Mateusz Malinowski
Centralny Port Komunikacyjny Sp. z o.o.
Deputy Director for the 'Control-command and signalling subsystem' and 'Energy' Subsystems
mateusz.malinowski@cpk.pl

DOI: 10.35117/A_ENG_25_03_04_09

Integrated approach to implementing control-command and signalling, telecommunications, and power supply systems for High-Speed Rail in Poland

Abstract: In the introduction, the article discusses the specifics of CCS, telecommunications, and power supply systems on railway lines, as well as the barriers to effective implementation of these systems to date. It also characterizes the technical specifics of the planned Polish HSR network. The article then outlines the key role of the Eulynx specification in defining the requirements for CCS systems on this HSR network, presents the optimal hardware architecture for this system, and discusses the important role of telecommunications and data transmission systems and their designed technical characteristics. The next system described is the 2x25 kV AC traction power supply, where, in addition to the technical aspects, the succes story is presented regarding the design of this system and the arrangements for its connection to the power transmission grid in Poland. In conclusion, an implementation approach is presented, understood as the optimal split of tenders and contracts for industry packages.

Keywords: HSR in Poland; Eulynx; ETCS without signals; Interlocking; CTC; SIL4 Cloud; MPLS-TP; 2x25 kV AC Power Supply

Introduction

Control-Command and Signalling (CCS), telecommunications, and power supply systems, when compared to other components of the multi-disciplinary railway infrastructure, require a uniform approach across the entire high-speed rail (HSR) line under construction and, in some cases, across the entire national railway network. Additionally, their integration with analogous systems in adjacent areas, as well as with centralised (network-wide) systems within each discipline, is far more complex from both technical and organisational-contractual perspectives than in traditional construction sectors, such as track infrastructure. For example, welding rail joints at the boundary of two track contracts is a routine, repeatable process that requires far less conceptualisation than implementing an electronic interface between CCS systems at the boundary of two signalling control areas.

This creates a paradox:

- On one hand, digital systems are currently experiencing the fastest pace of development, with manufacturers introducing new, significant functionalities. As a result, previous versions and generations of these systems quickly become obsolete,
- On the other hand, due to strong interdependencies with existing systems on the railway network, there are major obstacles to deploying the latest system generations. The need to maintain compatibility with legacy systems preserves outdated technologies, acting as a barrier to introducing new functions that could improve efficiency, reliability, and punctuality in railway operations.

Poland's high-speed rail network (HSR), whose first element will be the 'Y' line connecting Warsaw, Łódź, Wrocław, and Poznań, will require different technical solutions than the conventional rail network, primarily due to the higher train speeds. Key requirements include:

- In the Control-Command and Signalling (CCS) sector, ETCS Level 2 must serve as the foundation for train operations, transmitting movement authority information directly to the driver's cab. At speeds above 160 km/h, optical signalling (trackside signals) cannot be relied upon, so high-speed rail lines will not be equipped with signals for mainline operations. This approach was formalised in the November 2023 amendment to the *Regulation on detailed conditions for railway traffic management and signalling*. However, shunting signals will remain, as current versions of ETCS do not yet fully support supervised shunting movements.
- The design speed of 350 km/h necessitates the use of a 2x25 kV AC traction power supply system.
- In radio communications, system designs (e.g. radio site density) must at a minimum facilitate a seamless migration to the FRMCS system, while wired transmission networks will be based on the MPLS-TP standard.

This means that before the implementation of the aforementioned systems on the HSR network, their suppliers will have to subject the currently available systems to significant development work and enhance them with new functionalities (e.g. adapting the CCS system to a semaphore-free configuration) or entirely new solutions will be applied—ones that have not yet been used in practice in Poland but have been tested in many other countries (e.g. the 2x25 kV AC traction power supply system), which will also require specific implementation work in the domestic market. Taking advantage of the opportunity to introduce new (or significantly modified) systems, it is essential to ensure that they align with the current level of European technical knowledge rather than repeating certain outdated models, both in terms of system architecture and its operation.

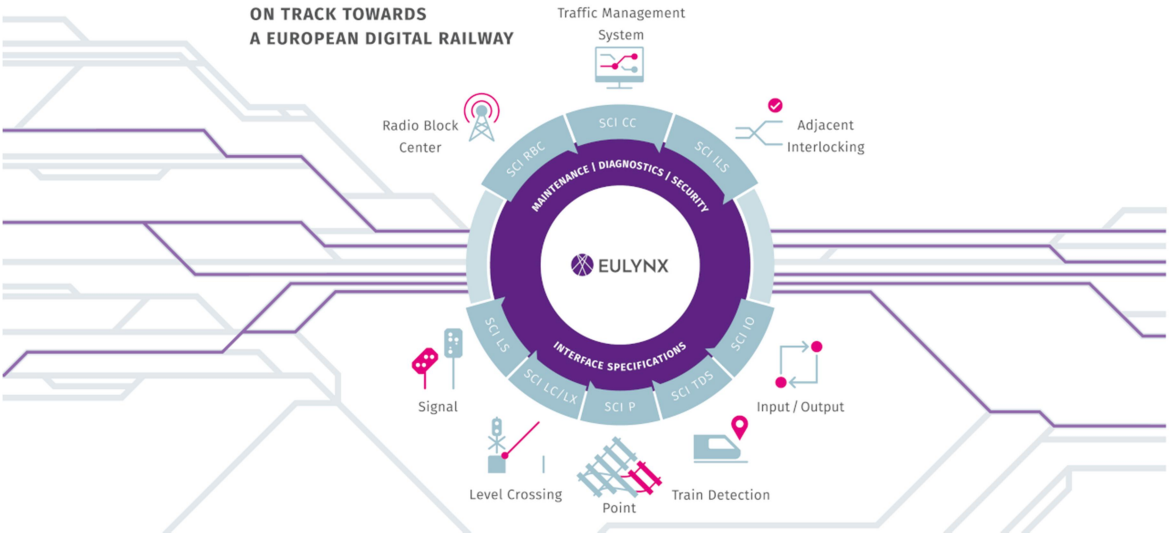
Control-command and signalling (CCS) and telecommunications systems

Centralny Port Komunikacyjny sp. z o.o. (CPK), as the entity responsible under current regulations for the construction of new high-speed rail (HSR) lines in Poland, has decided to fully adopt EULYNX standards, which primarily define interfaces between individual components and devices within the control-command and signalling (CCS) system. CPK has been collaborating with EULYNX for approximately two years, and as of 1 January 2025, it has become the seventeenth member of the organisation. EULYNX already includes several major European railway operators, such as the French, Italian, German, Dutch, Belgian, Swiss, Austrian, Norwegian, Swedish, Finnish, and Czech railways (for details, see https://eulynx.eu/about-us/).

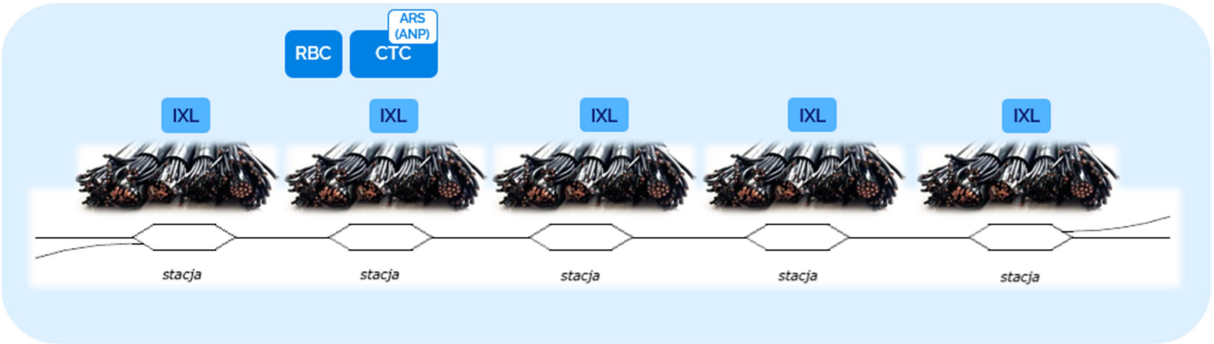
A significant part of the EULYNX specifications has been adopted as the basis for work within the ‘System Pillar’ of Europe’s Rail, meaning that they are highly likely to become a requirement in the next major revision of the control-command and signalling subsystems TSI. In addition to the well-known aspect of EULYNX, which is communication interfaces, these specifications also cover other important areas, including cybersecurity.

The EULYNX standardisation not only facilitates integration between systems from different manufacturers, whether in adjacent control areas or across different system layers (e.g. an interlocking system (**IXL**) from one supplier integrated with a centralised traffic control (**CTC**) system from another). However, an even more critical aspect is the operational phase of a railway line after its construction or modernisation, where the lifespan of individual CCS system components differs significantly. For example, the lifecycle of an interlocking system (IXL) is considerably shorter than that of most trackside devices. This end-of-life (**EOL**) issue—where, 15–20 years after delivery, a manufacturer ceases support, stops supplying spare components, etc.—was the primary reason behind the creation of the EULYNX initiative. This challenge is already present at several locations on the Polish railway network and will continue to grow. If all connections between an interlocking system

(IXL) and other CCS components (e.g. trackside devices, which may still be fully functional after 15–20 years) are proprietary to the manufacturer, and the infrastructure manager has neither knowledge of them nor intellectual property rights, then replacing an EOL interlocking system with a new one from any supplier—while retaining the rest of the CCS system—becomes impossible. The infrastructure manager is therefore forced either into non-competitive direct negotiations with the previous supplier, which usually does not result in a reasonable price for replacing only the interlocking system (IXL), or into a complete replacement of the entire CCS system at the station (rather than just the IXL) if they wish to maintain a competitive procurement process, which means an even greater financial outlay. Systems delivered in accordance with EULYNX specifications will naturally be free from this issue.



1. Systems, Devices, and Interfaces Covered by EULYNX Specifications (Source: eulynx.eu)



2. Graphical Illustration of the Typical Legacy Architecture of a CCS System on a Railway Line Section (With an interlocking system (IXL) located at each station's signal box, transmission is distributed via bundles of multi-core copper cables over distances of up to several kilometres.)

To achieve these objectives, EULYNX had to precisely delineate the functions performed by individual components of the CCS system, including interlocking systems (IXL) and object controllers (OC). The EULYNX approach aligns with modern CCS system architectures, where downstream transmission from the IXL is carried out via fibre-optic cables, eliminating any limitations on the maximum transmission distance. Replacing thick bundles of copper cables running from each signal box to individual trackside devices—

which limit this distance to 6.5 km, even with significantly increased cable cross-sections—with fibre-optic transmission, while supplying power to the OC and trackside devices locally (i.e. to a container or cabinet housing the OC), will greatly simplify the system and enhance its reliability.

The simplicity and resulting reliability of the CCS system on the HSR network are also supported by the limited number of trackside device types. While point machines and axle counting-based occupancy detection systems are essential for HSR operations, the role of trackside signalling is marginal (limited to shunting signals at selected control points), and level crossing protection systems will not be used at all.

Summarising the above considerations, the final preferred architecture of the CCS system on the HSR network is emerging, in which a single IXL module will cover a relatively large area, approximately 150 km of railway line (most likely corresponding to the area of one CTC module and one Radio Block Centre (**RBC**)). Decentralised OC containers/cabinets will be located near each major cluster of trackside devices, with 2–4 OC containers/cabinets for a small station and up to a dozen or more at a large station.

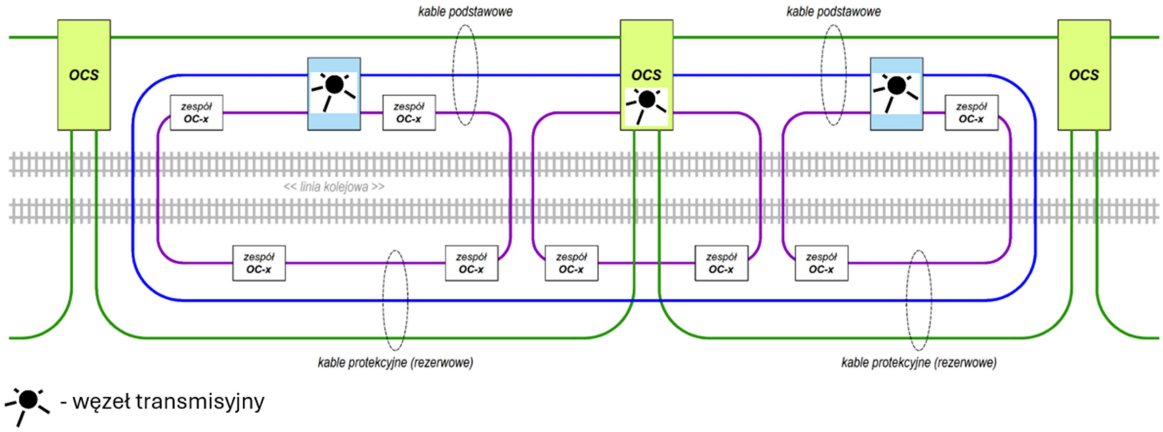
A further step in improving the reliability of the CCS system, based on large IXL modules and decentralised OCs, is ensuring geographic redundancy of modules that are critical to the continuity of railway operations, as well as operator workstations. It should be recalled that, to ensure the required level of safety, CCS systems inherently use independent processing on at least two hardware channels, with consistency checks (the so-called '2-out-of-2' structure). Meanwhile, to achieve the required reliability, two such sets are typically installed at a given location (e.g. in a signal box), meaning a 2x'2-out-of-2' structure, with strict requirements for switchover time to the backup set in the event of a failure of the primary set. At first glance, such a structure may seem sufficiently over-dimensioned, but it is completely vulnerable to failure scenarios where an entire building, along with the equipment inside, becomes unavailable. This can occur not only in extreme cases such as natural disasters or war, but also in more mundane and likely situations—for example, if a fire alarm is triggered and, upon the arrival of the fire brigade, the first action is to switch off the building's main fire protection power switch (PWP). This would immediately render the CCS system in the entire area controlled from that building unavailable, regardless of the number of redundant power sources within the building or the hardware redundancy of the CCS system itself. The solution to this issue is to place the backup IXL set in a different geographic location, along with the necessary number of backup operator workstations. One could imagine adding a third backup set in a third independent location, and so on. However, it is important to balance increasing investment costs against the expected improvement in reliability.

The target state is that with 2–3 OCS (Operations Control Centres) on the 'Y' line, each OCS will be able to control any traffic control point. This configuration is fully achievable based on the experience of other European infrastructure managers.

In this architecture, the fibre-optic transmission network no longer functions as a separate entity alongside CCS systems, primarily serving to connect adjacent CCS systems at different stations. Instead, it becomes an integral part of these systems, as it is responsible for linking the IXL with (sometimes very distant) object controllers (OC), as well as connecting the primary and backup IXL sets (and similarly for CTC and RBC). As a result, the transmission network becomes an inherent component of the CCS system, and its reliability becomes crucial to the overall system's reliability. A physical ring topology at each level:

- in the backbone network connecting different OCS locations;
- in the network linking the OCS with control points within its area;

- in the network connecting the telecommunications node at a control point with individual object controllers (OC), combined with the MPLS-TP standard, will ensure the required reliability.



3. Schematic Illustration of Different Levels of the Transmission Network (The indicated connections do not necessarily require separate cables—they may be dedicated fibres within a single cable—but the ring topology must be maintained.). Source: CPK internal regulations

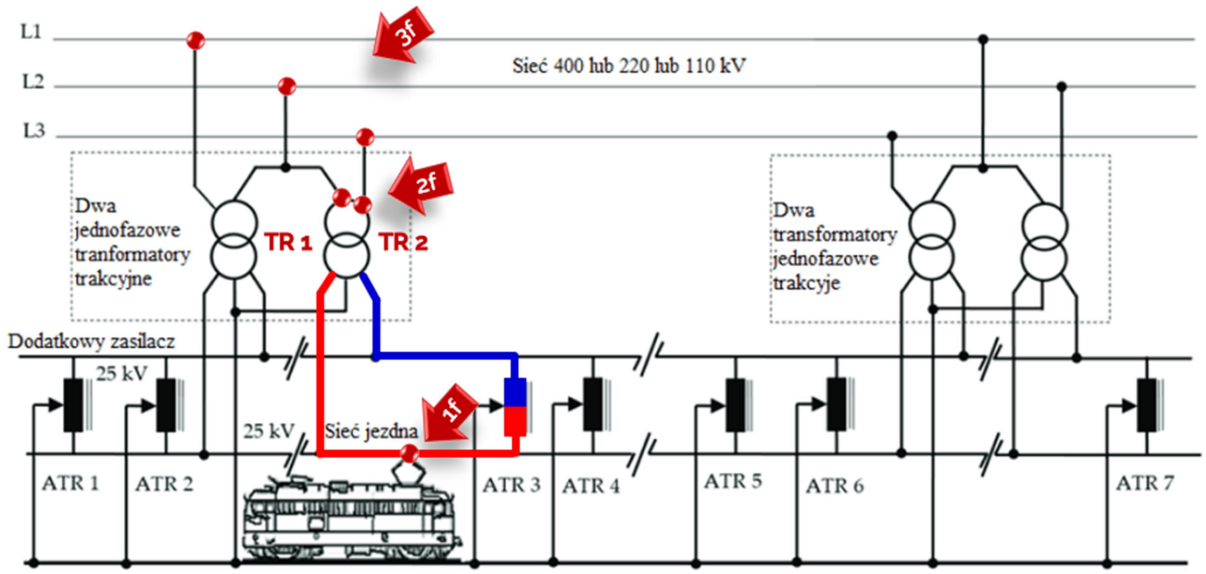
4. Graphical Illustration of the Target CCS System Architecture. (At individual stations, only external devices and their associated object controllers (OC) are located in a decentralised manner within containers/cabinets, along with data transmission nodes and power supply. The interlocking system (IXL), centralised traffic control (CTC), and Radio Block Centre (RBC) are located in the OCS for a given area, with their backup sets housed in the OCS of the neighbouring area, and vice versa.)

It is natural to associate this CCS system architecture with the architecture of non-railway IT systems, which are based on two or more redundant data centres. The open question remains whether safety-critical CCS applications such as IXL, CTC, and RBC should remain tightly linked to hardware (as is currently the case), or whether, in line with European trends, there should be a move towards separating the 'business logic' of these applications from the hardware they run on. Without a doubt, such a separation would be another step toward solving the issue of End-of-Life (EOL) systems. It would also significantly impact the approval process, as only the interlocking application and the SIL4 safety layer would need to be certified, while Commercial Off-the-Shelf (**COTS**) hardware could be cyclically replaced. However, this would require regulatory changes at the level of the relevant ministerial decree. That said, considering the regulatory changes already implemented in railway legislation for HSR over the past 3–4 years, such a transition does not appear to be a major legislative challenge.

2x25 kV AC traction power supply

The existing 3 kV DC traction power system on the Polish railway network is insufficient for train speeds exceeding 250 km/h. For this reason, the 2x25 kV AC power supply system will be implemented on the HSR network.

This system imposes an asymmetrical load on the power grid. However, contrary to some incorrect claims, it is not a single-phase load. The train itself is a single-phase load, but a single traction transformer already loads two phases, and a complete 2x25 kV AC traction substation, which contains at least two traction transformers, acts as a three-phase load (although, as mentioned, an asymmetrical one).



5. Conceptual Diagram of the 2x25 kV AC Traction Power Supply System

It is precisely this asymmetry—rather than the total power demand—that necessitates relatively strong connection points between 2x25 kV AC traction substations and the National Power System. For many years, theoretical discussions on the development of Polish HSR often focused on this issue. Some argued—though the specific reasoning was never clearly justified—that Polskie Sieci Elektroenergetyczne S.A. (PSE), as the Transmission System Operator, and especially Distribution System Operators, would refuse to connect this type of power load to their networks, thereby preventing the construction of HSR in Poland.

However, concrete actions in this area—carried out in accordance with the Energy Law Act and its implementing regulations—have only been undertaken by CPK.

First, in November 2022, thanks to strong cooperation between CPK and PSE, the investments necessary for connecting the HSR power supply were included in the Transmission Network Development Plan for 2032. Then, in May 2023, CPK submitted applications to PSE for the connection of five traction substations—two on the Warsaw–Łódź section and three on the Łódź–Wrocław section. As a result, in May 2024, the connection conditions were issued. The connection conditions for the two substations on the Sieradz–Poznań section are expected in March 2025. Interestingly, these two facilities will be connected to the 110 kV network—one via PSE S.A. and the other via the distribution system operator Energa-Operator S.A.—while maintaining the use of conventional single-phase traction transformers. The 110 kV network nodes in these locations were found to be sufficiently robust for connection.

At this point, it is worth mentioning that power electronics converters are now available that allow asymmetrical loads to be connected even at weaker network points. However, these converters are significantly more expensive to purchase and operate, and their lifespan is shorter than that of a conventional transformer. Fortunately, on the 'Y' line, due to the availability of a sufficiently strong power grid nearby, such converters were not necessary.

6. 2x25 kV AC Traction Substations on the 'Y' Line (Red – 400 kV voltage, Green – 220 kV voltage, Yellow – 110 kV voltage)

Naturally, the formal procedures were preceded by comprehensive technical analyses. Due to the unconventional nature of the connected load, CPK commissioned a broad-ranging expert study to assess the impact of the new loads on all relevant parameters of the National Power System (KSE). The goal was to ensure, in cooperation with energy sector partners, that this impact would remain within permissible limits. Based on train movement simulations and the resulting one-second power profile, the following analyses were conducted:

- Power quality analysis, including:
  - Supply voltage asymmetry analysis,
  - Harmonics analysis,
  - Voltage fluctuation and rapid voltage change analysis;

- Load flow analysis;
- Short-circuit analysis (considering both minimum and maximum short-circuit power).

The study considered:

- Two time horizons for the development of the National Power System (2028, 2033);
- Two balance periods (summer peak, winter peak);
- Two renewable energy generation scenarios (low, high).

This resulted in a total of 2 × 2 × 2 = 8 scenarios for the National Power System.

On the traction power side, 32 scenarios were considered. This number stems from the fact that, in addition to the standard operating state, contingency scenarios N-1 (failure of a single key system component, such as a traction transformer) and in some cases N-2 (failure of two key components) were also examined.

To perform these analyses, the expert entity engaged by CPK imported data from the computational model provided by PSE (*.kdm files, PLANS software) into software capable of asymmetry analysis (in this case, PowerFactory). The next step involved recreating the geometry of the phase conductors of transmission lines within the model to account for naturally occurring system asymmetry. Finally, for this refined model, unbalanced power flow calculations were carried out, incorporating the loads from the newly constructed traction substations across all the above scenarios. It should be emphasised that this was the first and, so far, the only such comprehensive analysis concerning asymmetrical loads in Poland.

A crucial factor in successfully securing connection conditions for the 2x25 kV AC traction substations to PSE's network was CPK's holistic and system-wide approach from the outset. This was carried out within a dedicated project, independent of the highly fragmented division applied in designing the 'Y' line, which was split into approximately ten sections. A crucial factor in successfully securing connection conditions for the 2x25 kV AC traction substations to PSE was CPK's holistic and system-wide approach from the outset. This was carried out within a dedicated project, independent of the highly fragmented division applied in designing the 'Y' line, which was split into approximately ten sections. A single project team within CPK is responsible for all 2x25 kV AC substations, supported by one expert entity conducting analyses across the entire 'Y' corridor. Communication with key stakeholders, particularly PSE, takes place within a single coordination stream. A fragmented approach would have been ineffective: technically, (it would have been impractical to consider mutual redundancy between substations over shorter sections); procedurally, conducting multiple isolated analyses instead of a single, cohesive study would have been inefficient; and organisationally, if stakeholder communications were split into separate channels for each substation, handled by different individuals, it would have caused coordination issues.

A single project team within CPK is responsible for all 2x25 kV AC traction substations, supported by one expert entity conducting analyses across the entire "Y" corridor. Communication with key stakeholders, primarily PSE, takes place within a single coordination stream. A different approach would be ineffective—technically (how could mutual redundancy between substations be considered over short sections?), procedurally (why conduct multiple sectional analyses instead of one cohesive study?), and organisationally (if stakeholder communication were split into separate streams for each substation, handled by different individuals).

Implementation approach

The construction of HSR in Poland is on the verge of transitioning from the design phase to the implementation phase. At this stage, a key challenge is ensuring the appropriate division of the contracted scope of construction works into sector-specific packages. This should take into account, among other things:

- The need to ensure consistent and uniform technical solutions, which will facilitate the future operation and maintenance of the railway line—for example, a standardised type of traction network;
- The specific nature of certain disciplines and systems, which can only be correctly designed and built over long sections that form a logical, self-contained whole, as discussed earlier;
- The need to integrate equipment from various disciplines into a unified control and management system;
- Clear responsibility of individual contractors for ensuring that their subsystem complies with requirements and standards, as well as for the formal certification process of structural subsystems (Infrastructure, Control-Command and Signalling, Energy) concerning sections that form a functional whole from the perspective of a given subsystem;
- The specific nature of constructing a new railway line (as opposed to modernising an existing line), where works in different disciplines generally proceed sequentially, rather than simultaneously in multiple phased stages.

For these reasons, CPK will award contracts for the 'Control-Command and Signalling' and 'Energy' subsystems separately, with each procurement covering the longest possible section of the HSR line. The optimal solution would be to align the available funding with the mechanisms provided in the Public Procurement Law, so that these tenders could cover the entire 'Y' corridor—with some sections included as part of the core contract and others as an option right.