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Safety & Capacity of Automatic Level Crossings in the ERTMS Era

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The purpose of this thesis was to explore the potential of an ETCS controlled level crossing. This is a qualitative study, and only automatic level crossings were examined. This study only focused on continuous supervision models on ETCS Level 2 and Hybrid Level 3. These levels are technologically mature and allow the implementation of development solutions compared to the current intermittent JKV supervision model.

ETCS level crossing solutions presented by the ERTMS Users Group were studied. Also, other solutions and innovations enabled by continuous supervision were explored and presented.

The study showed that it is possible to achieve a fail-safe level crossing with ETCS control, where the protected state of the level crossing is supervised as a condition for a crossing. Alternatively, ETCS control can optimize the waiting times for road users. In addition, there exists a Hybrid -model, which could reduce the waiting times and increase safety.

ETCS offers different solutions for different environments and traffic volumes. It is already possible to improve safety and capacity with the current system, but ETCS provides a more efficient way to do it.

Keywords	ERTMS, ETCS, Level Crossing

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Tämän insinöörityön tarkoitus oli selvittää jatkuvan eurooppalaisen junan kulunvalvonnan (ETCS) mahdollistamia parannuksia tasoristeysten turvallisuuteen ja kapasiteettiin. Tämä tutkimus on kvalitatiivinen ja siinä tutkittiin vain automaattisia tasoristeyksiä. Tutkimuksessa keskityttiin vain jatkuvan kulunvalvonnan ETCS tasoihin Level 2 ja Hybrid Level 3, koska nämä ovat teknologialtaan kypsiä ja mahdollistavat kehityksen pistemäiseen junan kulunvalvontaan verrattuna.

Insinöörityössä tutustuttiin ERTMS Users Groupin esittelemiin eri tasoristeysten ohjaus tapoihin ERTMS aikakaudella. Samalla tutkittiin myös muita jatkuvan junan kulunvalvonnan mahdollistamia toiminnallisuuksia.

ETCS ohjauksella on mahdollista toteuttaa täysin turvallinen tasoristeys, jossa sen suojattua tilaa valvotaan ehtona ylitykselle. Vaihtoehtoisesti ETCS ohjauksella voidaan optimoida merkittävästi tien käyttäjien odotusaikoja. Näiden lisäksi on tunnistettu kolmas Hybrid -malli, jossa pyritään huomioimaan tien käyttäjien odotusaikojen lisäksi myös turvallisuutta.

ETCS tarjoaa eri ratkaisumahdollisuuksia erilaisiin olosuhteisiin ja liikennevirtoihin. Turvallisuutta ja kapasiteettia voidaan parantaa jo nykyisellä järjestelmälläkin, mutta ETCS tarjoaa tehokkaamman tavan siihen.

Avainsanat	ERTMS, ETCS, Tasoristeys

Contents

List of Abbreviations

CWT	Constant Warning Time
DMI	Driver Machine Interface
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETCS L2	ETCS Level 2
ETCS HL3	ETCS Hybrid Level 3
FRMCS	Future Railway Mobile Communication System
GSM-R	Global System for Mobile Communications - Railway
JKV	Finnish National ATP (Automatic Train Protection -system)
LX	Level Crossing
LX area	Area from the point where the train must be halted without a MA over the LX to point where the train is considered to pass the LX
MA	Movement Authority
RBC	Radio Block Center
SRS	System Requirement Specification
TIMS	Train Integrity Monitoring System
TTD	Trackside Train Detection
VSS	Virtual Sub-Section

1 Introduction

This study was carried out as part of a Digirata project in Finland. Digirata is a preparatory project for ERTMS implementation in Finland. The implementation will be carried out based on the Digirata project's results. This level crossing study was commissioned by the Finnish Transport Infrastructure Agency and executed by Sweco Finland Oy.

This is a qualitative study to explore the potential of the ETCS controlled level crossing. The study is limited to automatic level crossings only. Interlocking connected level crossings are not considered. Handling level crossings with the intermittent train protection model of the JKV era is used as a benchmark in the study.

The current situation in Finland and the ERTMS will be presented first to understand the impact of ETCS on level crossing's fully. The study only examined ETCS Level 2 and Hybrid Level 3, as the operation is based on continuous supervision on them both. Also, they are technologically mature enough to be considered. The continuous train supervision model enabled by the RBC connection allows new ways to control level crossings.

Level crossing's cause a huge number of accidents and close calls in Finland and around the world. Therefore, it is important that ETCS has the potential to address this and improve the reputation of rail transport in a safer direction. This study is intended to spark discussions on the future of level crossings in the ERTMS era.

2 The current state analysis of Finland

Level crossings (LX) can be classified as a significant safety risk factor in the railway transportation infrastructure. There are over 2,800 level crossings located in Finland, and approximately 25% of them are equipped with a warning system (Liikenneturva 2021). The equipment levels depend on the traffic volumes and traffic frequency.

On top of that, there is a major scale project in 2020-2021 to remove unnecessary ones and improve risky level crossings' in Finland. It aims to remove 130 LX and improve 60 LX safety by installing warning systems or improving sights. Level crossings are removed from centralized vehicle passage routes and the transportation routes of hazardous substances (Liikenneturva 2021). The speed limit for units' operating over level crossing is limited at 140 km/h in Finland unless the road user crossing has been blocked by mechanical locking.

2.1 The spectrum of level crossings across Finland

Depending on the traffic volumes and circumstances, the safety of level crossing

s varies. There are five different protection types in active service:

- Light system
- Light and audible system
- Half-barrier system
- Full-barrier system
- Double-barrier system

Most of the level crossings in Finland operate independently along the railway infrastructure. These are called automatic level crossings. Interlocking connected level crossings differ significantly from automatic by the activation style. The activation depends on the routes set by the interlocking system and the movement authorizations given. These interlocking connected level crossings are designed to be situated near stations or switches. This study focuses only on automatic level crossings.

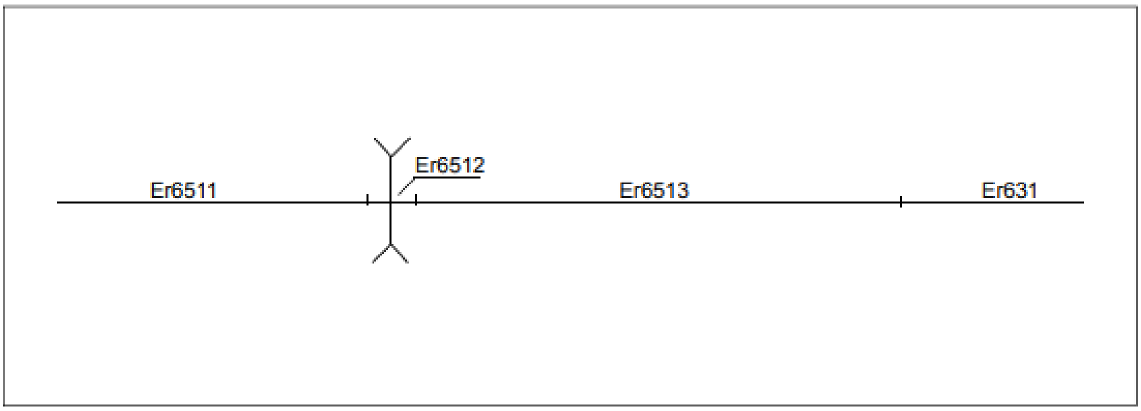

Figure 1. Level crossing safety system activation by track circuit (Väylä 2014)

Automatic level crossings' alarm activation in JKV (Finnish Automatic Train Protection) era is based on track circuit or axle counter sections. Once the train has passed on to an alarm section, it activates the level crossing's safety sequence. In this example, when approaching from right to left, the activating track circuit is Er6513, as shown in Figure 1. The train passing the track circuit Er6512 discharges the safety functionalities. Currently, it is only possible to apply a single warning time tied to the speed allowed on the line. This is due to the JKV intermittent train protection model. It means that it does not matter at which speed the unit is approaching. The LX will be activated on the same geographical spot every time, also called fixed distance announcement. This model can stretch the arriving gap on the LX for passenger and freight train up to 30 seconds, therefore causing extra waiting time for road users.

2.2 Accident reportage and fundamentals of level crossings

Level crossings cause over 30 accidents annually in Finland. On average, five times out of 30, they will cause a serious injury, and three of them are fatal (Väylä 2021). It must be borne in mind that it is always the road user's responsibility to cross the LX safely. In this sense, LX safety functionalities can be defined as precautions because the train cannot steer away from hazardous situations or cannot come to a halt fast enough in most cases. The responsibility always lies with the road user.

3 ERTMS & ETCS

ERTMS (European Rail Traffic Management System) is a major industrial project implemented by the European Union. ERTMS offers high safety performance, removing technological borders offering competitive and seamless rail transport. The objective of ERTMS is to develop and deploy a single harmonized control command signaling and a fully interoperable communication system. The goal is to remove barriers to communication and signaling that can be sourced from a broad supply base and whose evolution is based on compatibility. ERTMS has also been used outside the EU. For example, in Argentina, Turkey, South Korea, Taiwan and Algeria.

ETCS (European Train Control System) and the GSM-R (Global System for Mobile Communication -Railways) or FRMCS (Future Railway Mobile Communication System) are the two main parts of ERTMS. ERTMS is the backbone of a digital railway system. ETCS will replace all different train protection systems across Europe. This will simplify the cross-border traffic, enhance the supply markets, and lower the general pricing of the industry to make it more attractive for customers and investors.

There have been defined several different operation levels for the ETCS. Those levels differ considerably technically from each other, but the main reason for this is to allow the member states to choose the levels based on their needs and budget. The ETCS Levels that will be examined in this study are Level 2 and Hybrid Level 3.

3.1 RBC & FRMCS

The radio block center (RBC) is the core of operation on ETCS L2 (Level 2) and L3 (Level 3). RBC runs all train operations in its coverage area on trains that have established a data radio network connection. The train receives MA (Movement Authority) from the RBC it is connected to according to information received from the interlocking, such as route occupancy, route state, etc. It also receives information from trains regarding their position and configuration information, such as the train length and axle load category.

The general assumption among European countries is that the RBC to train connection is provided by an existing GSM-R. Finland sought a derogation from the European Union and renewed its voice radio system with a Finnish government authority network Virve in 2019. This gives the privilege to a smoother transition to FRMCS for Finland because no migration is needed in the transition phase from GSM-R to FRMCS. Finland can be among the first adaptors of FRMCS.

The special permit to use Virve will end as soon as the FRMCS arrives at markets. Virve 2.0 will be available for commercial use in 2022, according to expert estimates. A decision on the choice of FRMCS has not yet been made, however. Another possible solution will be other commercial networks. FRMCS will very likely be based on 5G technology. It will also be based on the IP-Protocol. (LVM 2020: 19, 36.)

3.2 ETCS Level 2

Compared to JKV and ETCS L1 (Level 1) intermittent train protection model, the ETCS L2 operational principle is based on continuous supervision. MA and other signal aspects, such as speed information and route data are displayed in the DMI and provided for the train over FRMCS. On ETCS level 2, it is possible to decrease or operate entirely without lineside signaling. The harmonization and capacity increase significantly. On ETCS L2, the TTD (Trackside Train Detection) is still responsible for the train detection and integrity supervision. Eurobalises at this level are used as "electronic milestones" to calibrate the location of the train. This way the RBC always knows the train’s position within a certain tolerance. The operational principle of ETCS L2 is shown in Figure 2.

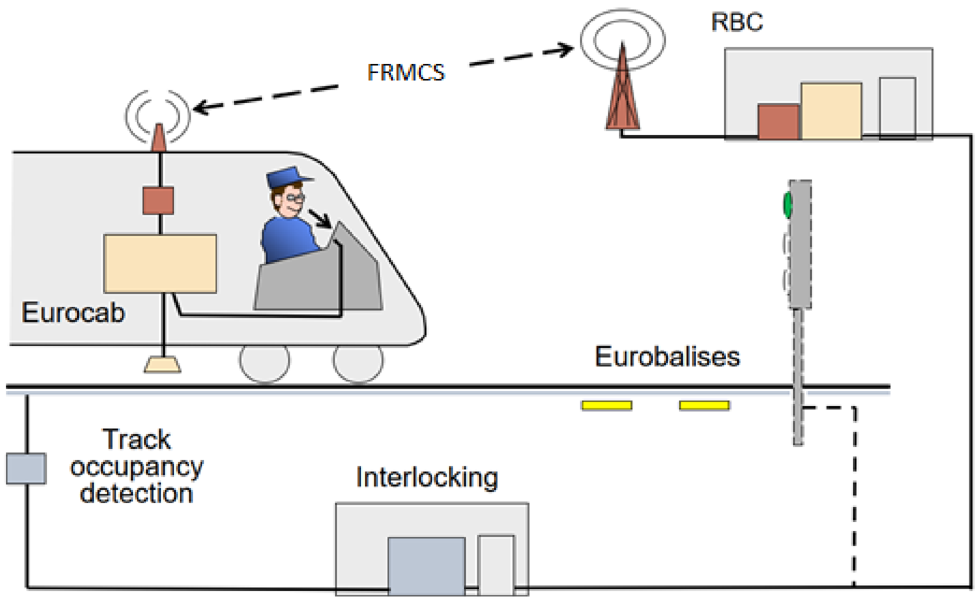

Figure 2. ETCS Level 2 (VIA Consulting & Development – Digirail staff training 2019 - modified)

The positive effects on track capacity are based on shorter block lengths. These supervised blocks can be divided into smaller ones, allowing trains to operate closer to each other. This also gives traffic planning officials numerous opportunities to improve scheduling.

3.3 ETCS Hybrid Level 3

The natural upgrade from L2 would be ETCS L3. Despite its potential benefits, many issues are still related to the compatibility of rolling stock and degraded situations. ETCS HL3 (Hybrid Level 3) is a derivative concept to L3. The technical concept is more mature compared to L3, although obtaining almost the same number of benefits in terms of track capacity.

The operational principle of Hybrid Level 3 is based on the trackside occupancy detection in the same way as in Level 2, but the concept introduces VSS (Virtual Sub Section) technology in addition to that.

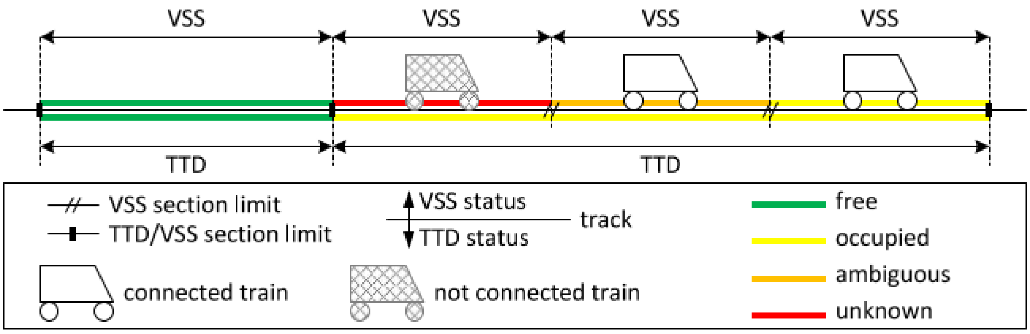

Figure 3. VSS - Section conventions (ERTMS Users Group 2017: 9.)

Dividing the track into even smaller sections allows trains to operate closer to each other. To gain the benefits of HL3, the train must have an on-board TIMS (Train Integrity Monitoring System). TIMS supervises the train's length and reports deviations in it immediately to RBC. This technology enables the function to set free the VSS without a physical axle counter system. It is possible to reduce TTD from the track by dividing the track into VSS sections, but this requires TIMS from the rolling stock in the same proportion to gain the desired capacity.

Another issue related to the rolling stock is that there are no technical solutions available for freight train TIMS. Hybrid Level 3 could be a solution to relieve traffic in peak hours on busy tracks, where freight trains without TIMS could operate in quiet hours.

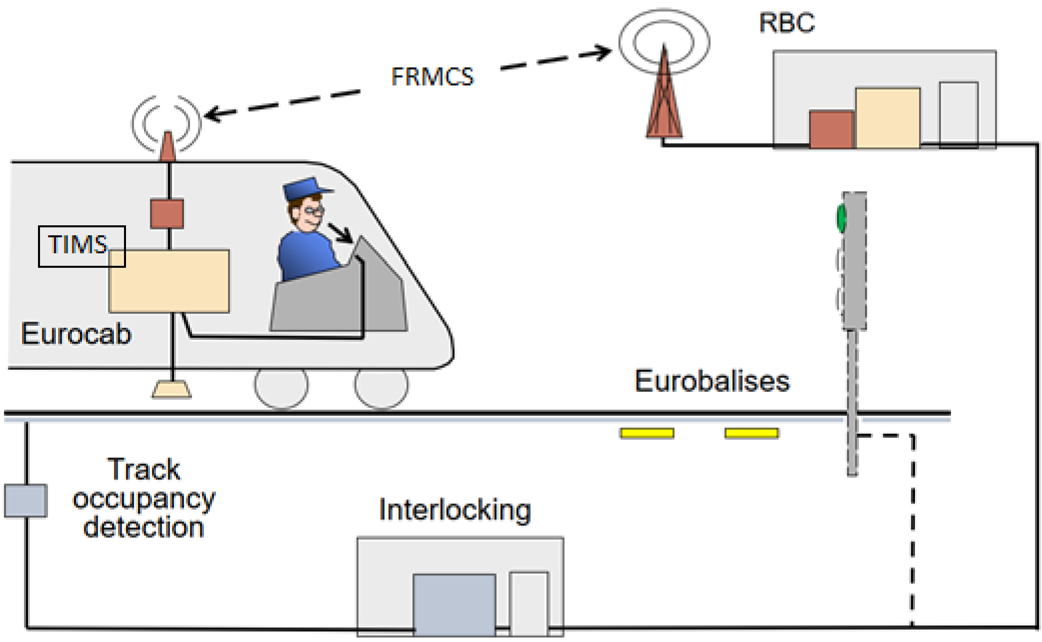

Figure 4. ETCS Hybrid Level 3 (VIA Consulting & Development – Digirail staff training 2019 - modified)

The operational principle of HL3 is much related to L2, as shown in Figure 4. TIMS and VSS are the only main components making the difference.

3.4 Implementation of ETCS in Finland

The first official NIP (National implementation plan) of ETCS in Finland was introduced to the EU in 2006. That was updated and delivered to the EU in 2017. According to the latest NIP, the plan is to launch a pilot test track in 2020-2023. This piloting aims to clarify the possible benefits that would be achievable in ETCS Level 2. This project is known as Digirata, and the pilot track will be located in Southern Finland. The government of Finland is making a political decision on which ETCS level the national implementation will be based on Digirata’s test results. (Liikennevirasto 2018: 12.)

Finland might not benefit from the interoperability aspect in the ERTMS era because Finland's rail gauge differs compared to neighboring countries for now. Also, there is no need to rush with the partially immature ERTMS technology simply because the JKV system is still fully functional. The primary motivator for Finland is the need to replace the aging JKV system and maintain the safety levels, also obtain the economic benefits of the ERTMS. The ERTMS system is continually evolving and maturing as more ETCS track kilometers are built across Europe. (Liikennevirasto 2017: 12.)

4 ETCS Level Crossing

In terms of level crossing functionalities and protection level, the regulations give countries options on a large scale. Traffic volumes, safety culture, and budgets vary a lot between countries and cities across Europe. For each level crossing project, it is possible to make a tailor-made solution. In Baseline 3 of the SRS (System Requirements Specification), LX supervision was being introduced. Also, two different solutions for handling level crossings have been introduced by the ERTMS Users Group. It is an organization for rail infrastructure managers using ERTMS.

4.1 Definition of ETCS level crossing

When defining an ETCS based LX, the following system functionalities must be considered (ERTMS Users Group 2020: 17):

- Allow level crossing passage at line speed
- Start of mission in rear of a level crossing
- On-sight routes over the level crossing
- Decrease of static speed profile in rear of the level crossing
- Avoid driver intervention when approaching an LX under activation
- Level crossing with short maximum waiting time
- Planned stop in rear of a level crossing
- Planned stop in advance of a level crossing

- Exceeding maximum waiting time
- Level crossing located close to each other

The definition has been made by considering both ETCS L2 and HL3 operational principles. The two main technical elements of HL3, VSS, and TIMS are evaluated here in terms of their effect on LX safety and capacity. In the HL3 concept, these elements are considered interdependent, but they can be separated from each other and evaluated as individual factors in this case study. But for the sake of clarity, it should be noted that there is no one without the other. Neither can benefit without the other.

TIMS will not provide any added value. TIMS enables freeing sectors without TTD and, in theory capable of activating the LX opening. But, it must be kept in mind that TIMS location information always includes some scatter. On this matter, TIMS does not provide similar safety factors and functionalities in degraded situations, which TTD equipment can provide. The degraded situations and backup functions are discussed in chapter 4.5.

VSS dividing technology allows trains to operate even closer to each other, providing more track capacity. Level crossings in Finland are not considered capacity-restricting elements. The high-volume traffic nodes are dealt with over/underpass solutions. There is potential in the technology, but simply because there is no need for development in the VSS area of influence, this technology is unnecessary in the matter of subject. Even if such a capacity complex project occurs, for which the track-section would need to be divided, it could be easily and cost-efficiently done by adding an extra axle-counter sector.

After evaluating TIMS and VSS, we can state that all the functionalities that HL3 could provide to level crossings' safety and capacity are not adding any significant value or are already included in L2. This can be summarized as follows.

$$(L2 = HL3) = ETCS\ LX$$

There have been defined two control solutions for the LX by the ERTMS Users Group (ERTMS Users Group 2020: 17-35.). Solution A is a model to improve level crossing safety with ETCS. Solution B is a model to obtain CWT (Constant Warning Time).

4.2 Safety as a condition – Solution A

ETCS can be used to raise the safety of supervised level crossing's significantly. By using level crossing's protected or partially protected state as a condition for the movement authority over the LX. (ERTMS Users Group 2020: 17-25.). Approaching train movement authority is granted to the starting point of the level crossing with a release speed of 0 km/h until the level crossing protected state extends the movement authority. Each individual train will be able to stop in rear of the level crossing in case of a malfunctioning level crossing. In a barrier-protected level crossing, the fully lowered state of the barriers is considered a protected state. In Finland's current 34 seconds t_announcement sequence requirement, this state is achieved 10 seconds before crossing. At the 10 seconds mark point, the position of the train from the LX is 389 meters when approaching with a static speed of 140 km/h. The following table shows an IC-train's (InterCity) braking test results as an example from ideal conditions and an estimate of the impact of bad conditions on them.

Table 1. Intercity train with load braking distance test data (VR Fleetcare)

	Ideal conditions			**Bad conditions (1.2x multiplier)**	
	Stopping distance (m)			Stopping distance (m)	
Speed km/h	*Min. requirement*	*R*	*R + mg*	*R*	*R + mg*
140	1000	615	443	738	532

R= Rapid (brake class)
mg= Magnetic brakes (additional emergency brakes)

It can be stated that no rolling stock on Finnish tracks has this kind of stopping capability within 389 meters from 140 km/h in case of a sudden malfunction. The Finnish minimum requirement is that from 140 km/h speed, the unit must be able to halt entirely in 1000 meters. This means that this safety upgrade of solution A comes with a downside. In order to implement solution A, a sacrifice must be made between these two options compared to the current JKV automated level crossing system:

- Decreasing speed at LX approach area – maintain current road user's waiting times
- Increase the waiting time for road users – Maintain line speed restrictions. This is listed as functionality that must be considered by the ERTMS Users Group, see chapter 4.1.

However, it is possible to cultivate at least some optimization of the waiting times because ETCS calculates each individual train's braking curve separately.

The protected state used as a condition is related to the level crossing's hazardous state warning functionality discussed in chapter 4.4.1.

4.3 Constant warning time – Solution B

A speed dependent announcement time (Constant Warning Time - CWT) was introduced as Solution B for the handling of level crossing (ERTMS Users Group 2020). The recommendation is to use the on-board functionality for generating position reports for triggering the LX. This requires that the speed and distance to LX are used for dynamically calculating when to trigger the level crossing. Also, timeclock synchronization between the on-board and RBC must be taken into account, resulting in a corrected timestamp used in the RBC to generate the correct time for level crossing triggering. The waiting time will be optimized since each individual train's property (actual position and speed) is taken into consideration as if there is a (virtual) balise which location is adapted to each running train.

When using an open-air connection, system delays must be taken into account. The following inaccuracies of the positioning components must be included in the equation.

- 2% in train speed

- 5% in train position (The distance between two balise groups in the LX approach area should be no more than 500m)

The ETCS on-board provides speed and position information to the RBC at regular intervals, and the calculation is repeated at every one of them. A prerequisite for using the speed and position information together with trackside speed profiles is that the conditions to send an L2 MA are fulfilled. One of these conditions is that the position of the train is unambiguous. MA over the LX will be given once the LX activation has triggered and the LX is protected. A safe closure of LX is assumed once commanded.

The following theoretical calculation example aims to show how much it is possible to cut the road users' waiting time using speed-dependent announcement triggering with an announcement time of 34 seconds (Finnish standard in JKV) for two trains with different static speeds.

Table 2. Input data

	km/h	m/s
V_Train1	80	22,2
V_Train2	140	38,9

Announcement distance needed for Train 1.

$$22{,}2\frac{m}{s} \cdot 34\ s = 755\ m$$

Announcement distance needed for Train 2.

$$38{,}9\frac{m}{s} \cdot 34\ s = 1323\ m$$

Waiting time for road users when Train 1 crossing over LX with fixed distance announcement.

$$1323\ m - 755\ m = 568\ m$$

$$\frac{568\ m}{22{,}2\ m/s} = 26\ s$$

$$34\ s + 26\ s = 60\ s$$

There is in theory a potential to optimize waiting times, according to this example a significant 26 seconds in case Train1.

Inaccuracies and system delays must also be included to create the real announcement time. The following example shows their effect on road users' waiting times in terms of the following assumptions. (ERTMS Users Group 2020: 35.)

- t_announcement is 34 seconds
- The distance between two balise groups in the LX approach area is not more than 500m
- V_Train = 140km/h
- The actual front end of the train is assumed to be at the min front end position of the position report, representing the worst-case scenario of position accuracy (worst case)

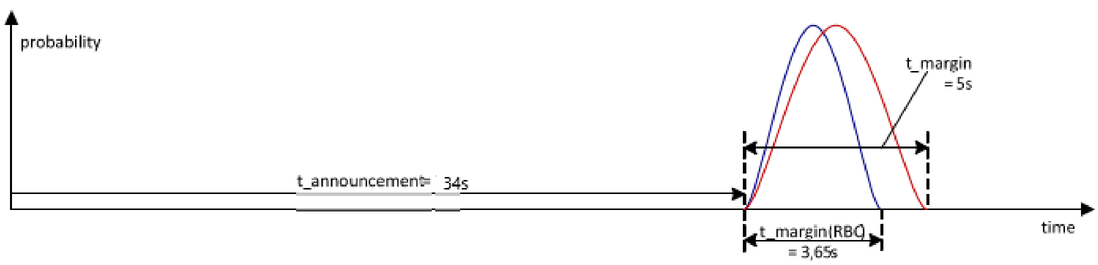

Figure 5. Real announcement time estimation on 34 seconds announcement time - modified (ERTMS Users Group 2020)

As shown in Figure 5, the real announcement time for Train 2 includes t_margin(RBC), increasing the waiting time in this example case by 10.7% in the worst-case scenario. This percentage is not directly comparable to Train 1 due to the difference in speed. A more detailed representation of the real announcement time can be found in the references (ERTMS Users Group 2020: 35-36.).

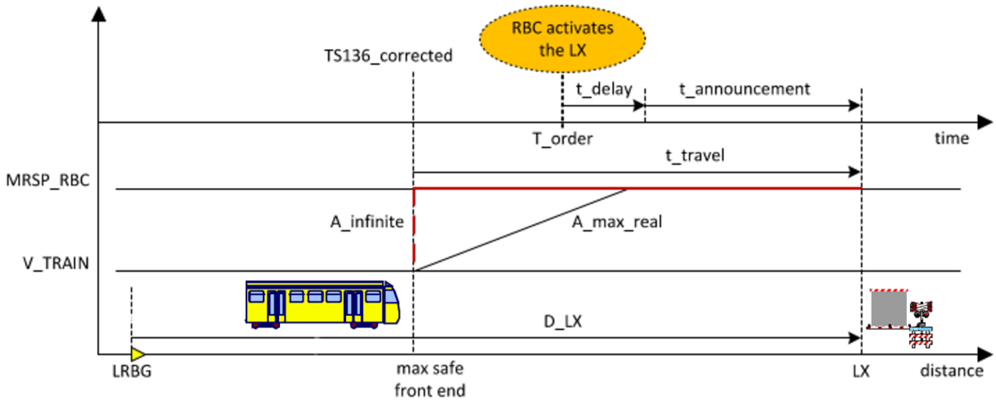

Figure 6. LX Announcement principle in CWT - modified (ERTMS Users Group 2020)

Figure 6 shows the different components of the CWT model. More details can be found in reference (ERTMS Users Group 2020: 35-36.).

Solution B aims at efficiency. CWT is gained, but safety, however, does not improve at all. The safe closure assumed once commanded represents a legacy from the JKV era. At worst, it reduces safety if speeds are increased, and no action is taken to increase the protection levels.

4.4 Possibilities and innovation with ETCS

CWT provided by the ERTMS will be the primary goal in the new era. Continuous supervision and connection also offer an opportunity to explore other safety and capacity-related innovations. These can be viewed as case-specific accessories depending on each project individual conditions and accident history. Tarva LC program, developed in 2012, would work as a reference because Finnish level crossings are divided into seven categories based on their level of safety.

These innovations can only be seen as linked to solution B, since solution A is already seamless in terms of safety. Ideas are presented on a theoretical level.

4.4.1 Level crossing hazard state warning

The most dangerous situations occur when a large-scale vehicle is stuck in the way of a train crossing an LX. Small vehicles and humans are also dangerous. Risky and high-speed hazardous situations can occur especially on short-sighted crossings with a little time to react. Obstacles on the track and malfunction situations are the two most significant causes of accidents on an LX infrastructure. Both of these issues can be dealt with at least at some level, thanks to the continuous supervision model of ETCS.

Obstacle detection has long been studied as a field of technology to improve the safety of level crossings. Sensor-based information could be gathered from the LX, and this could affect the safety sequence of it. Optical beams, scanning laser radars, or induction circuits could be activated to a supervision state when the approaching train activates the safety sequence. In case of a hazardous state, it is possible to inform the train operator via RBC. There are two message packets built into the ETCS that could deliver such warnings that lead to emergency braking.

Table 3. ETCS Packets

PACKET NUMBER	DESCRIPTION
76	Packet for sending a fixed text message
88	Level crossing information

Malfunctions of the beams and red lights at the level crossing can also cause a hazardous state. A system called Tarmo is currently in use in Finland. The fault situations caused by degraded level crossings are divided into two safety categories based on their urgency level. Urgent faults are reacted to immediately. Urgent faults include faults in beams and red lights and non-urgent faults can be caused by, for example a low battery voltage state. Tarmo transmits the fault information to the traffic control center and they will act as required by the situation. In case of critical malfunction, the traffic control can set areal speed restrictions and inform units regionally about the hazardous situations.

ETCS and the RBC connection enable the possibility to add the approaching unit operator straight to the chain of information, allowing the operator or the ETCS to react immediately to these sudden hazardous states. For example, a unit is approaching an LX at a speed of 140km/h, and it receives a hazardous state warning 10 seconds before arriving on the LX area. The unit is located at this point 389 meters away from the LX area. If the unit has been tripped at this point or initiated emergency brakes, it is possible to slow down the unit's arrival speed significantly and increase the salvation time by seconds despite the braking delays. This would be especially beneficial in short-sighted level crossings. This study does not take a position on exact figures in such a case.

However, when talking about equipment like this, the possibility of vandalism must also be considered. The train may be assigned an emergency stop in hazardous situations and halt the train entirely, causing scheduling delays and problems if misused.

4.4.2 Display information to road users

As we move deeper into the digital era, information related to the train arrival, etc. could be provided to the road user. Steps from the train arrival can be simulated on an information board in some form. At worst, such information may work just the opposite, but with well-considered communication, it is possible to eradicate at least the most dangerous last seconds of crossing attempts. A system like this could act as a reassuring safety element at a level crossing and even give some sense of control of the situation to a busy or bored road user. At ETCS controlled level crossing, this kind of functionality could be easily carried out by joining a pre-defined information sequence to the t_announcement activation signal. Thanks to CWT, the same information sequence applies to all approaching units. The following figure shows what this type of information might look like in a sequence diagram.

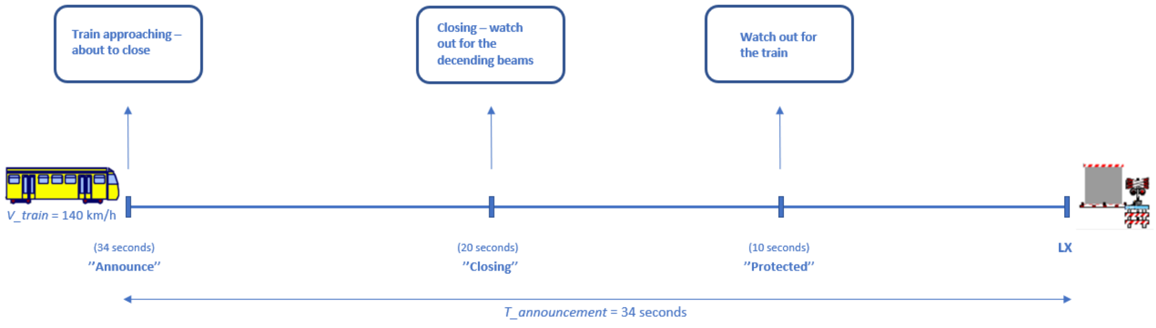

Figure 7. Information displaying concept

4.5 Level crossing backup function

The ETCS solutions introduced by the ERTMS Users Group require an RBC connection. It is assumed that level crossings are located on a track equipped with ETCS. The degraded situations when the RBC connection is lost must be handled with a mechanical solution. Track maintenance units without ETCS on-board equipment also need a mechanical solution. All different ETCS modes and possible situations which could occur that will require a backup function must be considered. These situations are listed below. National values also determine the speed restriction associated with each situation.

- OS - On sight mode – 35 km/h (Liikennevirasto 2015: 6.)
- SR - Staff responsible mode – 50 km/h (Liikennevirasto 2015: 6.)
- Maintenance unit – 50 km/h (Väylä 2020: 31.)

The best and most reliable backup solution would be an axle counter or track circuit alarm sector for the activation in these special situations, with the same principle as the current solution. The alarm section should be dimensioned according to the highest speed allowed in these special situations. ETCS units in staff responsible mode and maintenance units on-line are permitted to operate at 50km/h, representing the least restrictive situations measured in speed limits. Based on this, a fixed distance announcement point should be placed, based on a speed limit of 50 km/h. With a 34 seconds announcement time, the fixed distance location would be 472 m. This is considered a safe distance from the CWT principle activation and thus does not have a limiting effect on units operating under normal conditions and speed limits while providing a fail-safe backup function for degraded situations.

4.6 Increase speed restriction

Level crossing areas are almost invariably a part of the line speed limit. Therefore, it can be stated, that they are not capacity restricting elements in terms of speed limits. There are some exceptional cases in Finland where the line speed has had to be reduced momentarily due to an unprotected level crossing. Restrictions like this are very case-specific. Although 140 km/h has been set as the maximum speed allowed for operating over a level crossing in Finland, its use is not very common.

Level crossing safety could be improved even without ETCS solutions. There are in-service half-barrier systems in the 140 km/h speed limit area in Finland, and these could be upgraded to full-barriers even with the current protection models. Protected level crossings, however, are expensive and are highly dependent on budget issues.

If there is a need to increase the national level crossing speed limit in Finland, the additional safety achieved by ETCS solutions could justify it. But if bottlenecks emerge in Finland, it has to be discussed how low the threshold for resolving the problem with over/underpass can be. This topic is complex and challenging, and it can be said to be the sum of many factors.

5 Conclusions

The study revealed that ETCS offers several options for handling automatic level crossings in the ERTMS era. An ETCS handled level crossing offers the possibility to make tailor-made solutions for each LX case based on their individual circumstances. The same model does not have to be used at every level crossing. Another benefit is definitely the flexibility of the system. Alarm times for example, can be adjusted on a case-by-case basis as first aid with ease if close calls occur.

Table 4 summarizes three different identified models and describes their common features. The JKV intermittent model has been used as a benchmark in these. In addition to the ERTMS Users Group solutions, a third hybrid solution has been identified. Safety and CWT can be used as adjusters.

Table 4. ETCS based models on level crossings

LX ETCS model	Vision & Description	Advantages	Disadvantages
1. *ERTMS users group - solution A (chapter 4.2)*	Targeted safety improvements. Using safety as a condition. This kind of targets could be for example level crossings near schools and along school trips.	Hazardous situations cannot arise. Safety will be an condition for operating over the level crossing. Fail-safe model as long as there is as RBC connection.	Requires a speed reduction or will increase road users waiting time. Does not take obstacles at level crossing area into account.
2. *ERTMS users group - solution B (chapter 4.3)*	Improving the traffic flow of the current operating model by using CWT.	Constant warning time. Standarized sequence allows the innovation in chapter 4.4.2.	Does not improve the safety of level crossings.
3. *Hybrid solution*	Combines solution B with safety enhancing solutions. Additional safety measures by informing road users (chapter 4.4.2) and/or supervising the level crossing protection state but not as a condition (chapter 4.4.1).	There are benefits gained from both safety and capacity perspectives. Fully implemented CWT and additional safety compared to current model.	Expensive and complex. Risk of vandalism.

It should be noted that there is room for improvement in the safety of level crossings even without ETCS solutions. By increasing mechanical protection or re-designing the layout, it is possible to improve safety with the current existing solutions. However, ETCS enables more efficient improvements in safety and capacity.

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