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The Railway 4.0. Concept – the vision of a digital railway in the Czech Republic (CR)

Keywords

Railway digitalization, ETCS, GSM-R, FRMCS, Intelligent transportation systems on Railway

Abstract

The paper presents a new alternative approach to the modernization of control and security technologies on the railway network in the Czech Republic, referred to as the "The Railway 4.0 Concept". The presented concept is based on the comprehensive introduction of digital technologies that fulfil the vision of Intelligent Transport Systems on Railways (ITS-R). The paper describes the architecture and basic components of the system based on the distributed technologies with the centralization of logical elements. The paper also places the given issue in the context of current developments in the implementation of the ETCS system in the Czech Republic.

1. Introduction

The long-planned and long-term implementation of the ERTMS/ETCS system is currently underway, not only on the Czech railways. This technology brings, in particular, increased safety in controlling the movement of rail vehicles, i.e. the elimination of error on the part of the train driver. However, the ERTMS/ETCS cannot be seen only as a safety enhancement system, or as a way of meeting one of EU's interoperable requirements – a requirement to implement a single train protection system. The ERTMS/ETCS technology can clearly be seen as a fundamental element enabling change in the approach to more efficient utilization of the railway system and its implementation must not only follow the safety parameter but must also lead to increased capacity and usability of the railway by the Czech transport system. Therefore, the question today is not whether to introduce such a system, but how to introduce these new technologies so that they bring real benefit to the railway function and overall transport in the Czech Republic.

2. History of the Railway 4.0. Concept

The Railway 4.0. Concept was created as a technological elaboration of the vision "Intelligent Transport Systems on Railways" (ITS-R)², which was defined by the

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² The ITS-R vision was added into the strategic materials of the Ministry of Transportation in 2016 within the Implementation Plan of the Action Plan for the Development of Intelligent Transport Systems (ITS) in the Czech Republic by 2020 (with an outlook to 2050) as project No. 63, ZD-20, Pilot verification of ITS-R technology -

SDT Working Group. The vision of ITS-R³ defined the fundamental vision of railway technology development. It should clearly lead to the concept of intelligent vehicles, i.e. vehicles which, thanks to the on-board technologies ETCS, ATO, GSM-R/FRMCS, 4G/5G, will enable the full security of their operation, including automation and optimization of their driving. At the same time, they will enable their full involvement in logistic transportation systems in both freight and passenger transport. Finally, they will also provide services to passengers in the form of voice and data communication. However, the infrastructure aspect of these technologies, which must supply adequate technologies in the form of, in particular, radio networks and an appropriate level of ETCS train control technology based on at least application level 2 with the possibility of using application level 3, must adapt to this concept of intelligent vehicles.

At present, it is not a question of whether this vision of intelligent transport systems will be realized. Current global trends, based on the present level of technology and the generally increasing demands for higher railway usability, clearly confirm this direction. Similar projects addressing the issue of comprehensive digitalization and modernization of railways can be found in most of the EU's neighboring countries. The Digitales Stellwerk⁴ project in Germany can be mentioned, which is a part of a comprehensive plan for digital railways⁵. The traditional Swiss railways SBB⁶ are dealing with a similar program in the SmartRail4.0 project. The comprehensive ETCS and GSM-R deployment program is already being implemented by the Norwegian railways Bane NOR⁷.

The main issue concerning the modernization of the railways in the Czech Republic should therefore be a discussion on how to manage this necessary generational and comprehensive change of technologies in a sufficiently short time, with reasonable financial resources, so that we can take advantage of the benefits that these technologies undoubtedly bring as soon as possible. The aim and the evaluation criteria of modernization strategies should therefore be an increase in the usability of the railway in terms of the speed requirements, infrastructure capacity as well as the accuracy and availability of railways, enabling effective involvement in integrated transport systems throughout the Czech Republic. In this context of a comprehensive approach, the safety parameter that is most closely linked to the ETCS system needs to be seen as a necessary and indispensable condition that is a natural part of the technologies being implemented.

The Railway 4.0. Concept was created while the author of this article was active in the Security Commission of the Ministry of Transportation of the Czech Republic (MDCR), which was established by the Minister of Transportation of the Czech Republic doc. Ing. Karel Havlíček, Ph.D. MBA in 7/2020, in response to a tragic accident at Pernink railway station. Within the framework of negotiations, a MDCR-O130 vision of the implementation of the ETCS and GSM-R systems to all railway lines

stage 0 <https://www.mdcrcz/Dokumenty/Strategie/ITS/Implementacni-plan-k-Akcni-mu-planu-rozvoje-inteligne?returl=/Dokumenty/Strategie/ITS>

³ http://www.sdt.cz/dokumenty/2015_Pozicni_dokument_SDT_rozvoj_ITS_na_zeleznici.pdf

⁴ https://de.wikipedia.org/wiki/Digitales_Stellwerk

⁵ <https://digitale-schiene-deutschland.de/en>

⁶ <https://www.smartrail40.ch/>

⁷ <https://www.banenor.no/Prosjekter/prosjekter/ertms/>

and vehicles by 2040 was introduced. From the outlined material⁸ it is clear that by 2040 all railway lines in the Czech Republic should be equipped with ETCS and GSM-R systems. This political demand, emphasizing in particular the requirement to increase the safety of the entire railway network of the Czech Republic, was the subject of a solution proposed to address this issue by experts from the Railway Administration, a state organization (hereinafter "SZ"). The proposal⁹ envisages possible solutions through comprehensive modernization of some major railway lines (most also intended for electrification) via ETCS technology at application level 2, on less busy lines it proposes implementation by repairing existing security devices and supplementing them with ETCS at application level L1, and for the least busy regional lines it proposes supplementing with simplified variants ETCS L1 LS and ETCS L1 STOP. In the case of the ETCS L1 version, the GSM-R line radio is also not introduced, on the contrary, the functional use of the TRS analogue radio system, which is installed due to the repair of existing SRV radios, is practically expanded. However, these simplified variants of the solution only respond to the requirement for accelerated implementation of a safety function preventing trains from an unauthorized passing through a prohibiting signal. Nevertheless, they cannot be considered as technologies that would make the railway more usable, including new technologies, as defined by the ITS-R concept.

The Railway 4.0. concept brings an alternative proposal for the possibility of a comprehensive approach to the introduction of digital technologies fulfilling the ITS-R vision on the entire railway network in the Czech Republic, respecting both the requirements of increasing railway safety and the requirements for higher usability and connectivity of railways for the Czech transport system. This paper provides a basic description of the architecture and key components of this concept. When dealing with the complex concept of technology alteration, it can be assumed that the network-wide introduction of these technologies can be managed in a sufficiently short time and at a reasonable economic cost.

3. Aspects of introducing modern technologies to the Czech railway

When deploying new technologies based on ETCS and GSM-R/FRMCS systems, it should be had in mind that the implementation of ETCS, which in principle deals exclusively with train security, as a train security device having both track-side and mobile parts, is directly dependent on the technology of infrastructure security devices. These devices are not part of ETCS and are therefore do not fall under interoperable specifications and must be addressed specifically by each infrastructure manager. These technologies can thus constitute a significant part of the infrastructure investment that ETCS technologies can build on. Due to the nature of the ETCS system, there are application conditions (functional and safety) that determine which infrastructure security equipment it is possible or appropriate to apply the ETCS system to. When determining the concept of modernization, it is therefore essential to first

⁸ <https://www.mdcr.cz/Media/Media-a-tiskove-zpravy/Bezpecnostni-komise-Hlavni-i-lokalni-trati-jiz-zn>

⁹ The proposal for the implementation of the ETCS system in the Czech Republic is presented today by the document "Plan of modern security of the Czech railways"

address the question of the initial situation in the Czech Republic. Unfortunately, even representatives of the SZ in the MDCR safety commission did not provide detailed information on the current parameters of infrastructure technologies. Therefore, it is necessary to describe this topic rather in the context of the current approach to the modernization of these technologies.

From the current publicly available information and experience of the author of this article, it can be stated that in the Czech Republic there have traditionally been massive investments into control and security technologies, especially on corridor networks of approx. 1500 km, which are the backbone railway system included in the TEN-T network. Nevertheless, there are systems in this part of the infrastructure dating back to the turn of the 19th and 20th centuries, specifically electromechanical security devices. Many railway stations and sections also have installations of relay technology, a track-side security device, which have been installed since the 1950s. However, the implementation of ETCS, application level 2, which is preferred on corridor networks, requires the replacement of these old technologies, as the deployment of ETCS would be too complicated and in some aspects also unfeasible for safety reasons. The connection of the ETCS system to the newer technologies of electronic interlocks installed at the turn of the millennium can also be complicated due to the moral outdated and unpreparedness of the technology to be connected to the ETCS system. Specifically, these are, for example, electronic and hybrid interlocking cores, which require data communication with the Radio Block Centre (RBC) and sufficient computing power. As these technologies currently have more than 20 years of active life and are technically and morally outdated, they are currently being replaced by new electronic systems that allow connection to the ETCS system. It is evident that the modernization of infrastructure and security equipment is not easy, it is difficult to solve in the range of corridor lines, and it is very time-consuming and financially demanding.

In the Czech Republic there are currently about 9700 km of tracks in operation. So far, no systematic and comprehensive change of security technologies has taken place on a larger segment of the off-corridor lines. Many of them have so far been modernized due to a lack of funds from their generated profits. Nevertheless, a number of national and regional lines, on which most of the necessary comprehensive modernization of the infrastructure has also taken place, have new electronic security equipment installed. Some electronic security devices are also installed as part of the repairs of outdated security devices. However, it can be stated that most off-corridor lines (national and especially regional) in the Czech Republic are burdened by considerable historical underinvestment in control and security technologies, where mechanical and electromechanical equipment from the turn of the 19th and 20th centuries, as well as relay technologies, are located. 1700 km of regional lines are not equipped with any security equipment and operation on them is controlled according to the regulation for simplified management of rail transport SZ D3 with a minimum of infrastructure technologies.

It is therefore a fundamental strategic question how to implement new technologies in a sufficiently short time and as efficiently as possible, which will enable the extension of new ETCS and GSM-R technologies to the entire railway network in the Czech Republic. The key question is certainly also whether it “pays off” to install relatively

expensive technologies on low-capacity regional lines, with current traffic up to tens of trains per day, or whether simpler and cheaper technologies should be applied instead. In this context, it is important to realize that the main role of railways should be primarily the implementation of backbone transport, which forms a unique alternative transport system to the road network, providing both passenger and heavy goods transport. The construction and operation of this railway infrastructure brings relatively high costs both for the infrastructure manager as well as for the carriers of rail vehicles. It is therefore necessary to consider the issue of efficient use of this infrastructure and to consider whether the absence of security equipment significantly (unduly) restricts the utilization of this infrastructure, and the installation of simplified security technologies will not significantly increase its utility in terms of capacity (supply offer), as well as its speed. All this can devalue investments in infrastructure and rail vehicles. Consequently, this will inevitably lead to increased investment and external costs for higher use of the road network, so savings from the cancellation or reduction of rail transport will certainly not bring overall savings from the point of view of the state or regions. Meanwhile, more intensive use of railway transport is currently clearly defined in long-term policies both in the Czech Republic and in the EU. The inhabitants of the Czech Republic are currently seeking housing outside large cities for socio-economic and environmental reasons, and it is clear that rail transport can ensure a sustainable way of connecting rural and urban agglomerations. In the area of freight transport, an increase in demand for local freight services in connection with the collection of municipal waste or individual package shipments can also be expected in the coming years. Therefore, it is necessary to perceive investments in railways in the context of the transport needs of the whole Czech Republic, not separately as a solution only to the issue of safety or the introduction of an interoperable ETCS system. The introduction of new technologies on regional lines can bring the potential to increase speed and usability even on such underused lines. However, it is an important prerequisite that transport on such lines be implemented as an overall transport concept, where the regional railways will form a fast capacity backbone of the region's transport system.

A specific problem in the Czech Republic in this context may be regional lines, which to an increased extent face many crossings in a density of up to approx. 1 crossing per 1 km. In addition to the safety problem (road-rail collision), crossings often also limit the speed of rail vehicles, thus limiting the usability of the railways. Within the MDCR security commission, the task of a comprehensive solution for safety at crossings was also assigned. In practice, this means that approx. 150 crossings per year were identified for the implementation of a crossing security device, typically a separate island crossing security device. The installation of such crossing facilities is relatively expensive, amounting to around 10 million CZK per installation, and in most cases does not lead to an increase in line speeds, due to the existence of other crossings with insufficient security among other things.

From the above description of the initial state of current technologies and the current method of alteration, it is clear that the introduction of new ETCS and GSM-R/FRMCS technologies in the current railway environment in the Czech Republic is an extremely complex problem and is a major technical and economic challenge, which must be promptly implemented in the coming years. The Railway 4.0. Concept brings

an alternative comprehensive approach to solving this issue, reflecting the current state of technology in the Czech Republic based on current modern trends in the field of security devices and communications.

4. A Description of the Railway 4.0. Concept

The Railway 4.0. Concept proposes a possible technological solution, which is based on the current knowledge of digital technology and reflects developments in this area abroad. The Architecture of Railway 4.0. is shown in Fig. 1. The architecture can be divided into the following groups of technologies, which form integral elements of the system:

- **Line transmission and power supply networks** - they consist mainly of optical communication and metallic power cables, which form the backbone infrastructure
- **Voice and data communication** - enables data and voice communication with on-board technologies, staff, and passengers on board the train
- **Object controllers** - a universal programmable element, ensuring the execution of input/output commands controlled by an integrated security device
- **Integral security device** - centralized logic of all control and security functions, principally integrating the function of PZZ, TZZ, SZZ, RBC
- **Superior operational and dispatch control of traffic** - connection to systems enabling remote traffic control and technology management

4.1. Line transmission and supply networks

The creation of the fundamental infrastructure enabling the transmission of control and diagnostic information and the supply of electricity to technologies is a key part of the implementation of digital technologies.

Railway is a line system and it requires solution to these technologies along its whole length otherwise it would not be able to ensure the system functionality as defined in the ITS-R vision. Therefore, there are vast and thus high-cost technologies from the point of view of investment and operation. The digital technology being currently implemented requires quality line networks. It is therefore necessary to project these networks with maximum synergy with infrastructural technologies to use investment costs as effectively as possible.

Architecture of Railway 4.0.

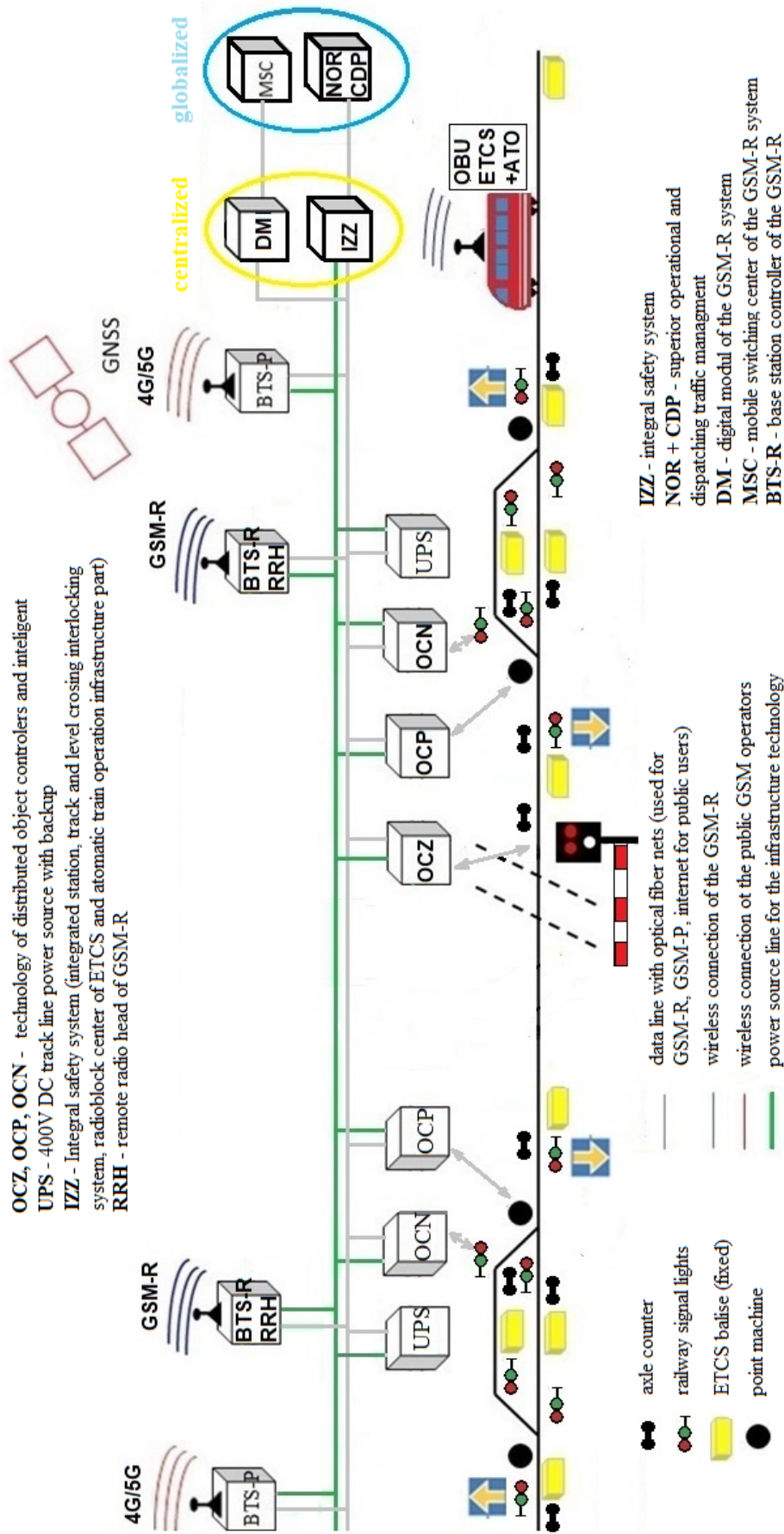


Fig. 1. The Architecture of Railway 4.0.

When making a long-term conceptual planning of technology modernization at all railways in the Czech Republic we can assume that the current cable routes are – or in the nearer future will have to be – fixed with optical cables around all railways because the existing railway cable network in most cases consists of outdated communication cables. Due to their construction they are mostly at the end of their lifecycle and it is not worth repairing them. Currently the standard is that along railways optical transmission networks are laid - optical cables. Optical routes are thanks to their properties (price, quality of data transmission) an essential part of solution to safety systems and communications. Therefore, the Railway 4.0 Concept is based on building these backbone data routes along all railways in the form of multi-fibre optical cables. Optical data connections serve for connecting object controllers (OCx), BTS-R system GSM-R, BTS-P of public operators or for further telematics technologies (cameras, detectors of obstacles occupancy, radio beacons etc...) which for their operation require to gain/provide the railway system with corresponding data.



Fig. 2. An example Westernmo data switch

The Railway 4.0 Concept proposes distributed technologies and therefore at each spot of external technology (crossing, switch, signal, points machine, scanner of axel counter) the relevant number of optical fibers will be ducted for connecting these components through an object controller. Transmission elements (industrial switches) system will be a part of the line transmission network, through which a reliable transmission layer both in inter-station and route sector will be implemented.

Optical fibers can be also used for other functions mainly of diagnostics feature. The application that is currently being discussed and within pilot projects verified is diagnosis of infrastructure faults (typically broken tracks or other defects) or detection of rolling stock failures (typically flat wheels). Optical fibers can be also used as elements for diagnosis and monitoring of rock or trees falls on superstructure or possibly as a protective perimetric system for protecting railway buildings from unauthorized enter.

As a further part of the line routes the Railway 4.0 Concept suggests supplementing these routes with a power supply line as well. This should serve for supplying all exterior elements and technologies. Those are particularly object controllers and peripheral devices of signaling installations controlled by them. It is also necessary to provide electric supply for sufficient support of technologies of radio transmission systems BTS-R or public operators BTS-P. The current solution to the supply of external technologies lies mainly in connecting public electric distribution systems. For this purpose, long power lines, which have an independent supply line, have to be built, consumption sub-measurement has to be set up. Due to the reliability of electric power supply each object has to be provided with a back-up accumulator with corresponding technology of chargers and air condition and heating if necessary.

The Railway 4.0 Concept comes with the possibility of line supply by a route cable¹⁰ that is ducted in excavation together with optical routes within the entire inter-station sector. Compared to the solutions so far, the Railway 4.0 Concept foresees the use of 400V DC supply. This supply technology is currently wide-spread in the systems of photovoltaic power plants and electric vehicles. The prerequisite of such an attitude is the use of low wattage technologies, particularly object controllers and their control peripheral devices. As low wattage technologies we can consider also the independent BTS both GSM-R and public operator networks that without control and transmission peripheral devices do not exceed the wattage of 150W to 300W. The object controllers themselves and transmission elements in most cases also do not exceed the wattage of 300W. The dimension of such supply networks has to be laid down in detail on the basis of the number of particular supplied objects. According to this, the number and placement of supply and back-up powers of UPS is set.

The choice of this technology seems to be favorable because of the following reasons:

- The supply voltage 400V DC does not require special cables, the technology of electric distribution systems, back-up and protections of similar now-a-days built buildings can be used, for example photovoltaic systems or electric vehicles.
- Supply back-up can be favorably implemented at railway station buildings where in most cases there is not any problem with connection to a public power line
- The use of DC fitting enables connection of power boosting supply powers anywhere along the supply route which increases acceptable wattage of technologies

From the point of view of costs for acquisition and operation of line networks it is appropriate to build such routes not only for the purpose of technological railway systems but also these networks to enable sharing cable routes for example for the Internet within the area or coverage of the area by public operators. Current optical cables provide a large number of optical fibers for reasonable prices. Compared to the cost of earth-moving – excavation and cable lying (the price of labor-intensive services and machinery) the price of optical cable is negligible. It is, therefore, desirable to lay a sufficiently large number of cables and optical fibers. Railway is attractive for lying optical routes for commercial purposes of area coverage with data services. Particularly regional lines can enable cheaper and easier implementation of data cables in the so-called white places of the Czech Republic than lying optical cables in the landscape including the necessity of negotiating with many landowners. For a railway the investments in building and running such networks may become – under the condition the legislative and economic rules are unambiguously set - potentially profitable.

¹⁰ Such a solution is known from older corridor technologies where the route supply system was made of the line 6kV/75Hz dealing with both tract circuits supply and decentralized security technologies as for example automatic block or crossings. However, this was very expensive and complex solution.

4.2. Voice and data communication

The Railway 4.0 Concept introduces the principle of a complex coverage of all lines with data and voice transmissions of mobile radio as a basic means for safe railway traffic control. For control and securing the railway the GSM-R system is currently being built, which in the forthcoming years (appr. after 2030) will have been gradually replaced by the FRMCS system. The Railway 4.0 Concept assumes that the GSM-R system (and FRMCS in the future) will be carried out by the system of distributed technologies which is based on the principle shown in Figure 2. In an appropriate object of the infrastructure, for example at a station, a unit – the so-called Digital Module (DM) – will be installed that via an optical cable enables to control other up to 6 remote transmitters, the so-called Radio Remote Head (RRH) which create the base station BTS-R. The maximum distance you can control with one DM module is up to 30 km. In most cases of terminal regional lines this distance will be fully sufficient though from a practical standpoint at many lines it will be necessary to increase the number of RRH and DH modules due to expected worse radio signal coverage of the area. The supply of RRH would be solely from the line supply cable. As for providing sufficient back-up we can consider elimination of local battery elements which would make the fitting simpler and cheaper.

This solution enables minimalization of technology in infrastructure comparing the current state of the GSM-R technology at the corridor network where each BTS contained all transmitting elements, accumulators of a power supply and air-conditioning. This coverage of tracks by the GSM-R system will be integrated in a standard way into the already built GSM-R network whose capacity is sufficient to cover all tracks in the Czech Republic. In the case of the system GSM-R (FRMCS) installation we can also - in a synergic way - use the technologies (line transmission and data networks, columns, switch boards) for coverage a track and its adjacent area by public operators' signal. It is assumed that this technology will become a distributed one that will not require local expensive and demanding technologies.

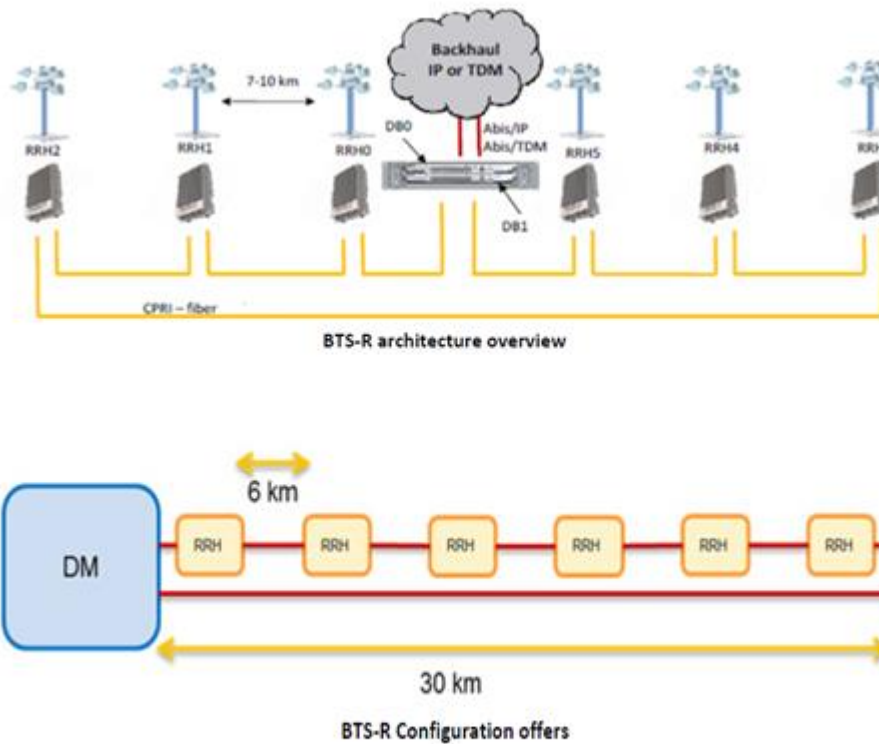


Fig. 3. Architecture of distributed technology GSM-R, source Kontron Transportation s.r.o.

4.3. Object controllers

An object controller ensures the function of input/output interface toward outdoor technologies (crossing scanner, railway barrier, signal, point machine, etc...) on the basis of data communication with integral security device. In principle it is the so-called smart periphery that carries out the transmission of data reports onto physical inputs/outputs. The object controller can also contain basic logical and diagnostic functions. For connection of specific technologies (for example control of the lights of level crossing signals PZZ, axel counter, electric motor of a railway barrier or points machine) in the object controller specific control interface can be fitted that is adjusted to the requirements of external technologies. From the standpoint of a railway security device this is technology that has to meet the requirements for electronic security device placed outdoors that meets the requirements for safety of electronic systems with HW and SW solution on SIL=4 level. The technologies of the object controllers themselves have to meet the conditions of outdoor environment as they will be placed in an outdoor closet by a track.

It is appropriate to design an object controller as a device that is universal and independent of a concrete product. Generally, for such devices we use sign COTS (commercial off-the-shelf) or MOTS (modifiable off-the-shelf). Those are products that are offered to more producers as commercial, mass-produced ones. In contemporary technological development dealing particularly with automation and robotization of industry, also known as Industry 4.0, the market with such products has been developing fast and we can assume that it will also include producers that make products meeting railway requirements. The communication interface between OC and IZZ should be user-open (the owner/operator should get entire product documentation package). This should ensure the independence of OC technology suppliers. Currently for example the European initiative EULYNX¹¹ is dealing with such general specification. This initiative associates 13 managers of infrastructure in order to prepare standardization of interfaces and elements of signaling systems.

4.4. Integral Safety System

The integral safety system is used to implement all logical functions necessary for control and safety of railway operation. Current technologies require the installation of classical safety devices, such as PZZ - level crossing safety devices, TZZ - line safety devices, SZZ - station safety devices in local objects (usually relay rooms in station buildings), where all the technology is concentrated and connected by cabling to external elements. The Railways 4.0. Concept is based on distributed object controller technology with the centralization of logical functions into one center. It thus works with a so-called integral safety system that concentrates all logical functions. It is, therefore, a universal computing HW equipped with specific software integrating PZZ, SZZ, TZZ functions. It must also integrate the functions of the ETCS RBC system at application level L2 or L3. As the IZZ will use ETCS technology of application level L2 or L3, enabling the transition to direct vehicle control via GSM-R (in contrast to the current method of vehicle control via signals, which also



Fig. 4. An example HIMatrix controller HW that can be used as object controller



Fig. 5. An example HIMatrix computer HW that can be used for IZZ functions

¹¹ <https://www.eulynx.eu/>

uses ETCS at application level L1), we can apply more advanced approaches to train control in RBC, where trains are allowed to leave in direct 'successions' with dynamically assigned travel authorisation according to real train movement conditions, without having to wait for the release of an entire intermediate block section or a long track section. This can be achieved either by equipping the infrastructure with a larger number of axle counters¹² or by introducing the so-called "floating block" RBC function within the ETCS application level L3. The contribution of the ETCS L3 application level is that it will allow this train control function to be implemented with a minimum of infrastructure detection features, and also more efficiently in the context of 'flexible traffic control', without the constraints of infrastructure detection technologies. ETCS application level L3 requires an additional train integrity check¹³, which can bring investment and operational savings for the infrastructure at the cost of increasing the equipment especially of freight trains¹⁴. However, it is required that exclusive operation with ETCS-equipped trains and continuous GSM-R / FRMCS track coverage are in place.

More efficient traffic control can also be achieved by massive introduction of the ATO system¹⁵, which will enable further optimization of train speeds with the positive effect of maximum infrastructure utilization, stabilization of operations and significant energy savings. In order to increase capacity, especially on single-track lines, it is possible, using the above-mentioned technologies and the principle of traffic control, to set up approx. 2km long passing tracks with two tracks, e.g. in the intermediate block section, which can very effectively ensure the so-called "fast passing" of trains. These modern control approaches, conditioned by the introduction of ETCS technologies at application level L2 or L3 together with GSM-R / FRMCS, allow a significant increase in infrastructure capacity and train speed on both corridor lines and single track lines compared to the current situation.

The IZZ conception should allow for easy SW configuration of the system so that in case of a change in the SW configuration (typically the addition of another controlled area or modification of an existing one), only the relevant part of the SW configuration is changed and subsequently tested without affecting the remaining functional part of the IZZ. According to findings from abroad, IZZ can also be considered as a so-called "cloud" solution, providing very high computing and data space and very high availability and reliability of the solution. It goes without saying that the requirements for this part of the safety system will also be at SIL=4 level for HW and SW functions; and it is absolutely necessary to ensure adequate protection of the entire computer solution against cyber-attacks.

¹² typically every 200m, especially at a track junction before entering a station

¹³ The requirement to check the integrity of the train is addressed in TSI Subset026-3v360 in chapter 3.6.5.2 and can be provided by technical means on the train (a unit train is indivisible or the train is equipped with end of train detection technology) or by the operating staff.

¹⁴ End of Train systems are implemented around the world under the name "End of Train Device" (EOD) or End of Train (EOT) and are massively operated for example on the Canadian Pacific Railway system in the USA. In the EU, this system has not yet been uniformly specified.

¹⁵ ATO - Automatic train operation - a system of automatic train guidance on the optimum travel trajectory. The system is currently ready for approval as part of the new TSI Subset.

4.5. Master operational and dispatching traffic control

Master operational and dispatching technologies are used to control traffic on a given track or in an area where distributed technology will be deployed according to the Railways 4.0. Concept. It is assumed that the current approaches and technologies that are built and operated today within the Central Dispatching departments will be used. However, given the assumption that ETCS application level L2 or L3 technology will also be used, it can be assumed that this technology will also be adapted to these new rail traffic control options. It can also be assumed that master technologies for automatic train operation (ATO systems) will also be used and should be integrated into this part of the operational traffic control system. Significant developments in this area can thus also be expected.

5. Practical implementation of technologies according to the Railways 4.0. Concept

When implementing distributed technologies with centralization of logical functions according to the Rail 4.0. Concept, the construction must start with the building of the backbone line infrastructure, including both optical and power cables. When building this network, the location of the outdoor elements of the tracks, where optical and power lines will be routed to object controllers, and the location of BTS radio networks should already be known. This basic infrastructure must, therefore, be built robustly enough and with sufficient consideration to ensure that any further modifications to the superstructure will not disrupt it and will enable it to continue to function flawlessly even if the infrastructure is upgraded over time. The next step is to build local object controllers. Their construction is not too demanding as it is an industrial technology that can be installed in industrial distribution boards for outdoor installation. Poles for the installation of BTS for GSM-R and GSM public operators will also be built.

A great advantage of the implementation of distributed technologies can be seen especially in solving the problem of level crossing safety, which is a significant source of danger and slowdown of traffic on regional lines. The Railways 4.0. conception practically allows every level crossing to be equipped with an adequate level of external features that will ensure crossing safety pursuant to legal requirements. The benefit of this solution, apart from the increase in safety, is above all the possibility of running trains at the maximum line speed without any restrictions resulting from the currently insufficient level of level crossing safety along the entire track section. At the same time, the investment and operating costs of building such level crossing safety system will locally be significantly lower, because the costs of most of the functions implemented locally at the level crossing (level crossing logic, power supply and data communication, etc.) are already solved by means of line communication and power supply networks and centralization of logic functions in the IZZ.

Last but not least, a backup power supply must also be built. Buildings that already have or allow for the new installation of a power connection from the public power grid will be given priority. Station buildings generally meet this requirement

without the need for extensive internal occupation of the building as is necessary in the case of conventional installation of station safety equipment. When using a 400V DC supply voltage distribution system, it is also possible to reinforce the lines in other buildings on the track if necessary; however, calculations to date show that at standard station distances of up to approx. 7km, it will be sufficient to supply this track power line only bilaterally from adjacent station buildings. With a sufficient high-quality implementation of this network, a very long service life of at least 50 years or more can be expected.

When connecting object controllers to external peripherals, a unified type method will be used, which will be specified for each type of external peripheral separately. The final activation of the technology is realized only by configuring the IZZ, where specific inputs/outputs of object controllers are assigned to relevant SW objects, which are further handled by the IZZ software. This is expected to greatly simplify and speed up not only the design of these technologies but also the final wiring and testing of the entire system.

It is evident that with regard to the size of the railway network which must be covered by the ETCS and GSM-R / FRMCS system in relatively short time, the construction and expansion of this technology cannot be combined with complex modernization activities on the railway construction part, which progress at a significantly slower pace (for technological and economic reasons) than that of line cabling and BTS radio networks construction. On the contrary, the approach based on the Railways 4.0. conception significantly accelerates the coverage with modern control and safety technologies of even those parts of the infrastructure where no heavy medium repair work or possibly complex modernization of the infrastructure has been carried out so far. A system with distributed technologies has the conceptual requirements to be significantly more adaptive and modifiable in its ability to implement configuration changes or renewal of individual parts than is usual in the case of static locally centralized installations. This is because only partial segments of the technology are replaced when a change or renewal is implemented, while the costliest segments related to power, data networks and central logic remain unchanged or undergo partial configuration changes.

6. Economic parameters of the Railways 4.0 Concept

The costs for the implementation of the Railways 4.0. Concept were processed by the author of the article in the form of an estimate of investment costs according to the SFDI rules¹⁶ for the purposes of the discussion of this proposal in 2020 in the safety commission of the Ministry of Transport and Communications working group infrastructure. This estimate based on a model example of a typical regional line, suggests that the cost of the presented comprehensive view of modernizing railway control and safety is not significantly higher than the currently planned costs, even in case of application of significantly simplified ETCS L1 LS or STOP installations without GSM-R track-side radio. In the case of the Railways 4.0. conception, the scope of

¹⁶ <https://www.sfdi.cz/pravidla-metodiky-a-ceniky/cenove-databaze/> , Sborník pro oceňování železničních staveb ve stupni studie proveditelnosti a záměr projektu

technology, functions and usability of the railway is comprehensively addressed at the highest possible level of current knowledge, with the possibility of also meeting future requirements, e.g. autonomous operation of trains without drivers. The costs of track safety may range from 5 to 7 million CZK/km¹⁷ of single-track line and thus respect the estimated amount of financial resources defined in the vision of the Ministry of Transport - O130 for the introduction of the ETCS system until 2040. In addition, lower operating costs can be expected when this technology is implemented. This is due both to the use of highly reliable technologies with detailed diagnostics and lower operating costs ensuring a reliable and secure power supply and centralized logical parts of the system.

7. Conclusion

The presented Railways 4.0. Concept proposes a new alternative approach to the modernization of control and safety technologies on the railway network of the Czech Republic, which should enable a comprehensive introduction of digital technologies on the railway network in the Czech Republic. The Railways 4.0. conception is technological elaboration of the ITS-R vision, while it not only pursues the issue of modernization of safety systems, introduction of the ETCS system enabling the increase of the level of safety of railway operation in the Czech Republic, but also sets the technological environment enabling the increase of the usability of the railway and its readiness for greater inclusion in the integrated transport systems of the regions in the Czech Republic. The conception was discussed at the level of the Ministry of Transport and Communications of the Czech Republic and the Railway Administration in 9/2020. Based on the decision of the Director General of SŽ Bc. Jiří Svoboda, MBA, SŽ took over the official patronage of this Railways 4.0. conception and will further develop this solution within the framework of joint work group Railways 4.0. comprising experts from SŽ, CTU in Prague, Faculty of Transportation Sciences and industry representatives. The work group is currently developing this conception to the level of implementation project documentation and is working towards the subsequent implementation of a pilot verification of this conception on the real infrastructure of the test track of the Railway Administration.

¹⁷ Approximately 200 k Euros to 270 k Euros per km of installation