DEFINING FEATURES FOR A VSS STATE MACHINE COMPUTER PROGRAM

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Traffic and Transport Management Abstract
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This thesis explores 3 important definitions for a graphics-based ETCS Hybrid Level 3 Virtual sub-section (VSS) state machine program. The underlying aim of this thesis is the need to create a computer program that can help people visualize different states and transitions of the Hybrid Level 3 system more effectively. The contents of this study are found mainly in the European Economic Interest Group's (EEIG) ERTMS users' guidelines for ERTMS/ETCS Level 3, the Hybrid Level 3 concept (ref: 16E0421A_HL3). This thesis aims to provide part of a guideline for developing a graphical user interface (GUI) program for the ETCS Hybrid Level 3 virtual sub-section state machine.

Hybrid Level 3 is a conceptual variant of the ETCS Level 3 that allows for greater flexibility in trains that can use a line fitted with Hybrid Level 3. The proposed graphics-based state machine aims to enhance the learning experience of individuals who are new to the ETCS environment by providing a visual representation of the train and track section's operational status and behaviour.

The study will begin by reviewing acceptable procedures in the field of railway control systems, as well as state machine models. This will provide a foundation for the development of the program and ensure that it is consistent with existing standards.

Overall, this thesis contributes to the development of train control systems by proposing essential features for a novel graphics-based state machine that would help understand the Hybrid Level 3 concept. In addition, can help with the development process by providing a reference implementation of the logic that can guide the development of an actual application.

In conclusion, this thesis aims to define features for a graphical user interface program for the ETCS Hybrid Level 3 virtual sub-section state machine and to provide a guide for developing such a program. This guide will be based on the study's results and provide a roadmap for developing future programs in this area.

Pages 22 pages

Keywords ETCS, Hybrid Level 3, virtual sub-section (VSS), automatic train protection, track section, graphical user interface, state machine

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Työn nimi Ominaisuuksien määrittäminen VSS-tilakoneen tietokoneohjelmalle

Ohjaaja Teppo Sotavalta (HAMK), Kai Kiihtelys, Ross Gammon

Tässä opinnäytetyössä tutkittiin kolmea tärkeää määritelmää grafiikkapohjaiselle ETCS Hybrid Level 3 Virtual sub-section (VSS) -tilakoneohjelmalle. Aiheen taustalla on tarve luoda tietokoneohjelma, jonka avulla ihmiset voivat visualisoida tehokkaammin Hybrid Level 3 -järjestelmän eri tiloja ja siirtymiä. Tutkimuksen sisältö löytyy pääasiassa European Economic Interest Groupin (EEIG) ERTMS-käyttäjien ohjeista ERTMS/ETCS Level 3, Hybrid Level 3 -konseptille (viite: 16E0421A_HL3). Opinnäytetyön tarkoituksena on tarjota osa ohjeista graafisen käyttöliittymän (GUI) kehittämiseen ETCS Hybrid Level 3 virtuaalisen suojavälin tilakoneelle.

Hybrid Level 3 on ETCS-taso 3:n käsitteellinen muunnelma, joka mahdollistaa laajemman liikkumavaran junissa, jotka voivat käyttää ETCS-taso 3:n hybridi linjaa. Ehdotetun grafiikkaan perustuvan tilakoneen tarkoituksena on parantaa niiden henkilöiden oppimiskokemusta, jotka ovat uusia ETCS-ympäristössä, tarjoamalla visuaalisen esityksen junan ja rataosuuksien toimintatiloista ja käyttäytymisestä.

Selvitys aloitetaan tarkastelemalla hyväksyttäviä menettelytapoja junaturvallisuuden saralla sekä tilakonemalleja. Tämä antaa perustan ohjelman kehittämiselle ja varmistaa, että se on johdonmukainen olemassa olevien standardien kanssa.

Kaiken kaikkiaan tämä opinnäytetyö edistää rautateiden junaturvallisuutta ehdottamalla uudenlaisen grafiikkapohjaisen tilakoneen oleellisia ominaisuuksia, jotka auttaisivat ymmärtämään Hybrid Level 3 -konseptia. Tilakone voi myös auttaa kehitysprosessissa tarjoamalla viitetoteutuksen logiikasta, joka voi ohjata varsinaisen sovelluksen kehitystä.

Lopuksi tämän opinnäytetyön tarkoituksena on määritellä ominaisuuksia ETCS Hybrid Level 3 virtuaalisten suojavälien tilakoneen graafiselle käyttöliittymälle ja tarjota opas sellaisen ohjelman kehittämiseen. Tämä opas perustuu tutkimuksen tuloksiin ja tarjoaa näkemyksiä tulevien ohjelmien kehittämiseen tällä alalla.

Sivut 22 sivua

Contents

ETCS	European Train Control System
ERTMS	European Rail Traffic Management System
PTD	Positive Train Detection – based on position reports from trains
TTD	Trackside Train Detection – using conventional methods e.g., axle counters
VSS	Virtual sub-section
HL3	Hybrid Level 3
MA	Movement Authorities
GUI	Graphical User Interface

1 Introduction

This thesis was conducted as a part of Ramboll's ongoing projects to introduce ERTMS/ETCS training material in various European markets. In this thesis, I will be exploring the question of defining three basic principles for an ETCS Hybrid Level 3 (HL3) Virtual sub-section (VSS) state machine. The objective of this study is to define three fundamental principles for the design and implementation of such a state machine. By establishing these principles, we aim to provide a clear and concise framework for developing and deploying the state machine in a real-world application. This research is significant as it will contribute to advancing the field of railway control systems and help improve the efficiency and safety of rail transportation. The outcome of this study will be a set of guidelines that can be used as a reference for future projects in this area.

ERTMS (European Rail Traffic Management System) is a large-scale industrial initiative implemented by the European Union to facilitate safe, efficient, and seamless rail transportation by removing technological boundaries. The primary goal of ERTMS is to create a single, harmonized, and interoperable control, command, signalling, and communication system. The system aims to eliminate communication and signalling barriers, drawing from a broad supply base with a focus on compatibility and evolution. At present, over 20 train control systems are in use throughout the European Union. National rail companies equip their trains with at least one, and sometimes more, systems to ensure safe operation within their respective countries.

The two main components of ERTMS are the European Train Control System (ETCS) and the Global System for Mobile Communication – Railways (GSM-R) or Future Railway Mobile Communication System (FRMCS). ETCS will replace all different train protection systems across Europe, simplifying cross-border traffic, enhancing supply markets, and making the industry more attractive to customers and investors. The various operation levels of ETCS are technically distinct from one another, allowing member states to select a level that suits their needs and budget. This study only examines ETCS HL3, as the virtual sub-sections are only present in this concept of ETCS Level 3. (ERTMS, n.d.)

2 ETCS Levels

ETCS (European Train Control System) is a train control standard that relies on onboard equipment to continuously supervise train movements and bring the train to a stop if it exceeds the permitted stopping point. Information sent to the train cab is obtained from trackside equipment, either by Eurobalises or radio, depending on the operating level. The driver's response is constantly monitored, and if required, ETCS assumes control and triggers the emergency brakes. (European commission, Mobility and Transport, n.d.-a)

Level 1 involves continuous supervision of train movement (i.e., the onboard computer continuously supervises the maximum permitted speed and calculates the braking curve to the end of movement authority) while non-continuous communication occurs between train and trackside, generally through Eurobalises. Lineside signals are necessary. Train detection and train integrity checks (i.e., the train is complete and has not been split) are performed by the trackside equipment outside the scope of ERTMS.

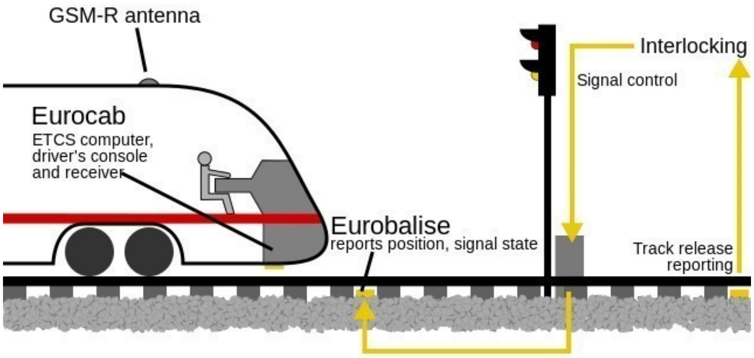

Figure 1 ETCS Level 1. (European Commission, n.d.-b)

Level 2 involves continuous supervision of train movement with constant communication via GSM-R between the train and trackside. Lineside signals are optional in this case, and train detection and train integrity checks are performed by the trackside equipment beyond the scope of ERTMS.

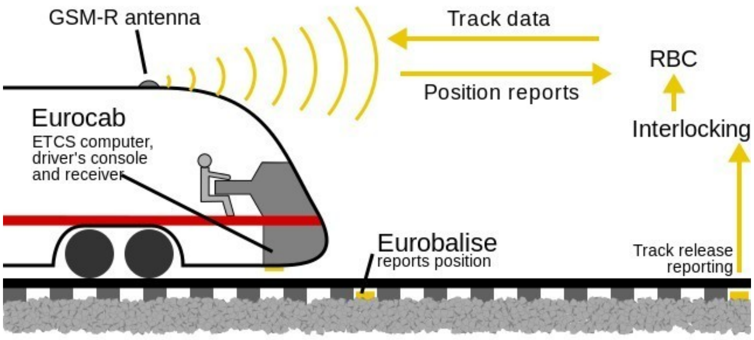

Figure 2 ETCS Level 2**.** (European Commission, n.d.-b)

Level 3 involves continuous train supervision with continuous communication between the train and trackside. The main difference with Level 2 is that train location and integrity are managed within the scope of ERTMS, i.e., there is no need for trackside signals or train detection on the trackside other than Eurobalises. Train integrity is supervised by the train using the onboard Train Integrity Monitoring System (TIMS).

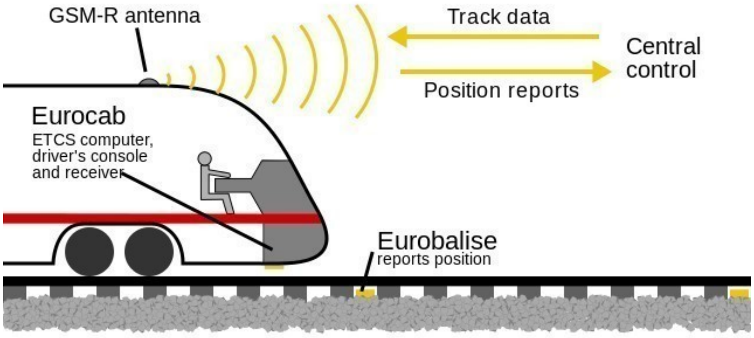

Figure 3 ETCS Level 3. (European Commission, n.d.-b)

In Level 3, positive train detection (PTD) information is detected and reported by the onboard system directly to the trackside, which, based on logical rather than physical track block sections, decides whether it is safe to issue movement authorities (M.A.), reporting them back to the onboard system via radio. For this to be feasible, PTD information must be reliable, and the communication between the onboard and the trackside systems must be guaranteed at all times. These pre-conditions are not easily met. (European Commission, Mobility and Transport, n.d.-b)

This has led to proposing a **Hybrid Level 3** concept that combines PTD information with limited trackside detection. These trackside train detection sections (TTD) are broken into smaller virtual sub-sections (VSS). This allows for trains with non-ideal equipment or with communication problems (illustrated as “not connected train” in Fig.4) to still use the line, albeit below full capacity. (Hansen et al., 2020, p. 316)

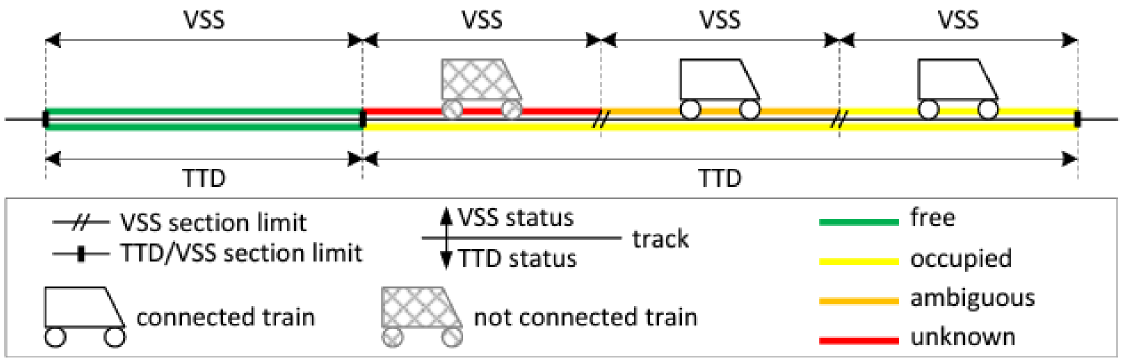

Figure 4 Virtual sub-sections of the HL3 concept displayed (EEIG ERTMS Users Group, 2017, p. 9)

3 Finite State Machines

A *finite* state machine (FSM) is a mathematical model that represents systems operating in a sequence of well-defined states. It consists of conditions, transitions between them, and actions or events that trigger the transitions. At any given time, the machine is in one of its states, and transitions occur when specific circumstances or conditions are met. FSMs are widely used in engineering and computer science to model systems such as digital circuits, control systems, and software programs.

In an FSM, a state represents a condition or mode of operation, and a transition represents a change from one state to another. The transitions are usually triggered by events or input signals and can either be deterministic or nondeterministic. A deterministic transition occurs when there is only one possible next state for a given input, while a nondeterministic transition occurs when there are multiple possible net states.

FSMs can be classified based on their complexity and the type of input they receive. Simple FSMs have a small number of states and transitions and are relatively easy to design and analyse. More complex FSMs can have hundreds or thousands of states and transitions and may require specialized tools and techniques to model and analyse.

One of the key advantages of FSMs is that they provide a clear and concise representation of a system's behaviour. They are easy to understand and can be used to verify the correctness of a system's design. However, FSMs can become overly complex and difficult to manage as the number of states and transitions increases. (Sipser, 2012, pp. 31–53)

A classic example of a finite state machine is the turnstile entry control at a subway station. The turnstile has two states: Locked and Unlocked. The turnstile remains locked until a coin is deposited, which triggers a transition to the Unlocked state. However, the turnstile does not actually rotate until a passenger moves through it and completes the transition. Once the transition is complete, the turnstile returns to the Locked state, waiting for the next coin to be deposited. In this example, the transition triggers are depositing a coin and passing through the gate, which causes the turnstile to move between the Locked and Unlocked states. (Wright, 2005. p. 1)

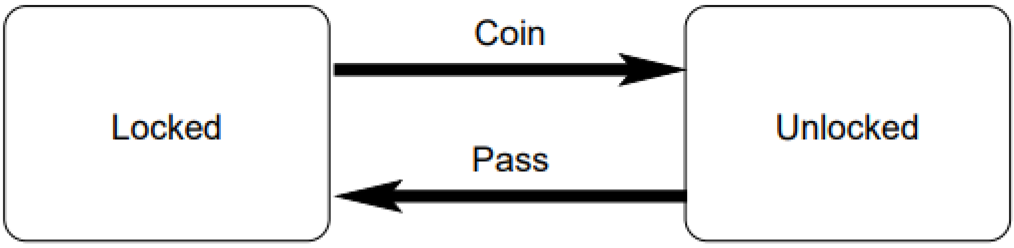

Figure 5. Simple State Machine Model of a Turnstile (Wright, 2005, p. 1)

An *infinite* state machine is a type of state machine where the number of possible states is infinite, but there is still a finite set of inputs and outputs. This type of machine is used when there are too many possible states to define them all explicitly.

Instead, the machine is defined by a set of rules that determine how it should respond to inputs and transitions between states. (Hopcroft, 2001, pp. 219–220)

In this thesis, the scope of the study will be limited to defining features of a finite state machine (FSM) because the number of possible states and transitions in a Hybrid Level 3 VSS state machine is relatively low.

3.1 VSS State Machine

The four states in an event-driven VSS state machine based on the principles of the ETCS HL3 system are “Free”, “Occupied”, “Ambiguous”, and “Unknown”. These states represent different conditions or situations that can occur within the system. Here is a brief explanation of each state:

Free	The trackside is certain that no train is located on the VSS.
Occupied	The trackside has information from a position report that an integer train is located on the VSS and the trackside is certain that no other vehicle located in rear of this train on the same VSS.
Ambiguous	The trackside has information from a position report that a train is located on the VSS and the trackside is NOT certain that no other vehicle is located in rear of this train on the same VSS.
Unknown	The trackside has no information from a position report that a train is located on the VSS, but it is not certain that the VSS is free.

Table 1 States defined (EEIG ERTMS Users Group, pp. 10–11)

In an event-driven VSS state machine, the system transitions between any two of the four states based on events or inputs that it receives. For example, the system might transition from the “free” state to the “occupied” state when it receives a signal from a train that it is entering the section of the track.

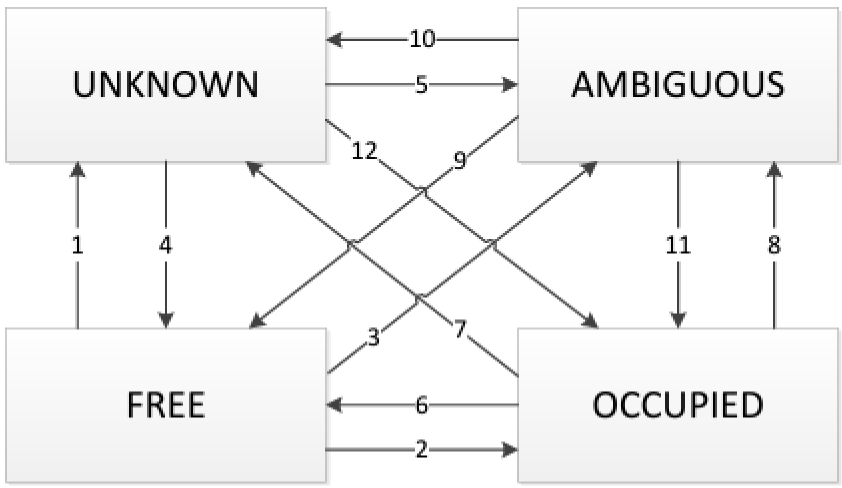

Figure 6 **VSS section state diagram** (EEIG ERTMS Users Group, p. 24)

VSS states are updated based on the following events:

- PTD information on front-end position – processed first. PTD: based on position reports from trains.
- PTD information on rear-end position – including integrity and safe train length.
- TTD information – occupied/free. TTD: using conventional trackside methods
- Timer expiration

(EEIG ERTMS Users Group, p. 24)

3.2 Example of an operational scenario

Simple single track operational scenario:

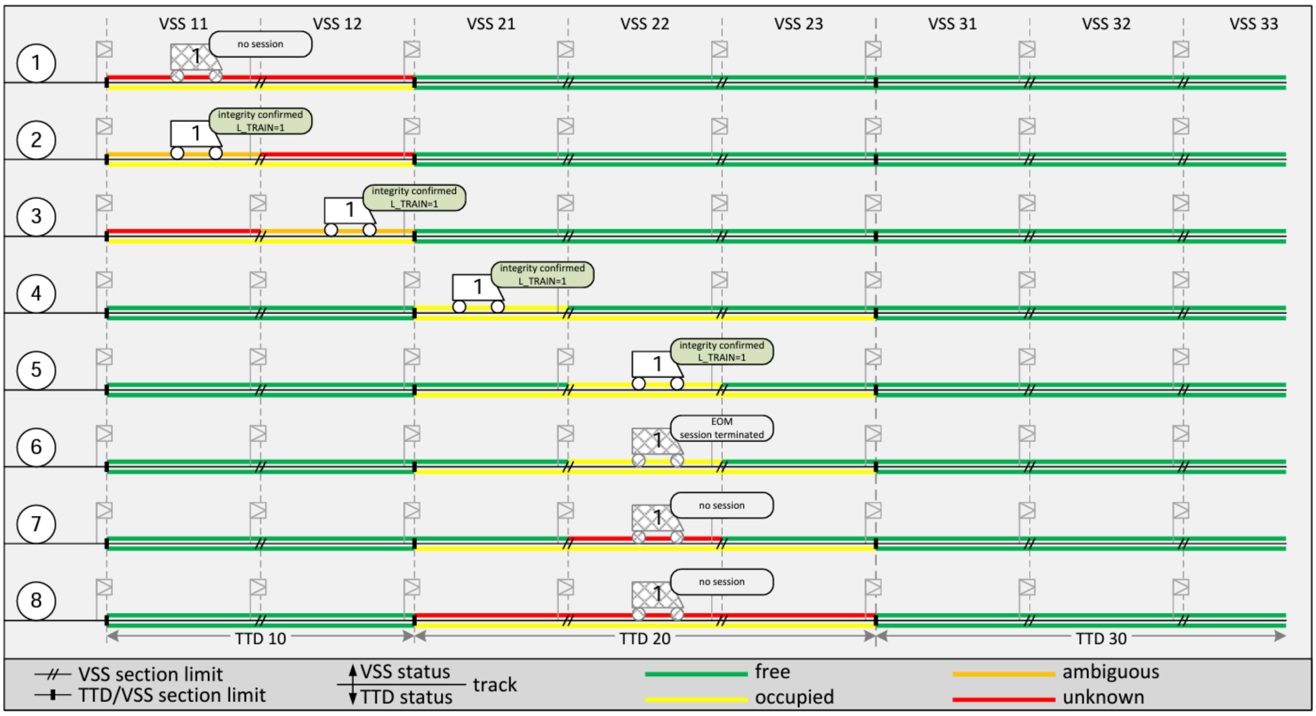

Figure 7 Example scenario – Start of Mission / End of Mission (EEIG ERTMS Users Group, 2017, p. 35)

- Step 1 – Train 1 is standing on VSS 11 with the desk closed and no communication session. All VSS in TTD 10 are “unknown”.
- Step 2 – Train 1 performs the Start of Mission procedure, i.e., the session with the trackside is established. Integrity is confirmed. Because train 1 reports its position on VSS 11, this VSS becomes “ambiguous” (#5A).
- Step 3 – Train 1 moves to VSS 12 which becomes “ambiguous” (#5A). VSS 11 goes to “unknown” (#10A).
- Step 4 – Train 1 moves to VSS 21 which becomes occupied.
- Step 5 – Train 1 continues to VSS 22 which becomes “occupied” (#2A).
- Step 6 – Train 1 performs the End of Mission procedure (EoM).
- Step 7 – Due to the EoM procedure VSS 22 goes to “unknown” (#7A) and the disconnect propagation timer of VSS is started.
- Step 8 – The disconnect propagation timer of VSS 22 expires. All remaining VSS in TTD 20 go to “unknown” (#1C).

The Hybrid Level 3 specification describes 12 transitions from a VSS state to another state. Each transition is divided into various cases (#1A, #1B, etc.), and each case has various conditions associated with it. The state transitions consider several factors, including updates in the TTD status, new position reports from trains, and the expiration of various timers. Some timers are designed to expire when a train fails to send a position report within a specific timeframe. (Hansen et al., 2020, p. 319)

The table below describes the transition conditions that are related to the example scenario pictured in **Figure 7.**

#1C	[TTD is occupied] & [there is/are only “free” or “unknown” VSS or none between this VSS and the VSS for which the “disconnect propagation timer” is expired]. & [VSS is located on the same TTD as the VSS for which the timer is expired]
#2A	[TTD is occupied] & [train is located on the VSS] & [VSS where the estimated front end of the train was last reported, was [occupied] after the processing of this previous position report] & [current state of the VSS where the train was last reported is not “unknown”]
#5A	[train is located on the VSS]
#7A	[train is located on the VSS] & [[mute timer expired] OR EoM [End of Mission]]
#10A	[VSS is left by all reporting trains]

4 Key components and features for a graphics-based Virtual Sub-section (VSS) state machine for ETCS Level 3 hybrid

As the expected outcome of the development for this computer program would be a state machine that incorporates graphics for improved visualization and user comprehension, we should investigate some important aspects that would be associated with a graphical interpretation of a state machine.

A good baseline for a graphical user interface ETCS L3 hybrid VSS state machine would likely include the following elements:

- A well-designed visual representation effectively conveys information to the user. The visual representation should provide a clear and concise overview of the train's position, speed, and any potential obstructions on the track ahead. In addition, the visual representation should accurately reflect the train's movement, including acceleration and deceleration.
  To achieve these goals, the visual representation should incorporate various graphical elements, including color-coded signals, icons, and dynamic indicators. The use of color-coded signals is particularly important, as it allows the user to quickly and easily distinguish between different types of signals, such as speed limits and warning signals. In contrast, dynamic indicators can be used to display real-time information about the train's speed and acceleration or deceleration.
  The visual representation should also be designed to accommodate different levels of zoom, so the user can easily switch between a high-level overview and a detailed view of the track. Additionally, the visual representation should be designed to be easily understood by both experienced and novice users, without requiring extensive training or prior knowledge of the system.
- To ensure successful implementation, it is important to carefully map the requirements of different European signalling systems, while also takin into account their differences.

A critical aspect of the implementation is mapping of virtual signalling objects to physical trackside equipment. This requires a clear understanding of the signalling objects used in different systems, including their definitions, properties, and relationships with other equipment. However, with careful planning and implementation, it is possible to develop a program that meets the requirements of different European countries.

- A control panel for managing the state of the VSS, including buttons for manual control, as well as indicators for the current state and mode of the system.
- Support for different levels of automation, such as semi-automated and fully automated modes of operation. The different levels of automation can be selected based on the specific needs and requirements of train operation, allowing for greater flexibility and customization in the system.
- A menu for selecting the amount of rolling stock located on the track sections and the possibility to choose the train's operating mode, e.g., is the train connected to the ETCS or is the train without ETCS equipment.
- A display showing the current status of trains within the VSS or TTD, including position, speed, and direction.
- A log of recent events and alerts, such as train movements and system failures.
- The ability to monitor and record the performance of the VSS state machine in real-world operation for analysis and improvement. This feature allows for continuous refinement and optimization of the state machine to ensure optimal performance.

It is important to keep in mind that the graphical user interface should be clear and straightforward to use, with minimal clutter and unnecessary information. The interface should be intuitive and easy to understand for operators, with clear instructions and feedback.

5 User inputs and system outputs

In computer science, the user interface consists of two main components input and output. *Input* refers to the means by which users communicate their requests and preferences to the system, which typically involves using devices such as keyboards, mice, touchscreens, or voice recognition systems. On the other hand, *output* refers to how the computer displays or conveys the results of its processing and computations to the user. The output often involves using visual or auditory feedback such as screens, speakers, or headphones. Designing an effective user interface requires carefully choosing and combining input and output mechanisms that suit the user's needs, abilities, and limitations, while minimizing distractions and allowing the user to focus on the task. Ultimately, the best user interface is one that is seamless, intuitive, and transparent, allowing users to interact with the system effortlessly and without undue attention to the interface itself. (Galitz, 2007, p. 4)

5.1 User inputs

In terms of user inputs, it is important to consider the user's needs and the content in which the program will be used. Some general types of user inputs to view include button clicks, keystrokes, and mouse movements. It may also be helpful to gather feedback from the potential users during the development process to ensure that the user interface is intuitive and efficient. (Galitz, 2007, pp. 423–424)

The computer program receives these user-generated inputs and interprets them to understand the user's desired actions and requirements. The system then processes these inputs in conjunction with data from sensors, such as train speed, location, direction, and the state of the track ahead, to provide relevant and useful information to the user.

Inputs from other systems, such as train control systems, signalling systems, and communication systems, gather and process data that is used to determine the current state and appropriate transitions within the VSS state machine. This data can include train position reports, speed limits, and signalling aspects, which are used to ensure safe and efficient train operations in the ETCS HL3 environment.

Desired speed and direction for the train, which can be entered manually by the train operator or automatically based on a pre-determined schedule or routing. In addition, operational parameters, such as braking distances and operational constraints e.g., weight and length of the train, need to be considered during the operations.

Emergency commands, such as requests to bring the train to a stop or to initiate emergency procedures, can be entered by the train operator in case of an emergency. These are critical inputs that need to be detected and processed by the VSS state machine in a timely and accurate manner to ensure the safety of a train.

Test and simulation inputs can be used to test and evaluate the performance of the VSS state machine in a virtual environment. These inputs could include simulated train movements and positioning data, simulated communication messages between the onboard and trackside equipment, communication errors, and simulated sensor data to test the system's response to different operating conditions.

5.2 System outputs

Regarding system outputs, a graphical user interface state machine can provide visual representations of the current system state, the transitions between states, and any relevant data or information associated with each state. This allows users to easily monitor the system and identify any potential issues or areas for improvement. The graphical user interface can also provide notifications or alerts when certain conditions are met, or state transitions occur. Overall, using a graphical user interface-based state machine can significantly enhance the user experience and improve the efficiency and reliability of the system.

The system can provide instructions and guidance to the program user, including speed and direction commands and emergency alerts. These features aim to improve the user's experience while operating the system.

The actions determined by the VSS state machine can be implemented through the use of signals sent to other systems, such as train control systems, signalling systems, and communication systems. The control signals sent by the VSS state machine to these systems will trigger actions, such as adjusting the speed of the train or signalling to the control centre that a train has entered a particular section of a track.

A graphical user interface-based state machine can provide a lot of useful information about the behaviour of the system, such as data logs, performance metrics, and status reports. This information can be used to analyse and improve the system's performance over time, allowing for more efficient and reliable operation. By carefully monitoring and analysing these metrics, developers can identify areas where the system could be improved and make changes to optimize its performance.

6 Track layout with different configurational options

An example of a track layout for the computer program could include multiple track sections with different train speeds and changing track sections with different states e.g., free, occupied, ambiguous, unknown. The layout could also include different types of points and level crossings, and different length and curvatures. The VSS state machine would need to be able to detect changes in the state of the track sections and respond appropriately, such as by adjusting trains speeds or triggering train protection systems.

Smaller virtual sub-sections (VSS) can increase the complexity of the track layout and train control system, which can reduce the overall capacity of the track. This is because smaller VSSs require more frequent communication between the train and the traffic control system.

The optimal size of a VSS for maximizing track capacity depends on a range of factors, including the complexity of the track layout and train control system used, and the frequency of train operations. Balancing these factors is crucial as it ensures that the virtual sub-sections are sufficiently small to maximize capacity while also maintaining safety and reliability.

Sub-section length is an important consideration when designing different track layouts and configurations. In general, the capacity of the track can increase when virtual sub-sections are smaller, but it is important to note that there are other factors that can also affect track capacity.

In general, it would be effective to give the user the option to change sub-section lengths. If the user is less experienced, it may be better to lock the sub-section lengths to certain sizes to ensure that the system is operating in compliance with safety requirements.

Creating a simple options window for defining lengths for virtual sub-sections and different track layouts, points, station areas, and level crossings would be one essential aspect in the program's design. The options window provides an intuitive user interface that enables users to input and customize various parameters, such as the length of virtual sub-sections and track layouts, and the location of points and station areas. The options can also include various tools for manipulating the virtual track, such as adding or deleting sub-sections and changing the position of points. This flexibility would allow users to create and modify virtual track layouts to meet their specific need. Overall, the options window should provide an easy-to-use interface that simplifies the process of designing and customizing virtual track layouts.

7 Possibilities of graphics-based virtual sub-section state machine in improving the learning experience of ETCS HL3 systems

A graphics-based state machine is a powerful tool that can greatly enhance the efficiency and reliability of a computer program. By providing a visual representation of the program's internal logic, it becomes easier to understand and debug. This can lead to faster development times and fewer errors in the final product. Additionally, graphics-based state machines can be used to create more user-friendly interfaces for complex software. This allows users to interact with the program in a more intuitive manner, improving overall user experience. (Harel, 1987, pp. 231–233)

A graphics-based state machine can offer several benefits, including:

- Visibility: By using a graphical representation of the sub-section, operators can quickly and easily visualize the current state of the system, including the position and status of trains within the VSS/TTD. This can help them to identify potential issues and take corrective action more quickly.
- Intuitiveness: A graphical user interface can be designed to be more intuitive and user-friendly than a text-based interface. This can help to reduce the amount of time and training required for operators to become proficient in using the system.
- Automation: A graphics-based VSS state machine can include automated features, such as automatic switching between different modes of operation, which can help to improve the reliability of the system by reducing the potential for human error.
- Monitoring: A graphical interface can also provide real-time monitoring of the VSS, which can be used to detect and diagnose issues more quickly and to plan maintenance and upgrades more efficiently.
- Better decision-making: With a graphical representation of the system, operators can have a better understanding of the current situation and make better and more

informed decisions which can improve the overall performance and efficiency of the system.

This visual and interactive approach can make it easier for users to comprehend and navigate the complexities of an ETCS Hybrid Level 3 environment. It is also important to note that these benefits depend on the design and functionality of the graphics-based VSS state machine. It is not automatically guaranteed with a graphical user interface.

8 Conclusions

The objective of this thesis was to explore and define three important features for a graphics-based ETCS Hybrid Level 3 Virtual sub-section (VSS) state machine program. The motivation for this research stems from the need to enhance the visualization of different states and transitions in the Hybrid Level 3 system, and to facilitate the development of a graphical user interface program for the ETCS HL3 VSS state machine.

The research conducted in this thesis identified several important features for a graphics-based ETCS HL3 VSS state machine program. A well-designed visual representation was found to be crucial for effective visualization of different states and transitions. A control panel that allows users to switch between different states, user inputs for the train control systems and signals. Different track layouts with different sized virtual sub-sections were identified as important for improving accuracy and capacity. By incorporating these features into the design of a graphical user interface program, it is possible to develop a user-friendly and functional program that can enhance the learning experience.

The findings of this thesis make several contributions to the field of train signalling systems. The individual contribution of this research lies in its focus on developing a novel graphics-based ETCS Hybrid Level 3 VSS state machine program, with specific features that enhance the usability and functionality of the system.

This thesis has identified features for potential future exploration and development. Future research could build on these findings by exploring additional features and refining the existing ones to further improve the performance of train signalling systems.

In reflecting on the limitations of the study, it should be noted that the Hybrid Level 3 concept described in this thesis is not the only concept of implementing ETCS Level 3. There are currently 4 different variants being tested. There are over 20 different train protection systems used across Europe, many of them with their own unique set of challenges and requirements. In summary, the findings of this thesis are specific to the ETCS HL3 VSS state machine and may not be applicable to other systems. The limitations of the study included the fact that no program was tested in a real-world environment. This suggests the need for further research and testing.

In summary, this study has identified key features for a graphics-based ETCS HL3 VSS state machine program that can enhance its usability and functionality. These features include a well-designed visual representation, a control panel for switching between states different states and user inputs, and different track layouts with varying virtual sub-section sizes. While the study’s findings provide a valuable starting point for developing such a program, there is still potential for future exploration and refinement of additional features.

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