimise the use of capacity and/or increase the regularity of a network by increasing the predictability of train runs.
- Improve safety by reducing the number of restrictive signals encountered and reducing braking phases.
- Reduction in operational incidents by limiting the number of restrictive signals encountered.
- Utilize less time supplements to reduce energy consumption, carbon emissions and wear and tear, while still punctual.
- In unplanned situations optimal guidance to energy efficient headway, “adaptive cruise control”
- Improved driver guidance with updated information for the journey and incident investigations by utilising data collected by C-DAS.

3.6 TMS

3.6.1 Definition

As described in deliverable 15.1 from flagship project 1 TMS (Traffic Management System) is the global system for monitoring and controlling the traffic and the signalling systems from the control centres. It covers a broad range of functionalities and, therefore, it is expressed in some cases such as multi actor systems, which includes several actors. Traffic management systems can subscribe to the location and speed information from C-DAS fitted trains in the managed area. Also, ATO can feedback information, namely on actual status and expected arrival times timing points. This information from C-DAS/ATO is useful in order to update the RTTP (Real Time Traffic Plan) and a better accuracy in the conflict detection.

3.6.2 Concept overview

A main task of a railway Traffic Management System (TMS) is to provide information about routes and times to trains for conflict-free and punctual train operation (See Figure 9.).

A TMS must provide a RTTP specifying the exact routes for each train as well as target times at scheduled timing points. This RTTP is the basis for both the timely route setting by the Traffic Control System (TCS) and the accurate speed regulation of trains by ATO/C-DAS. The ATO/C-DAS translates the RTTP into a Train Path Envelope (TPE) for each connected train, which specifies both targets and possibly additional time windows at Timing Points (TPs) on the route of the train.

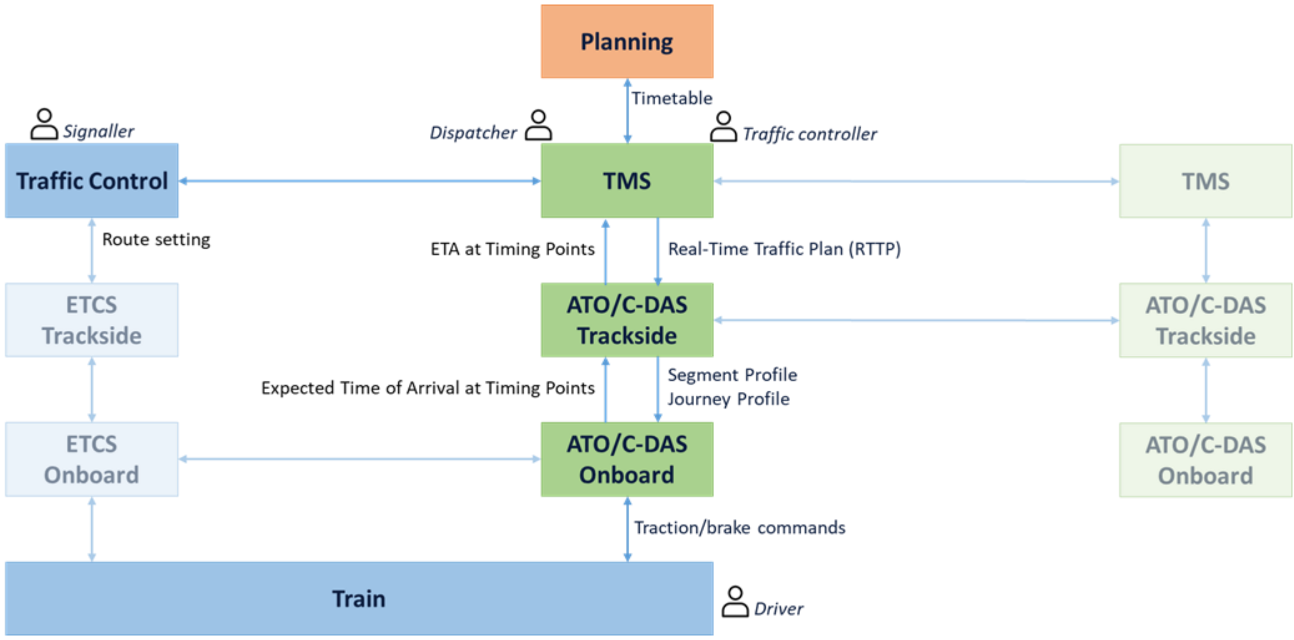


Figure 9: Explanation of TMS (source ER FP1 D15.1)

3.6.3 Motivation

When combined with ATO these advantages are expected with TMS

- Enhanced infrastructure and transport capacity by decreasing headways.
- Improved timetable stability and punctuality by means of consistent driving behaviour.
- Reduction in operational incidents by reducing the number of restrictive signals encountered.
- Energy savings by means of an optimized driving strategy.
- Improve safety by limiting the number of restrictive signals encountered and reducing braking phases.
- Reduced mechanical wear and tear and less noise by means of homogeneous driving with less braking.
- Increased passenger comfort by means of smoother, homogeneous driving.
- Reduced rolling stock and staff need due to increased robustness.
- With GoA4, no staff on board operating trains. Operation will be very predictable so less margins (time table supplements) are needed.

3.7 ERTMS HL3

3.7.1 Definition

ERTMS Hybrid Level 3 (HL3, also known as hybrid train detection, HTD) is in principle an ERTMS level 2 fixed block layout with additional virtual blocks. The virtual blocks are not monitored by trackside detection. The clearing of the virtual blocks is only possible by trains that have a train integrity function.

3.7.2 Concept overview

The level 2 blocks have track detection systems and physical detection systems will cover at least switches, level crossings and movable bridges. Besides that, a regular interval is needed to ensure a desired headway for level 2 only trains. The level 2 trains will be the infrequent trains on that corridor, for example freight trains and empty rolling stock. The trains that run frequent on the corridor, mostly passenger Diesel Multiple Unit (DMU) / Electric Multiple Unit (EMU) are relative easily equipped with a train integrity function that ensures that the train is in one piece. The ETCS module communicates with the Radio Block Centre (RBC) where the rear end of the train is located. For the majority of the trains running on a HL3 corridor shorter headways will be available and capacity is increased without increasing the number of physical assets along the track.

3.7.3 Motivation

- Capacity increase due to shorter headways
- Lower infrastructure costs due to virtual blocks
- Less failures of trackside detection and thus less disruptions of the railway traffic
- Faster and more efficient deployment of ETCS
- System is open for level 2 and 3 trains, so interoperability is ensured
- Faster implementation of moving block

3.8 ERTMS MOVING BLOCK

3.8.1 Definition

ERTMS Moving Block (MB) is also known as ERTMS Level 3. The detection of the trains is based on position reports of the trains itself rather than trackside detection systems. The clearing of the tracks is only possible with moving block if all trains have a train integrity function.

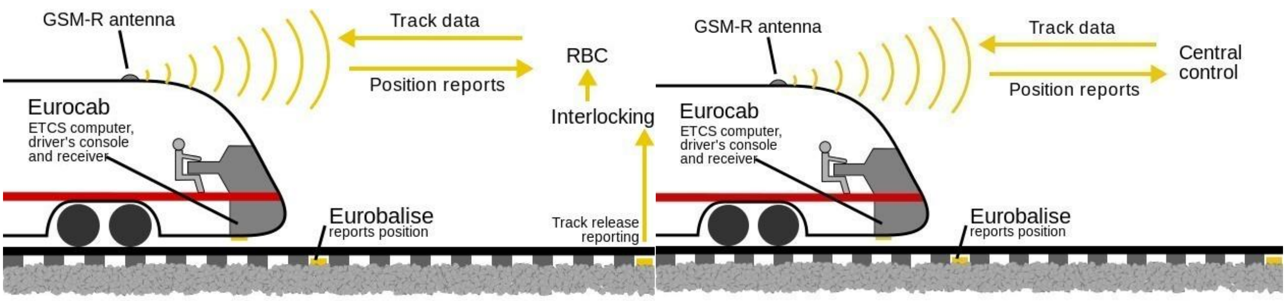


Figure 10: ETCS level 2 left and ETCS level MB on the right. (source:https://transport.ec.europa.eu/transport-modes/rail/ertms/how-does-it-work/etcs-levels-and-modes_en)

3.8.2 Concept overview

In ERTMS MB safe distance is projected in front of the train and determines the headway. Due to the absence of fixed blocks, less trackside equipment is needed to ensure the train safety. Besides that, due to the absence of blocks shorter headways are possible and this ensures a higher capacity. This concept is still to be developed; Therefore, it is not possible to do a detailed analysis on the effects of ERTMS MB on the business case on a more abstract level. In the DATO business case ERTMS MB will be taken into account but will not be evaluated in specific scenarios and capacity studies.

3.8.3 Motivation

- Lower infrastructure investments
- Higher capacity
- Faster deployment of ERTMS
- Less maintenance on trackside equipment
- Less disturbances and disruptions due to failures of trackside equipment

3.9 NG Brake

3.9.1 Definition

The work on Next Generation (NG) brake systems focused in R2DATO deals with Brake and Adhesion Management System (BAMS). In this context those systems, including adhesion detection systems (ADS) are linked to each other, but also communicate with other onboard systems like the ATO onboard module or the ETCS system. In addition, the BAMS might also communicate with trackside systems which store the adhesion values and share them with other trains or with the Traffic Management System (TMS). The detailed architecture still needs to be defined.

3.9.2 Concept overview

In a future realization, the BAMS onboard systems will determine the current adhesion or also receive the predicted adhesion further on the line. Based on this the BAMS will determine the maximum available deceleration and supply current Kdry (related functions not in focus of R2DATO) and Kwet values to the ETCS unit and/or available adhesion information to the ATO onboard unit. They will activate adhesion related units, e.g. sanding units when the track is too slippery. The ADS of BAMS will send adhesion data from running trains to trackside systems (receiving target to be defined). Based on this input, adhesion values in the railway network can be predicted and this information be provided to the trains for consideration. Beyond, the TMS can use the information for prediction of running times. The improved knowledge on the current situation and the better system performance will result in better predictable and shorter deceleration distances in wet and dry conditions.

3.9.3 Motivation

- In combination with GoA4 (or also GoA2 with improved driver advice) a train can keep running over slippery track conditions and stopping at the right point (consideration of current conditions).
- The new systems lower the workload for the driver with GoA2 (e.g., automatic activation of system functions).

- Less running time loss and variations in running times (higher, reproducible decelerations based on improved functionality) during slippery track conditions. This leads to a higher robustness and punctuality (less platform overruns, less signal passings at danger, less fall back to the train protection system etc.). The use of higher deceleration values at low adhesion conditions in combination with longer coasting phases or reduced accelerations can be utilised for reduction of energy consumption.
- Less headway conflicts in the operation during slippery track conditions (consideration of real, actual train performance). This leads to a higher robustness and punctuality.
- Shorter running times and headways in dry conditions due to an improved Kdry value (improved performance). This will increase capacity. This advantage relates to brake system functions not related to adhesion.
- Improved BAMS performance leading to less wheel and rail defects, less environmental impact, and material costs. This will lead to lower maintenance costs.

3.10 DAC FOR FREIGHT RAIL TRANSPORT

3.10.1 Definition

Digital Automatic Couple (DAC) is an innovative component to automatically couple and decouple freight wagons both physically (the mechanical connection and the air line for braking) as well as digitally (electrical power and data connection). DAC is key to enable the needed increase in efficiency and transparency of rail freight. (from: https://rail-research.europa.eu/wp-content/uploads/2021/04/DAC-Factsheet_EN.pdf). It's a prerequisite for a staff-les yard, one of the future concepts to make freight by rail more competitive.

3.10.2 Concept overview

Screw coupling is still today the coupling standard for freight trains in European countries. Coupling is done manually by a worker who must climb between wagons to hook and un-hook them, requiring physically exhausting manual operation in a hazardous environment.

A more efficient, sustainable and competitive rail freight system is essential to meet the needs of both climate protection and rising transport volumes. Digital automatic coupling is an enabler to create a modern and digital European railway freight transport. It will not only increase efficiency thanks to automation processes, but it will also ensure sufficient energy supply for telematics applications, as well as safe data communication throughout the entire train. (from: https://rail-research.europa.eu/wp-content/uploads/2021/04/DAC-Factsheet_EN.pdf)

3.10.3 Motivation

- Shorter turnaround times for freight operators. This will lead to more cost-efficient freight transport.
- A safer work environment since there is less staff on the tracks to couple, uncouple and checking the train.
- Longer trains, since the maximum force in the coupler can be higher. This will lead to a more cost-efficient freight transport of bulk materials.
- Shorter track occupations on railway yards. This will increase capacity or decrease infrastructure costs.

- Enabler for better braking systems that will give a shorter braking distance and thus will increase capacity. Those braking systems will also give better controllability of the train itself.
- With ATO the freight trains are more accurate controlled leading to less variation and a more robust operation.
- Enabler for ERTMS Moving Block and use of Hybrid Level 3 for freight trains , because the DAC makes a train integer for the signalling system..
- Opening up new markets, such as the transport with electrical reefer container for the transport of refrigerated products.
- Reduction of the derailment risk, since the buffers are obsolete.
- Safer rail system as the exact composition and location of dangerous goods in trains is traceable in detail along the entire trajectory

3.11 REMOTE OPERATIONS

3.11.1 Definition

Remote Train Operation (RTO) is an overarching term that refers to the remote control of a train. This means that the train operator is in a different location than the train cab and controls the train from there. This includes remotely executing various functions, such as control and environment monitoring. RTO can be applied as a standalone concept for actively controlling a train from a distance or as a fallback for taking control in a disrupted situation in ATO GoA4.

3.11.2 Concept overview

In RTO, the train is controlled from a location other than on board, for which various potential options exist as the concept is still in development. The train can be operated by a remote operator using a control device near the train, or a remote operation centre can be set up to control the train via a video connection to the train. RTO itself can be further divided into smaller sub-concepts or components, such as remote preparation, remote stabling, and remote shunting.

- **Remote Stabling:** The application of RTO for positioning, transferring, and marshalling trains (without passengers). These movements occur between stations and marshalling yards. In remote stabling, there can also be movement on the main track.
- **Remote Shunting**: The application of RTO for shunting (without passengers) within a marshalling yard. This includes activities like train departure preparation, combining, splitting, and cleaning. No movement on the main track occurs in Remote Shunting.
- **Remote Preparation**: Involves remotely performing (part of) the activities necessary to prepare a train for departure. Examples include remotely preparing the cabin, inspecting the inventory, conducting brake tests, and engaging the dead man's switch.

3.11.3 Motivation

- • Lower staffing costs due to the absence of travel time for personnel to and from trains.
- • Reduced transportation costs for bringing personnel to trains and shunting yards.
- • Improved working conditions for shunting staff.
- • Enhanced logistical flexibility with quicker start-up and solution times in case of disruptions

3.12 Dependencies between DATO concepts

The DATO concepts have relations with each other. In this paragraph the basic relations for exclusion or inclusion for the above-mentioned DATO concepts are described.

Selecting one driver support concept out of the 5: No Support, or C-DAS, or ATO GoA2, or ATO GoA3, or ATO GoA4

There are different levels of ATO, in this business case the focus is on GoA2 and GoA4. GoA3 is considered only on high level outline business case. When ATO GoA2 is used the C-DAS system can be used as a fallback system. In certain cases, the reference can be no support or the existing C-DAS system.

Selecting one safety system out of the 3: ETCS L2, or ERTMS HL3, or ERTMS MB

A rail safety system has to be defined for the proposed use cases. The reference is ETCS level 2. The class B-System is only in specific cases the reference, in those cases ATO is already in place over a class B System. From the DATO concepts either ERTMS Hybrid Level 3 or ERTMS Moving Block can be chosen. Since the ERTMS Moving Block is still in early development phase this will be described in the business case outline and not in specific case studies.

Dependency: ATO must have a TMS

ATO GoA 2 and GoA4 need a limited TMS function, or a TMS as described in paragraph 3.5. The limited TMS is only able to generate journey profiles and train path envelopes and cannot be updated for track and timetable changes.

Dependency: ATO GoA4 must have NG Brake and/or Remote operations

ATO GoA 4 has no staff on board so the system has to cope with reduced adhesion situations, since the driver on board cannot switch to manual mode anymore, or the train operation has to be taken over in a remote operations centre. For other purposes as operations in degraded modes a remote operations centre is also necessary.

Dependency: ETCS MB must have DAC

In case of a moving block safety system all trains must have a way to check for the integrity of the train. For freight trains the DAC is therefore needed.

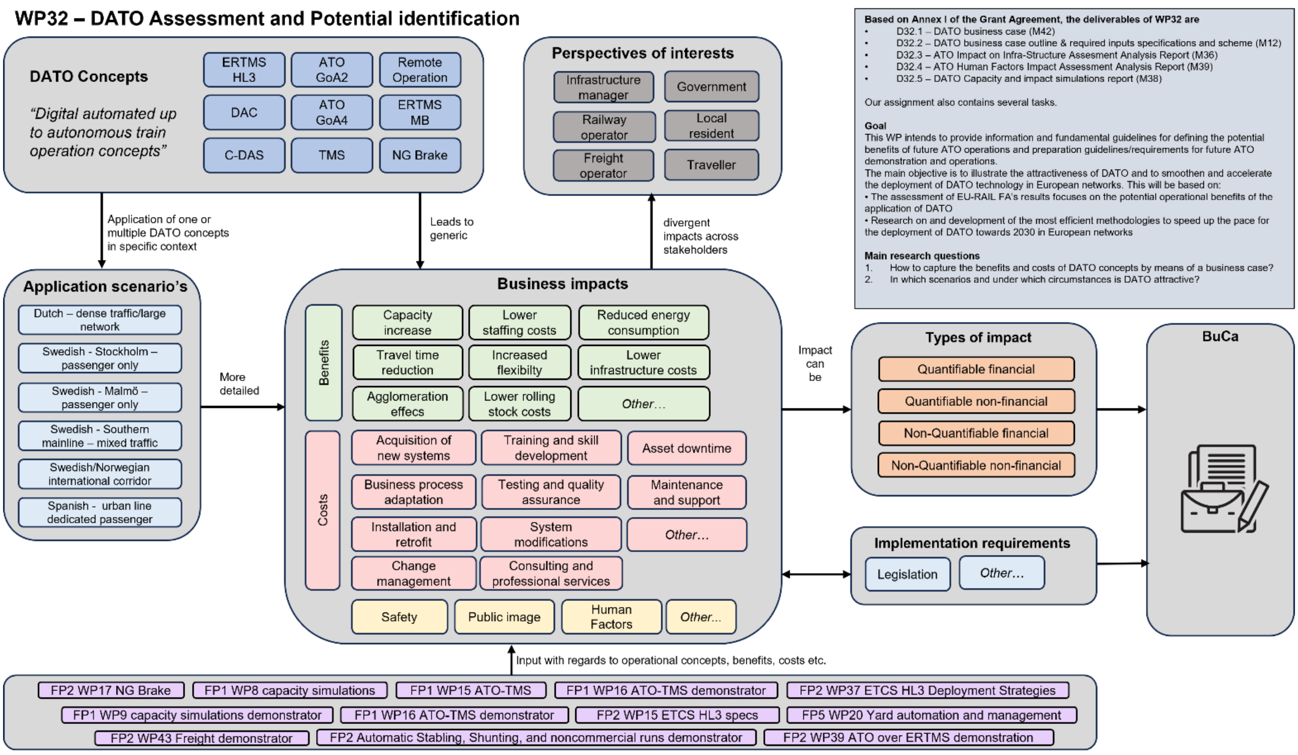
4 BUSINESS IMPACT

In this chapter, we will touch upon the potential business impacts that arise when a DATO concept is implemented. Having an overview of these potential impacts, supports in creating an understanding of the preliminary business case model elements. It is important to mention that these are potential (preliminary) business impacts that have been identified, as they are not quantified yet, but are frequently mentioned in relation to the various DATO concepts.

In Chapter Impact related to human factors we will zoom in on the impact of human factors, as this will be an important element for the simulation scoping.

Figure 11: Overview of WP32 DATO Assessment and Potential identification

Figure 11 gives an overview of different aspects that will be taken into consideration, based on the issues mentioned in the previous chapters. In the subsequent activities of WP32, we will research the business impacts of specific DATO concepts to further substantiate these assumptions. We will consolidate insights from other work packages, such as simulation studies and demonstrators.



It is important to note that the objective of WP32 is not to condense the impacts of the various DATO concepts into a single outcome or evaluation. This is because DATO concepts can provide different types of benefits for various stakeholders, depending on the specific application scenario—such as varying levels of technology maturity and distinctions between freight and passenger transport. These benefits may be either quantifiable or non-quantifiable, and they can be financial or non-financial. Additionally, implementation costs are still highly uncertain, making it challenging to accurately estimate a single figure for DATO concepts. Therefore, a strategic perspective will be adopted to establish a foundation for more detailed cost-benefit analyses of DATO concepts.

4.1 GENERIC DATO BUSINESS IMPACTS

Table 3 below provides an overview of the diverse high-level business case model elements that have been identified thus far. These elements can serve as a framework to easily identify costs and benefits associated with various DATO concepts. It is indicated which impacts are potentially applicable to each DATO concept.

The elements below are based on a first assessment with the purpose to make the direction more tangible but are not yet scientifically or otherwise substantiated.

Preliminary business impacts		ERTMS HL3	ERTMS MB	C-DAS	TMS	ATO GoA2	ATO GoA4	RTO	DAC	NG Brake
Benefits	Capacity increase	X	X	X	X	X	X			
	Travel time reduction			X	X	X	X		X	
	Lower staffing costs						X	X	X	
	Increased flexibility						X	X	X	
	Reduced energy consumption			X	X	X	X			
	Lower infrastructure costs	X	X	X		X	X	X		
	Lower rolling stock costs			X	X	X	X		X	X
	Agglomeration effects	X	X	X	X	X	X			
Costs	Acquisition of new systems	X	X	X	X	X	X	X	X	X
	Business process adaptation	X	X	X		X	X	X	X	X
	Installation and retrofit	X	X			X	X	X	X	X
	Change management			X		X	X	X		
	Training and development			X		X	X	X		
	Testing and quality assurance	X	X	X	X	X	X	X	X	X
	System modifications	X	X		X	X	X	X		X
	Consulting and professional services	X	X	X	X	X	X	X	X	X
	Asset downtime					X	X	X	X	X
	Maintenance and support			X	X	X	X	X	X	X
Other	Safety			X	X	X	X	X	X	X
	Public image					X	X	X		
	…									

Table 3: Generic potential DATO business case model elements

The overall value of DATO is dependent on the nature and magnitude of the most relevant costs and benefits associated with DATO. Whereas costs can generally be quantified in business cases using monetary units (e.g., €), benefits can be more difficult to quantify as they can be generated in conjunction with other system elements, are less tangible (e.g., risk reductions), or affect stakeholder interests in different ways (Srinivasan, Parlikad, 2017). It is even said that costs and benefits are so different that they may well be from 'different planets' (Schuurman, Berghout, Powell, 2009). As such, the business case impacts will be investigated from a cost and a benefits perspective.

In the next phases of WP32, the potential business case elements of costs, benefits and other impact will be specified to a much deeper extent, as we proceed to define the business case format in greater detail.

4.1.1 Impact related to human factors

While it is almost two centuries ago since the first railway line was opened, the digitalization trend has only started in the last few decades for control room and vehicle (train) operators. The introduction of the new safety system ERTMS (European Rail Traffic Management System) often is seen as catalyst of change for the digitalization of systems for train (traffic) operator. While there has been some research on the impact of automation on train operations, there remains substantial work to be done in this area, emphasizing the ongoing importance of exploring and understanding these changes.

From GoA2 and higher ATO is generally expected to relieve the operational workload of rail operators, particularly that of train drivers, by reducing the number of tasks they are asked to physically perform and shifting requirements from the execution to monitoring activities automatically performed by the system. This entails that the function allocation in human autonomous systems collaboration is going to shift requiring operators to perform cognitive tasks for longer periods i.e., sustained attention, vigilance etc. compared to physical and psychomotor tasks. The delegation of part of the current tasks to automated systems will likely transform the duties of these jobs and potentially the way of recruiting and training operators [47].

This is an important impact which is challenging to quantify. Therefore, this topic requires additional research and is worth mentioning here.

Lessons learned from automation in other transport domains such as aviation and maritime sectors indicate that training will be essential in preparing operators for this shift in role requirements. Training can also potentially increase operators' acceptance and awareness regarding the interaction with automated systems [48].

The results of empirical research [49][50][51][52] confirm that these train drivers when requested to operate in the context of automatized and autonomous systems (at GoA level 2 and up), tend to rely more on cognitive, perceptual, and communication skills with a marginal usage of physical/psychomotor skills. Such studies, performed mainly by simulation or survey studies, suggest that the shift from active driving to a more monitoring/supervisory role may lead to attention drift, fatigue, boredom, etc. which may interfere with a train driver's decision-making ability and ability to react to disruptions in a timely manner [53][54][55][56]. The focus of researchers in recent years has been mainly on drivers' collaboration with autonomous systems or identifying determinants for ATO development including costs and investment needed [57]. To our knowledge, literature discussing the impact of ATO on rail traffic controllers from a human factors perspective has been sparse. In fact, the literature on train traffic controllers seems focused on identifying how the technology should be developed for optimizing the collaboration between humans and the system, with a focus on correct and timely execution of performances with minimal consideration of the impact of ATO on traffic controllers' activities and other human factors such as cognitive workload etc. Certainly, the role of traffic control managers in terms of primary and secondary tasks should be modelled in the European context to ensure comparability and transferability of lessons learned. Moreover, it is necessary to identify key aspects that enable the correct execution of tasks during controller-automated train systems interaction. Those aspects should be tested from the technological (e.g., usability, accessibility etc.) and the human point of view (e.g., cognitive workload, fatigue, attention etc.) to ensure that operators can effectively supervise, monitor, and step in when necessary, and timely correct ATO processes. The agreement on such enablers could contribute to the assessment of the potential consequences of the implementation of ATO procedures on traffic controllers.

5 USE CASES, SCENARIOS AND REQUIREMENTS

5.1 INTRODUCTION

WP32 will create specific business cases alongside a general framework business case to demonstrate the influence of DATO concepts in different scenarios. Moreover, from those scenarios we can derive specific values or methods for the business case format. Scenarios help to illustrate the elements of the business landscape that are most common and plausible, allowing for the development of strategic foresight and long-term plans [58]. The potential benefits of DATO are highly dependent on specific circumstances which are best investigated on a case-by-case basis [59]. To explore under which circumstances DATO is most advantageous, the business case investigates the expected impact of DATO implementation from real world cases. In this chapter the proposed cases are discussed. These cases are real life examples from the partners of WP32 and a mix between small lines or networks and large complex networks. Another aspect is the type of railway traffic, this can be mixed or passenger only or dense or low traffic volumes.

For a case multiple scenarios are proposed. For every case there is a reference situation and an ATO GoA2 and/or GoA4 scenario. The scenarios can have multiple sub-scenarios where the DATO concepts are changed to see the effect of multiple DATO combinations. The combination of DATO concepts is limited to the combinations that are expected to have the most significant impact, moreover the DATO concepts that are not mature enough to model for capacity analysis are excluded. This is done to keep the number of scenarios within the feasible workload for WP8/9 of FP1 MOTIONAL. The uses cases for rail traffic simulations are described in the next paragraph.

5.2 PROPOSED USE CASES

This chapter provides an overview of the different use cases that will be the base for the simulations and DATO business cases.

The complete overview of the scenarios can be found in Appendix A.

5.2.1 The Netherlands: SAAL

The proposed use case for the Dutch rail network will be the SAAL corridor. SAAL is the acronym of Schiphol – Amsterdam Zuid – Almere – Lelystad. This corridor will be equipped with ERTMS Level 2 around 2031 and due to rising passenger numbers, ATO will be expected to be a method to increase the capacity and facilitate the extra trains to transport all passengers. If ATO is available, the complete corridor can be equipped with ATO although for capacity needs only Hoofddorp - Schiphol – Amsterdam Zuid is needed.

On this corridor ATO GoA 2 and 4 will be investigated. For GoA2 the benefits of adding a TMS will be simulated. Since this is a complex network, the simulations will be at a deterministic level also with a deterministic set of disturbances to assess the impact and recovery of disturbances. For all scenario's the basic timetable of 2030 will be assessed and also the timetable that is foreseen that makes use of ATO GoA2. For ATO the basic timetable of 2030 will need an optimization to incorporate the benefits of ATO GoA 2 and 4.

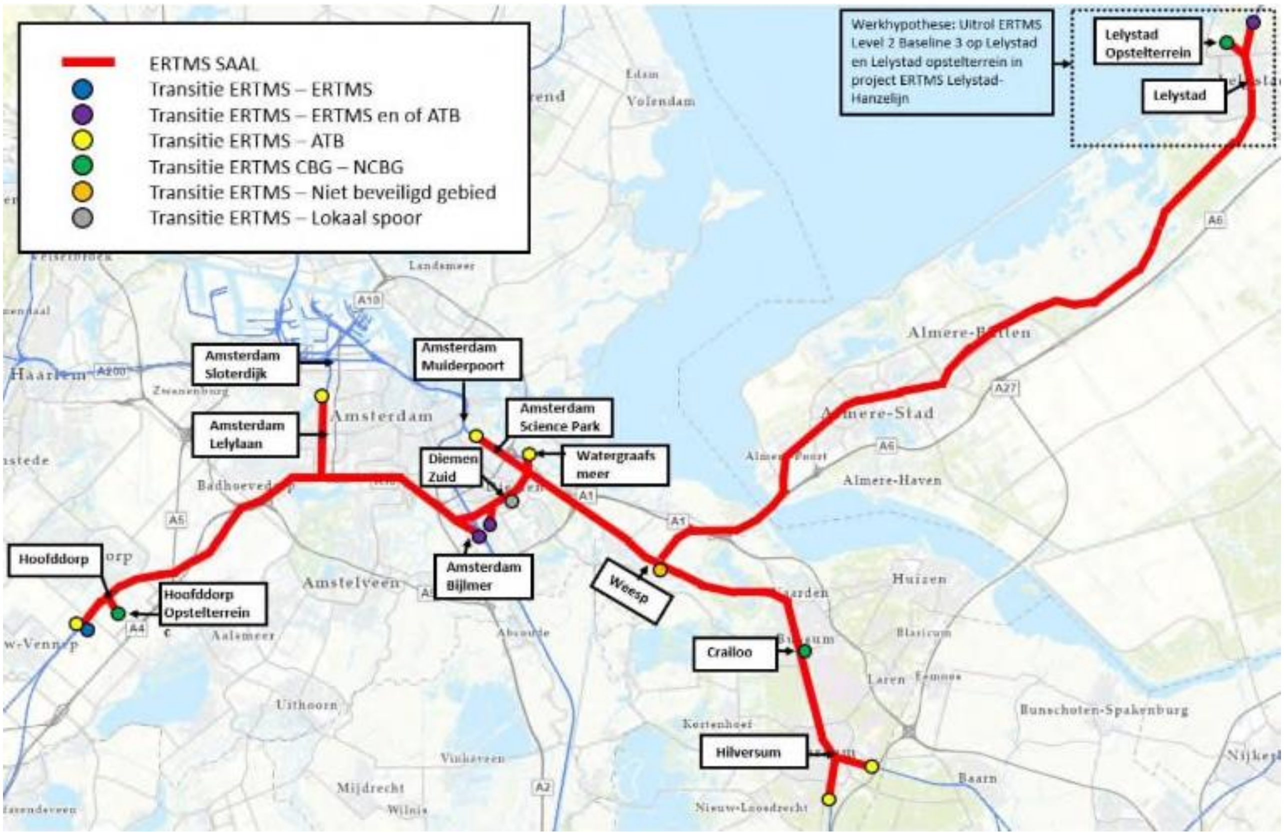


Figure 12: The rollout of ERTMS on the SAAL corridor
source: ProRail

5.2.2 Sweden: Stockholm

The Citybanan is the commuter line through the city centre of Stockholm. This line is 6km long for commuter trains only and has a very dense timetable. ATO GoA2 could be a solution to increase the capacity without building new infrastructure. The increase of capacity will be needed in the future in order to accommodate an increase of travellers. The line consists of four stations of which one is four-track and three are two-track. A previous study on the effects of GoA2 on Citybanan will serve as a base for the more detailed studies.

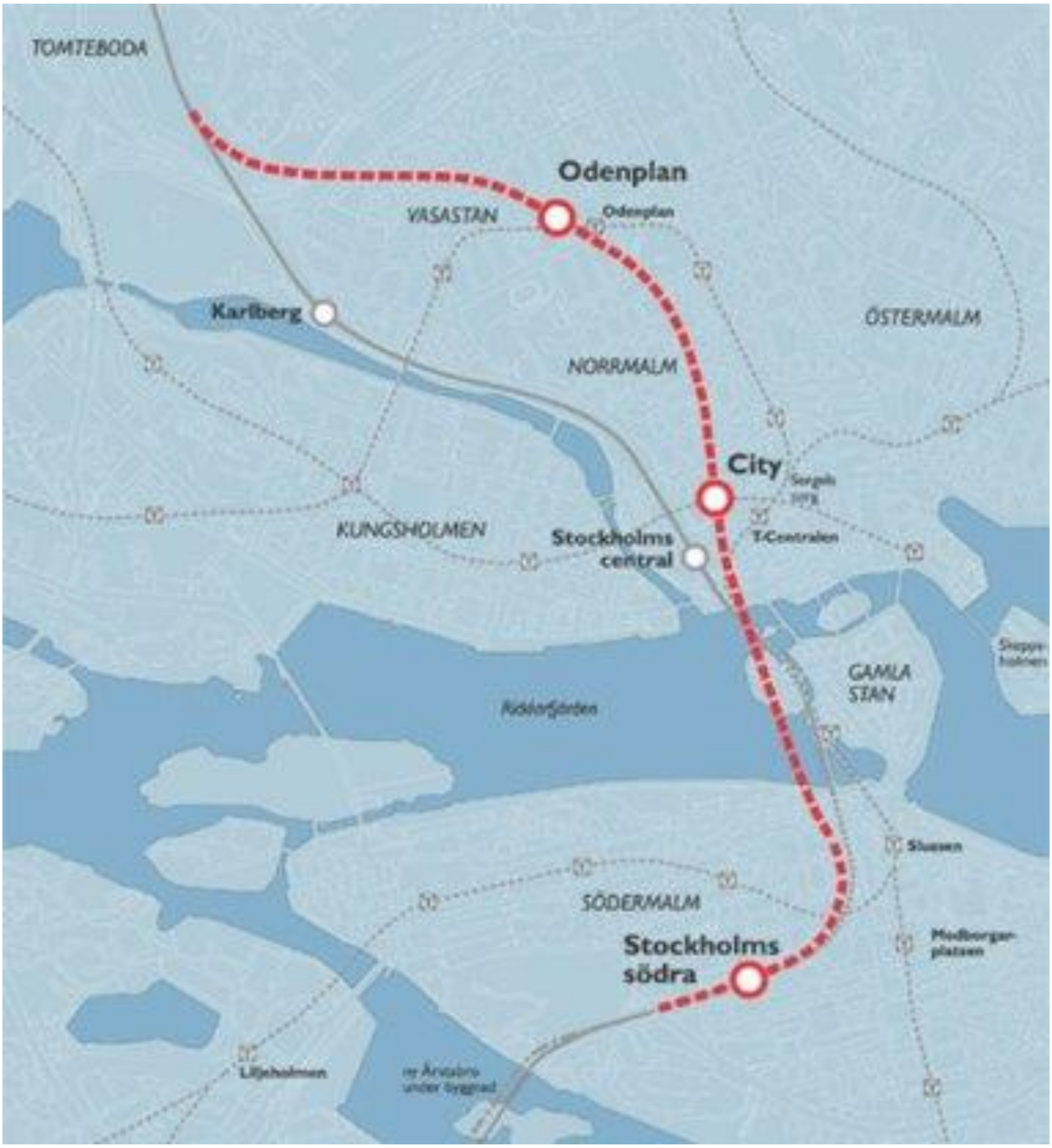


Figure 13: Stockholm Citybanan
source: Marktema

5.2.3 Sweden: Malmö

Similar to the Citybanan in Stockholm, Citytunneln in Malmö is a 6 km double track tunnel with only passenger traffic. However, regional, commuter and long-distance trains operate the tunnel but no freight trains. The line consists of three stations of which two have four tracks and one has two tracks. The line is considered a bottleneck in the region and more capacity will be needed. ATO GoA2 will be analysed for the line to estimate the capacity effects.

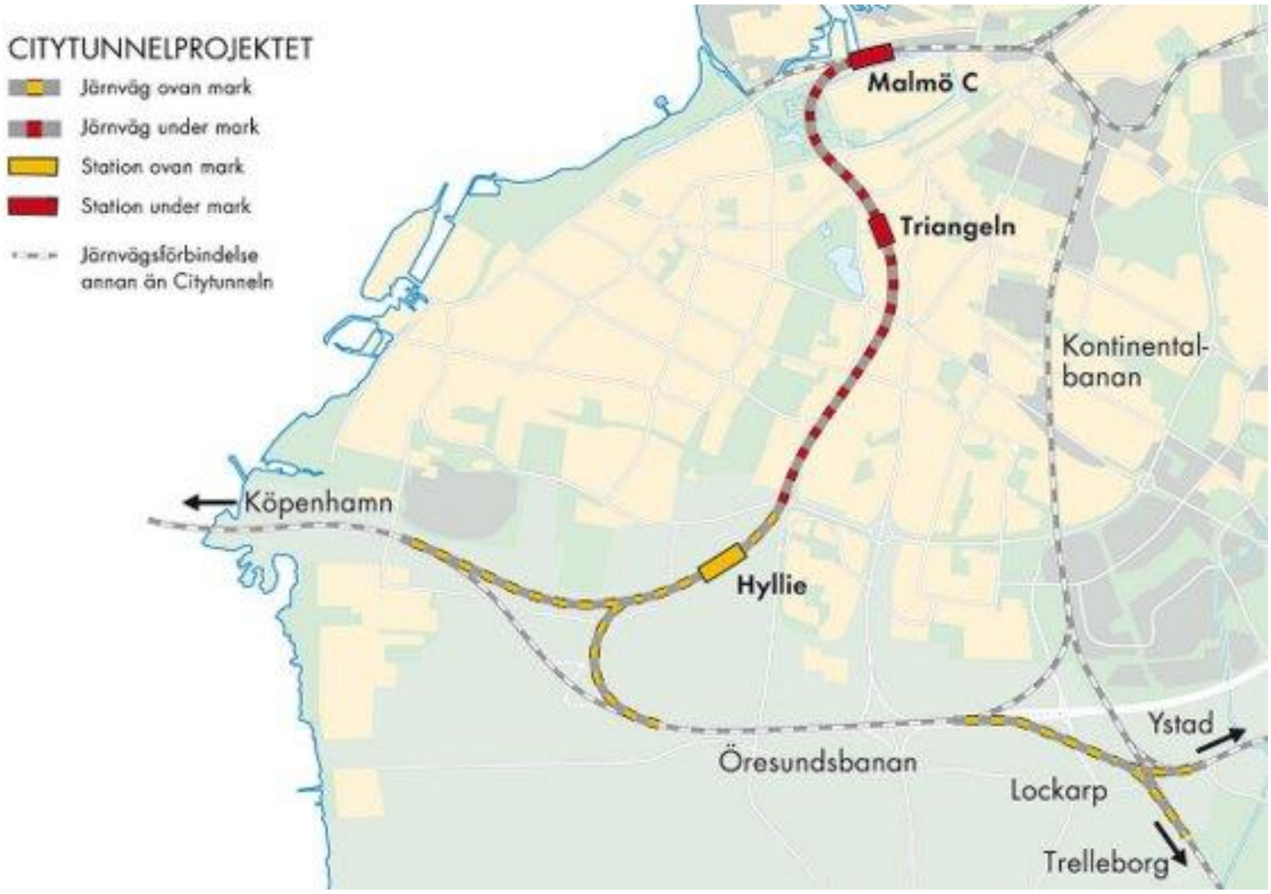


Figure 14: Malmö Citytunnelprojektet
Source: Rjaber

5.2.4 Sweden: Southern Mainline

The Southern mainline between Norrköping and Mjölby is a 79 km long double track with mixed traffic of commuter, regional, long-distance, and freight trains. Due to the mix of traffic the line has capacity problems and the effects of GoA2 will be studied to evaluate the potential capacity gains.

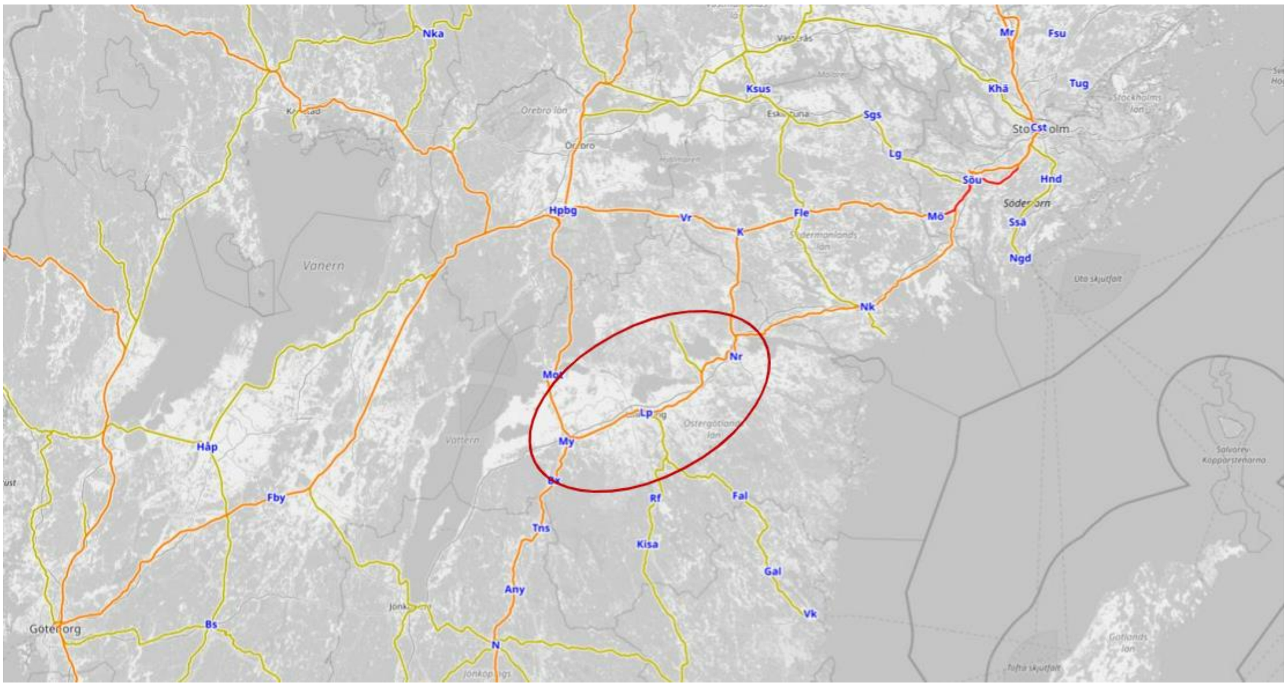


Figure 15: Sweden - Southern Mainline
Source: Openrailwaymap

5.2.5 Sweden – Norway: Kiruna – Narvik

The Iron ore line in Northern Sweden and Norway between Kiruna and Narvik is a 174 km long, single-track. The traffic is dominated by heavy 750-meter Iron ore trains and some additional freight and passenger trains. Both ATO GoA2 and GoA4 will be studied for this line to see the potential effects. For GoA2 the capacity effects will be the focus, while for GoA4 a focus will be on the punctuality.

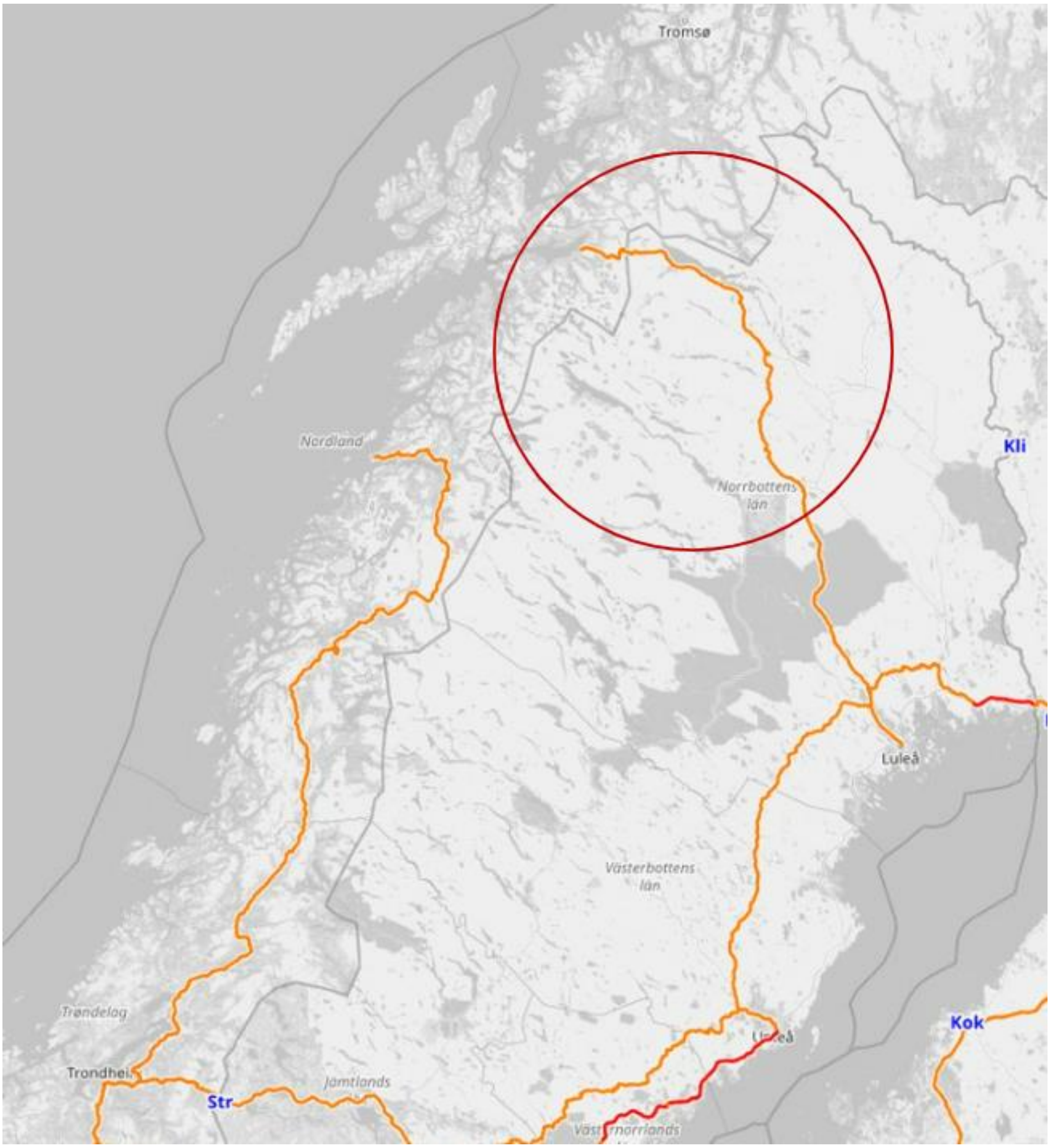


Figure 16: Iron ore line between Sweden & Norway
source: Openrailwaymap

5.3 Capacity simulations specifications for FP1: WP8-9

The simulations will be required to gain insight in the benefits of ATO on capacity, wear and energy consumption. Moreover, the effects of the other EU Rail developments that can possibly affect the ATO capacity, wear and energy consumption benefits will be simulated. In this chapter the requirement for the capacity simulations for work package 32 are proposed. In cooperation with WP8/9 from FP1 an iterative process will be setup to align the requirements of the business case with the feasibilities within the WP8/9.

5.3.1 Input

The relevant parameters of the simulation must be state of the art. Therefore, input is needed from other work packages or work packages 8 or 9 itself. Input will be needed for the simulations from at least:

FP1:

- Work package 15/16 for TMS parameters.

FP2:

- Work package 17 for NG brake parameters

5.3.2 Simulation Method and requirements

Since the simulation will cover networks with dense railway traffic, the simulation tool must be fitted to simulate all dynamic effects within the railway system itself. Headways and running times must be accurate. Therefore, simulation with a microscopic tool is preferable.

These are the proposed requirements for specific scenario's:

1) Infrastructure modelling
    a) ERTMS Level 2 for the ATO parts.
    b) The following type of networks will be modelled
        i) A very dense network with freight trains; SAAL in the Netherlands
        ii) A dense network in a suburban area: Stockholm
        iii) A dense mixed network: Malmö.
        iv) A dense mixed network: Southern Mainline Sweden
        v) Rural single-track line: Northern Sweden and Norway
    c) The network is at least to the next major train station
2) Rollingstock modelling:
    a) C-DAS for energy optimal driving will be the reference. The maximal coasting strategy will be considered as the state of the art.
    b) The ATO levels GoA2 or GoA4 will be simulated depending on the scenario.
    c) ATO is using the energy efficient train control (EETC) strategy. This is the optimal combination between coasting and constant speed.
3) Timetable
    a) The simulation may use an hour pattern or a day pattern if available. For ATO the timetable needs to be optimized for the ATO running time slack and ATO headway buffers. (To be decided upon in WP8/9) The hour pattern must run for enough time to cancel the start-up effects.
    b) ATO has to be simulated with a minimal TMS and a TMS as described in FP1: WP15. The minimal TMS are the planned timing points and segment profile. In case of

rescheduling the ATO functionality is updated with 1-minute steps. If the route is changed the ATO is switched off.

c) The improved timetables have to aim for the same level of robustness or better.

d) Disruptions
   i) If a reliable answer is possible with a deterministic simulation, deterministic simulation is preferable.
   ii) For each scenario a set of specific single delays has to be used for determining the recovery time of the scenario
   iii) For stochastic simulation a representative set of normal delays for station stops, driver profiles and entrance of trains in the model.

5.3.3 Output

The following output is proposed:

- Punctuality and average delay per scenario. The punctuality definition may vary per county. In this case the country specific and a generic punctuality should be calculated,
- Realized and planned timetable with delays per run for travel time and operational benefit analysis,
- Recovery times per scenario,
- Acceleration and braking actions (start and end position and start and end speed) for wear analysis per run. (Coasting and small variations due to slopes are not included) per run,
- Energy consumption (for kinetic energy only) per train and total for energy savings analysis and,
- A log of the trains that have run with the ATO switched on per trajectory.

5.4 Human in the loop simulation specifications for FP1: WP15-16

Human in the loop (HITL) simulation for traffic controller and train driver.

5.4.1 Input

Input for the simulations will be derived from:

FP1:

- Work package 15/16 for TMS parameters.

FP2:

- Work package 39 for operational concept.

5.4.2 Simulations

Human factors research will be conducted in a multi-actor human-in-the-loop (HITL) simulation environment that facilitates the resemblance of a representative operational environment and its interactions between one train driver, a traffic signaller / controller and a traffic dispatcher. The simulation will be run in a setting reflecting the operations at the Dutch infrastructure provider ProRail, utilizing Dutch sections of railway infrastructure.

Human factors requirements for the HITL

- Pre-experimental (individual) and Experimental (Team) scenarios (Type of scenarios, TBD in WP 16)

- Metrices (see 5.4.3 output) – Communication exchanges quantity and quality, correctness of decision making, etc. [Full list will be provided by WP 15]
  - Target GoA 2 (but also feasible in GoA 3 and 4)

Technical requirements for the scenarios are:

1) Infrastructure modelling
   a) ERTMS Level 2 for the ATO parts.
   b) The following type of networks will be modelled in the Netherlands: A very dense passenger network with freight trains; SAAL in the Netherlands
2) Rolling stock modelling
   a) GoA 2 and possibly GoA4 (ongoing assessment for the HITL simulation environment)
      i) Mainline
      ii) From stopping point to stopping point.
      iii) Manual opening of doors.
      iv) Driving under Full Supervision (according to TSI).
      v) ATO disabled when train stops at stopping point
3) Timetable
   a) The simulation will use scenarios with variable time frames and an hour or day pattern.
   b) ATO has simulated with a TMS as described in FP1: WP15. All changes in the operational plan of the TMS will result in an updated journey profile.
   c) Delays, small disruptions

5.4.3 Output

The following output is desired:

- Human factors metrices from a technological point of view: usability, accessibility etc.) and human point of view: cognitive workload, fatigue, attention etc.) to ensure that operators can effectively supervise, monitor, and step in when necessary, and timely correct ATO processes. These metrices will be defined as part of D15.2 in FP1.
- Team human factors metrices that measure the interaction between train drivers and traffic controllers/operators. These metrices will be defined as part of D15.2 in FP1
- System performance, such as
  - Punctuality and average delay per scenario
  - Recovery times per scenario,
  - Energy consumption (for kinetic energy only) per train and total for energy savings analysis
  - Unplanned stops
  - Unplanned braking behaviour

5.5 LINKS WITH OTHER WORK PACKAGES

WP32's Deliverable D32.2 Dato Business Case quite heavily depends on output from other work packages within R2DATO and other Flagship Projects such as FP 1 Motional. Based on the Grant Agreements for FP1, 2 and 5 we have made an inventory of relevant work packages and Deliverables see Figure 17.

WP#	Title	Input	Month	Output	Month
FP1: Motional					
8 and 9	Capacity Simulation	Requirements and specifications (D32.2)	12	Capacity impacts results overview (D9.2)	42
15 and 16	ATO-TMS	Requirements and specifications (D32.2)	12	Definition TMS	
				Demonstrations by Human-in-the-loop simulator (D16.1)	43
				Demonstrations of TMS functionality for improved C-DAS operations (D16.2)	43
FP2: R2DATO					
15	ETCS HL3 Specifiaction	*tbd*		HL3 System Specification with identification of use cases and related engineering rules (D15.1)	21
17 and 18	NG Brake	*tbd*		ATO impact of brake/ adhesion management systems including considerations on certification methods; resume on adhesion determination methods (D17.1)	34
				Summary of ATP impact of BAMS including considerations on certification methods, ADS and long term perspective of dynamic braking curves adaptation (D18.1)	42
31	Remote control center	*tbd*		ATO Onboard and Remote Supervision & Controlstrict formal modal demonstrator (D31.1)	42
37	HL3 Deployment strategies	*tbd*		Determining ETCS HL3 capacity impact analysis using simulations (D37.4)	40
				Methodology for optimised placement of (virtual) blocks (D37.2)	40
38	Automatic Stabling, Shunting and noncommercial runs	*tbd*		Results of remotely monitored stabling and bringing a train to the station with remote monitoring (D38.3)	42
				Results of automatically stabling a train and bringing a train to the station in GoA4 (D38.4)	42
				Results of the NG Brake performance tests (38.5)	42
				Results of remotely controlled shunting (in cooperation with FA5) (D38.7)	42
				Use of an ATO-specific TMS in stabling and shunting operation, and in non-commercial runs (D38.8)	42
				Analyses of all data collected during the tests, including expected benefits and contributions to KPIs (D38.9)	42
39	ATO over ERTMS demonstration on mainline	*tbd*		Best practices report from mainline capacity assessment, including testing Operational Concept (OC) for mainline operations (D39.2)	42
				Report of DATO test results (D39.4)	42
				Report of DATO over ERTMS L3 test results (39.6)	42
41	Remote Driving and Telecommand Demonstrator	*tbd*		Testing reports & assessment (D41.2)	24
43	Freight Demonstrator	*tbd*		ATO testing (D43.5)	42
FP5: TRANS4M-R					
20	Yard automation and management	*tbd*		Demonstration and validation report (D20.2)	21

Figure 17 - Relevant deliverables with input for WP32

Based on the planning in the respective Grant Agreements, (part of) this output will become available in the form of Deliverables too late for WP32 to include it in Deliverable D32.2 DATO Business Case (marked in red in Figure 17).

We plan an alignment process to safeguard and monitor that the output is available for WP32 in good time. Furthermore, we do not upfront rule out options such as working with draft versions. The alignment process will start in month 13 but has already started with WP 8/9 and WP15/16 of FP1 and WP17 of FP2.

It is not unimaginable that other, not yet identified, work packages also have interesting and relevant input for WP32. For alignment with those work packages, the following process is foreseen.

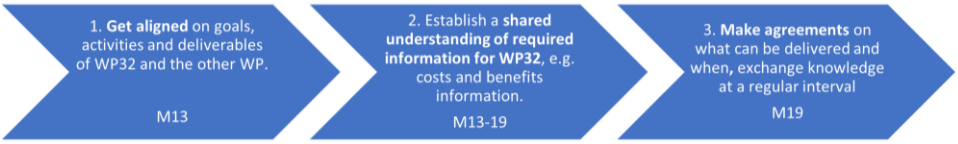


Figure 18 – Alignment of work packages

6 NEXT STEPS

Deliverable D32.1 DATO Business case will be built in accordance with the principles and outline set out in chapter DATO business case outline of this Deliverable.

This document has provided a research outline and motivation for how business cases for DATO can be developed. The next steps involve the iterative creation of one (or several) DATO business cases based on the outlined format and approach. This step will be supported by further research on specific areas within the outline such as business case development or human factors.

Meanwhile, Deliverables D32.3 (ATO Impact On Infra-Structure Assessment Analysis Report), D32.4 (ATO Human Factors Impact Assessment Analysis Report) and D32.5 (DATO capacity and impact simulations report) will also be developed. These will also provide information for the DATO business case.

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APPENDIX A

Scope	References					GoA 1,5
	NL-A	SE-A1, Stockholm	SE-A2, Malmö	SE A3, Southern mainline	NO/SE-A4 Iron ore line	NO/SE-A
ATO level mainline	none	none	none	none	none	GoA1,5 (+C-Das)
ATO level shunting yard (shunting+stabling)	none	none	none	none	none	
C-DAS	Yes**	No	No	No	no	Yes
TMS	No	No	No	No	no	Yes
Timetable	6-Basis (2030)					
Safety system mainline	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2
Safety system shunting yard	None/ERTMS L2	None/ERTMS L2	None/ERTMS L2	None/ERTMS L2	none	None
Network Characteristic	Hour pattern, dense mixed traffic	Dense passenger traffic	Dense mixed traffic	Dense mixed traffic with freight	Single track, medium frequency, high capacity utilisation, mix passenger/ freight and cross border	
Models available	Models in Railsys/OpenTrack	Model in Railsys	Model in Railsys	Model in RailSys	Model in Railsys	
Remarks					High variation in horizontal and vertical curvature	

Scope	GoA 2							GoA 4	
	NL-B1	NL-B2	NL B3	SE-B1 Stockhol	SE-B2 Malmö	SE B3, Southern mainline	NO/SE B4 Iron ore line	NL-C	NO/SE Iron ore line-C
ATO level mainline	GoA2*	GoA2*	GoA2*	GoA2	GoA2	GoA2	GoA2	GoA4	GoA 4
ATO level shunting yard (shunting+stabling)	GoA2+R	GoA2+R	GoA2+R					GoA4	none
C-DAS	No	No	No	No	No	No	No	No	no
TMS	No	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Timetable	6 Basis optimized	6 Basis optimized	High freq (8-4)					6 Basis optimized	
Safety system mainline	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2	ERTMS L2
Safety system shunting yard	None/ERTMS L2	None/ERTMS L2	None/ERTMS L2	None	None	None	None	None/ERTMS L2	None
Network Characteristic	Hour pattern, dense mixed traffic	Hour pattern, dense mixed traffic	Hour pattern, dense mixed traffic	Dense passenger traffic	Dense mixed traffic	Dense mixed traffic with freight	Single track, medium frequency, high capacity utilisation, mix passenger/ freight and cross border	Hour pattern, dense mixed traffic	Single track, medium frequency, high capacity utilisation, mix passenger/ freight and cross
Models available				Model in Railsys	Model in Railsys	Model in Railsys	Model in Railsys		Model to built in Proton (macro simulation)
Remarks									

	Delta with reference