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**Koniecpol prosthesis as a stimulant of railway transport development**

**Abstract:** Modernization of the railway lines and efficient use of them are significant component of creating public transport offer. One of the example of modernized line is "Koniecpol prosthesis", which connects Opole with Częstochowa. This route was modernized to increase competitiveness of railway transport (in the time aspect) between Wrocław and Warszawa and Kraków. The aim of this paper is to show impact of that investment for changes in offer of railway transport in years 2013-16. Selected routes are characterized by high communication potential and expanded net of connections. Paper can be basis for future researches of effective use of modernized railway lines.

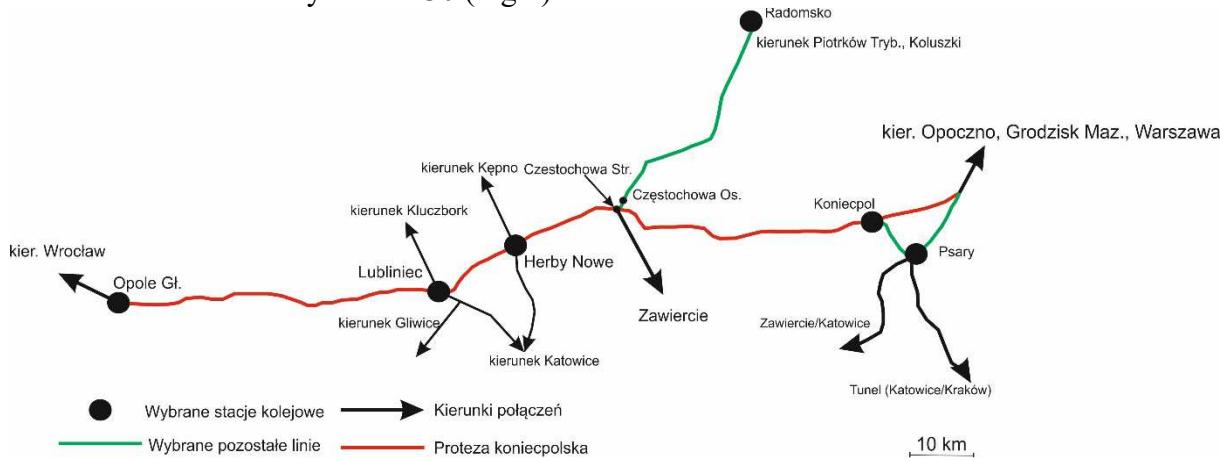
**Keywords:** Railway infrastructure; Revitalization; High-speed rail; Competitiveness

**Introduction**

The ESPON Project 1.1.1 report [4] assesses the polycentricity of the settlement network of the European Union. This assessment was based on three basic factors: the lack of dominance of one city over the rest in terms of population, the even distribution of key urban centers, and functional links between them. The results show that Poland is characterized by a very high level of polycentricity, which is a great potential in the context of country development and cohesion policy implementation. It is worth noting, however, that this high level was achieved largely thanks to the first two factors, while there is still a marked shortage in terms of functional links between Polish metropolises [8]. These relationships are primarily understood in the context of an efficient transport system, based mainly on the network of express roads and motorways, as well as the railway lines with the highest technical parameters.

Taking into account the economic and environmental risks resulting from the uncontrolled development of individual transport, it seems that rail transport should be given priority. Its basic element should be high-speed rail, i.e. according to the Transport Development Strategy until 2020, which will reach speeds of at least 250 km / h (for newly built lines) or 200 km / h (for adapted, upgraded lines) [13]. These railways provide high quality and service levels, are environmentally friendly and contribute to the implementation of innovation and technological development in transport [16]. In addition, according to Gorlewski's 2013 demand survey, most passengers in Poland would be able to pay more for train travel provided that the journey time is clearly reduced, which underlines the need to build such a line [5].

Plans for the construction of high-speed railways in Poland appeared almost 10 years ago and were mainly related to the design of the "Y" line (from the shape it was to assume) [12]. It would be a new line linking Warsaw with Łódź and further Poznań and Wrocław with technical parameters allowing for the speed of about 300 km / h [10]. These plans, however, did not translate into specific investments (apart from the underground tunnel in Łódź), until finally the Ministry of Infrastructure set aside the issue of high-speed rail in Poland for 2020 [2]. In order to survive the crisis, rail transport must have completely lost its competitive edge and needed an effective alternative that could be implemented in the years ahead. The solution turned out to be the revitalization of the Opole - Koniecpol section by Częstochowa, known as the "end-of-Poland prosthesis", thanks to which the Central Railway Line was connected with the international railway route E30 (Fig.1).



1. The course of the section Opole GŁ - Koniecpol - "koniecpol prosthesis" (source: own elaboration)

The aim of the article is to show the impact of this revitalization on the offer of rail transport connections on routes Wrocław - Warsaw and Wrocław - Kraków. The authors will focus mainly on dynamics of changes in number of connections, time and speed of passage and ways of routing trains on the above mentioned routes. The period of 2012-2016 was the most representative and the best to analyze the transport offer. The reference point was four annual timetables: from the two years preceding the investment (2012/2013 and 2013/2014) and two years after the new route (2014/2015 and 2015/2016).

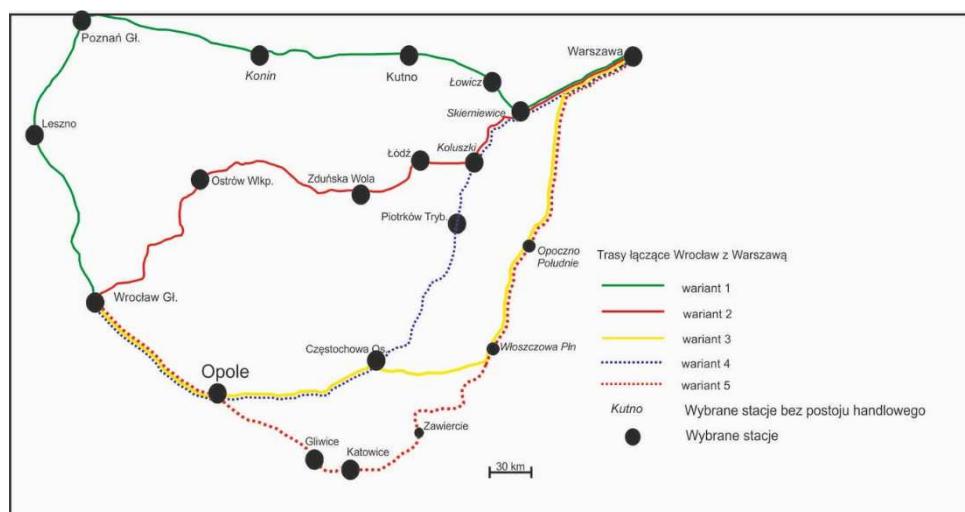
### "Koniecpol prosthesis" as a railway line

Reactivation of the "koniecpol prosthesis" included, among others, replacement of track pavement, modernization of railway crossings and revitalization of many engineering objects, which in turn resulted in the possibility of traveling at speeds of 120 to 160 km / h. "koniecpol prosthesis" has combined the Central Railway Line with the international E30 line with several sections, mostly single track, with varied technical parameters. In the worst condition was a fragment of Żelisławice - Częstochowa Stradom [1]. Infrastructure investment also involved the purchase of rolling stock, the electric traction units ED250 (from the "Pendolino" family) produced by the Italian company "Alstom". They were supposed to handle calls that were routed just by the "koniecpol prosthesis". These capacities could reach speeds of about 250 km / h, but this was not possible with the current state of infrastructure in Poland and was at best a prospect for the future [6]. Nevertheless, the departure of the first "Pendolino" train from Wrocław to Warsaw on 14 December 2014 was undoubtedly an important step in the construction of high-speed railways and certainly constituted an important step in Polish rail transport. A new category of Express Intercity Premiums has been created for record high speed connections, operated exclusively by the newly acquired "Pendolino" lineage with the highest travel comfort.

It is also worth noting that the characteristic feature of the "koniecpol prothesis" is that as a single railway line affects many transport routes. Apart from discussed in the article, it is used, for example, by passenger depot connecting Poznań with Krakow (through Częstochowa, Central Railway Main Line). This is a remarkable underline of the transit role of the line and the fulfillment of its role as a coherent railway network. It should be noted that there are two important railway junctions (Lubliniec and Herby Nowe) connected to the north-south routes on the section of Opole Główne- Częstochowa Stradom.

### Wrocław-Warsaw railway connection

Railway connections between Wrocław and Warsaw have always been a problem that was primarily a result of historical conditions. In the 19th century, when the first railway systems were established in Europe, these cities were under the rule of two different partitioning states: the Kingdom of Prussia and the Russian Empire. The first obstacle was the difference in rails used in both countries (1435 mm - Prussian railway, 1524 mm - Russian railway). The second barrier was a skeptical approach to the idea of a connection between two states, which did not fit in the context of the strategic concept advocated by St. Petersburg, about "diluting" the communication network [3]. The result of Russia's defense policy was the fact that by the end of the 19th century there were only single (from 1859 Sosnowiec-Katowice and from 1862 Kutno-Toruń) railway connections that crossed the Prussian-Russian border. In the next century when the first links between these areas finally appeared to be very cumbersome and inconvenient [11]. Interestingly, even in 1945, after joining the so called The Recovered Territories had a large reserve approaching the areas (including Lower Silesia), fearing further revision of the boundaries, which caused that Wrocław's rail links to Warsaw were still not given priority [7]. This ultimately led to the situation in which trains between these cities were trampled by different, circular roads with long passage time (Fig.2).



2. Variants of railway connections on route Wrocław - Warsaw (source: own elaboration)

The shortest route in terms of distance (option 2 - 376 km) (tab.1) did not guarantee the fastest route. This was related, among other things, with bad technical condition of the line on the section Oleśnica Rataje- Ostrów Wlkp. and a large number of monorail sections, especially on the section Grabowno Wielkie - Ostrów Wielkopolski. In the first analyzed timetable, variant 1 (through Poznań, Kutno) allowed to reach the shortest transit times (below 5:30 to Central Warsaw in the shortest route) (Table 2) by the highest category of Express Inter City trains (EIC Fredro trains and EIC Panorama). In the analyzed period (2012/13 and 2013/14 timetables) the route "Poznań" was the only possibility of reaching Warsaw by the highest category of train at attractive time of passage. With the opening of the

connection by the "koniecpol prosthesis" (variants 3 and 5) the carrier liquidated trains from Wrocław to Warsaw routed by Poznań and Kutno. The only departure is the night train TLK Aurora rel. Jelenia Góra - Warsaw East (by Ostrów Wlkp., Poznań, Kutno), which runs in the schedule 2015/16, whose driving time on the Wrocław-Warsaw section is 7 h 15 min. In the case of the above mentioned composition, there is an aspect of extended routing, since the omission of Poznań would allow the train from Ostrow Wielkopolski through Kalisz to the capital.

Option 2 by Ostrów Wielkopolski and Łódź, theoretically the shortest distance between Wrocław and Warsaw, in the analyzed period was operated by approximately a fixed number of PKP Intercity connections, between three (2015/16) and five pairs (2013/14) trains. By 2015, this would be the only combination of the lowest TLK category (your / cheap rail lines); From the 2015/16 timetable, IC connections are made using PESA Dart. Probably shortening travel time (on average to 5:35, tab. 1) and increased travel comfort could potentially increase the interest of travelers with this combination.

**Tab. 1.** Commercial speeds and transit times in individual variants on the route Wrocław - Warsaw based on timetables (from 2012/2013 to 2015/2016). Source: Own elaboration based on carrier data.

		2012/13		2013/14		2014/15		2015/16	
Wrocław- Warsaw	Distance (km)	Vh	Tsr	Vh	Tsr	Vh	Tsr	Vh	Tsr
Variant 1	470	86	05:29	88	05:22	-	-	-	-
Variant 2	376	57	06:37	61	06:10	58	06:35	67	05:35
<b>Variant 3</b>	<b>422</b>	-	-	-	-	<b>114</b>	<b>03:42</b>	<b>112</b>	<b>04:05</b>
<b>Variant 4</b>	<b>405</b>	-	-	-	-	<b>74</b>	<b>05:30</b>	<b>100</b>	<b>04:22</b>
Variant 5	477	83	05:44	66	07:11	72	06:36	-	-

Vh – commercial speed [km/h] Tsr – average journey time [h:min]  
Red variants use "koniecpolska prosthesis"

The greatest differences in the routing of trains are "south" directions, leading through Katowice, the Central Railway (CMK) or Częstochowa. Depending on the timetable, the degree of use was different. Until the opening of "koniecpol prosthesis" (variants 3 and 4) intensive route was used by Katowice and Zawiercie, further CMK (option 5). In the years 2012-2015, in addition to PKP Intercity trains, the connections were made by Regional Transport within the InterRegio category. Especially in the 2012/13 and 2014/15 timetables, the driving times were competitive at 6 h 33 min and 6 h 17 min respectively. The 2014/15 timetable was the last time the trains were routed through the commuter train. With the opening of the "koniecpol prosthesis" in 2014, variants 3 and 4 were used (Fig. 2). The qualitative change in the form of a very significant shortening of the journey time (average journey time with the use of the Late Polish denture was shorter by about 30% compared to the average travel time with other lines), was related to the introduction of the 2014/15 timetable Express Intercity Premium from Pendolino family.

The number of direct connections remained at the similar level (12-13 pairs) (Table 2), with a significant reduction in the 2013/14 schedule when the number of calls dropped to 8. In terms of train category, this was the timetable with the lowest number of trains in the highest category (only two EICs in Poznań, the others were TLK and IR). The opposite happened after the revitalization of the "koniecpol prosthesis", where the number of high-class trains has risen to 9 in the 2015/2016 schedule and they are now the vast majority on this route.

**Tab. 2.** Time and number of connections on the route Wrocław - Warsaw based on timetables (from 2012/2013 to 2015/2016). Source: own elaboration based on carrier data.

Wrocław – Warszawa route	2012/13	2013/14	2014/15	2015/16
Minimum travel time	5:28	05:08	03:40	03:41
Maximum travel time	07:58	06:43	06:50	07:15
Average travel time	06:06	05:49	05:22	04:35
Number of direct connections	13	8	12	13
Average travel time through the koniecpol prothesis	-	-	3:42	3:59

### Wrocław – Krakow railway connection

In the case of the connections between Wrocław and Krakow, the historical situation did not play such an important role. Although the cities also shared the border of the partitioning states (Prussia and Austria), this time it was not a barrier. It can be said that the Cracow-Upper Silesian line was an integral part of the Prussian route linking Wrocław with Upper Silesia, which allowed for efficient communication [3]. The problems connected with this line relate primarily to the last decades and are mainly related to infrastructure negligence. The route running through the heavily loaded knots of the Upper Silesian and the degraded Katowice-Krakow line, which is the worst section of the international E30 railway route (with a prevailing speed of around 50 km / h), did not allow any temporary competition with other modes of transport. In 2010, the road speed in this section was 74.5 km / h, and was the lowest in railway intercity rail [9]. In addition, after the completion of the entire A4 motorway at the Wrocław-Krakow section, the rail transport lost both with the car and bus transport, which was documented even in the competitiveness studies of mass transit carriers W. Parkitny [14].

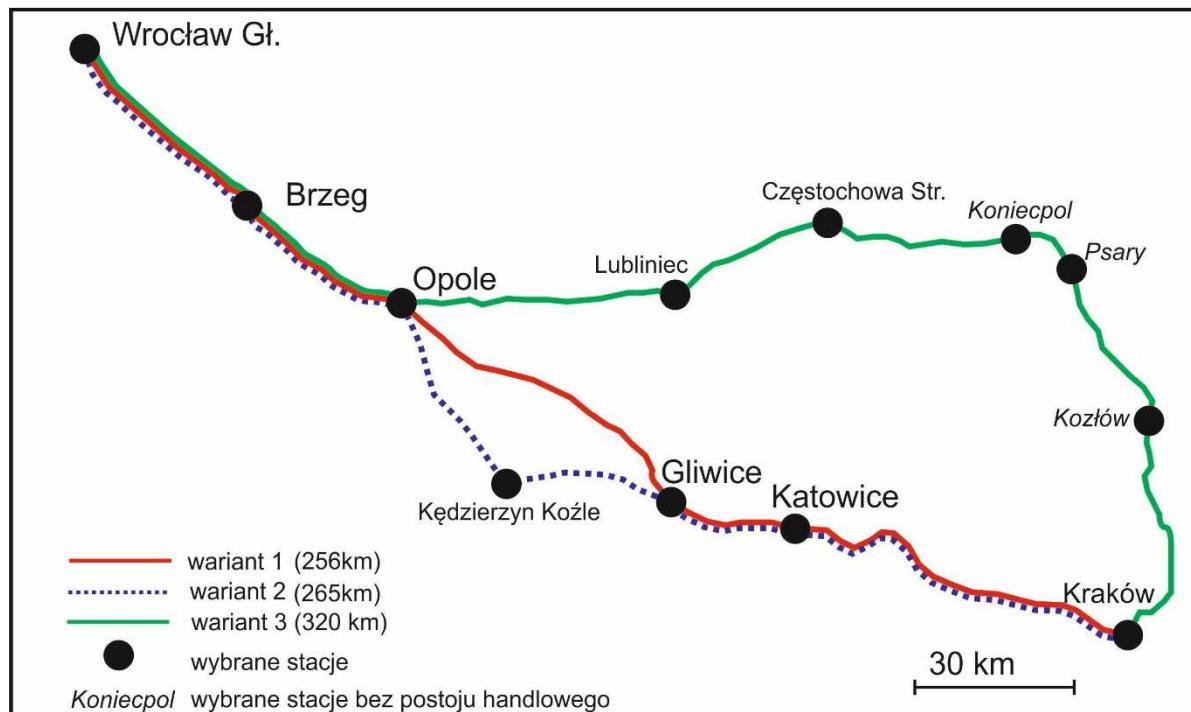
The railway connection connecting Wrocław to Krakow was originally implemented in two basic variants: Wrocław - Opole - Strzelce Opolskie - Gliwice - Katowice - Krakow (option 1) or Wrocław - Opole - Kędzierzyn-Koźle - Katowice - Krakow (variant 2) ) After the revitalization of the so called "koniecpol prothesis" appeared an additional opportunity to use the section of Opole - Lubliniec - Częstochowa - Stradom - Koniecpol and further towards Krakow (option 3) (fig.3). This variant was the longest in terms of distance, but due to the use of the above mentioned good technical parameters, it was possible to achieve much higher speeds, thus reducing journey time (Table 3,4).

**Tab. 3.** Commercial speeds and transit times in individual variants on the Wrocław - Krakow route based on timetables (from 2012/2013 to 2015/2016). Source: own elaboration based on carrier data.

	Odległość (km)	2012/13	2013/14	2014/15	2015/16
Wrocław- Kraków		Vh Tśr	V h Tśr	Vh Tśr	Vh Tśr
Variant 1	256	52 04:57	- -	58 04:26	54 04:47
Variant 2	265	47 05:36	52 05:03	51 05:11	53 04:54
<b>Variant 3</b>	<b>320</b>	<b>- -</b>	<b>- -</b>	<b>96 03:19</b>	<b>95 03:21</b>

Vh – commercial speed [km/h] Tśr – average journey time [h:min]

Red variants use "koniecpol prosthesis"



3. Variants of railway connections on Wrocław-Kraków route (source: own elaboration)

The impact of this investment on the state of railway connections on the Wrocław-Kraków route is illustrated by the analysis of changes in train travel time of PKP Intercity in the years 2012-2016 (Tab. 4). Although the journey time has decreased by 30 minutes just before the investment moment of application of the so called "koniecpol prostheses" in the 2014/2015 schedule. The average journey time has decreased by nearly 32% compared to the 2012/2013 schedule and by more than 25% compared to the 2013/2014 schedule. Up to this point, despite the modernization of the Katowice-Wrocław section, the Katowice-Krakow line was still a barrier with exceptionally low technical parameters. Time competitiveness was not conducive to the need to travel through Upper Silesia, which was connected with numerous restrictions and the necessity of stopovers. Due to the technical condition of the Katowice-Kraków bus, it is necessary to modernize and create an appropriate transport offer on the Wrocław-Kraków route both through Częstochowa and Upper Silesia. Option 3 afforded the opportunity to either bypass the neglected section of Katowice and Cracow as well as the entire Upper Silesian conurbation. The minimum journey time from Wrocław to Cracow after the investment has decreased by more than 1.5 h (compared to the average travel time from 2012-14 it is the oscillating difference between 1 h 46 min and 2 h 12 min), which made it possible to reach Cracow in just over 3 hours. In the end, the rail transport started to be competitive with bus transport and individual using the A4 motorway. With the assumption of a loss of time on motorway gates and potential traffic congestion in large cities, particularly in peak seasons, rail transport may become the most competitive time-travel mode on the Wrocław-Kraków route. An additional advantage may be the comfort of the trip, because the new "IC" category ("upgraded or new wagon") is used for "koniecpol prosthesis", which has a higher standard than the traditional "TLK" category".

**Tab.4.** Czasy przejazdu i liczba połączeń na trasie Wrocław – Kraków na podstawie rozkładów jazdy (od 2012/2013 do 2015/2016). Source: own elaboration based on carrier data.

Wrocław – Kraków route	2012/13	2013/14	2014/15	2015/16
Minimum travel time	04:57	04:56	03:13	03:17
Maximum travel time	06:03	05:21	05:11	04:56
Average travel time	05:30	05:04	03:46	03:40
Number of direct connections	9	7	9	10
Average traveltim through the koniecpol prosthesis	-	-	3:18	3:19

With regard to the number of connections, there are no obvious changes after the application of a new variant of connections, but it seems that 7-10 daily connections between provincial agglomerations distant from each other by nearly 200 km in a straight line is the appropriate result. However, on the basis of continuous, minimal growth in subsequent years from 2013/2014 to 2015/2016, the number of connections between Wrocław and Krakow may increase in the coming years. Remarks can only be given to the appropriate rhythm of the connections, ie maintaining the appropriate intervals between the connections, which is also an important factor influencing the quality of public transport [15]. There is also a shortage in providing evening and morning connections both in one direction and the other.

### Summary

Both routes are examples of connections for which "koniecpol prosthesis" are an important element of the railway infrastructure, and thanks to that, a significant improvement (quantitative, which was influenced by both technical aspects, prosthesis opening and trade), connected with increasing competitiveness of PKP Intercity and quality) rail transport offers. Reducing transit times, increasing commercial speeds and new train configurations are factors that increase the attractiveness of railways on these routes.

The merger of Wrocław-Krakow was originally carried out in two variants (Table 3) (Fig.3), characterized by long passages, at five hours, which could not constitute any competition (alternatives) for individual or bus transport. The quality of the qualitative jump after delivery of the "koniecpol prosthesis" is the commercial speed that has increased by about 80% since the 2014/15 decomposition, with a very significant fall in average driving time. The Wrocław-Krakow railway connection became competitive in terms of shortening of bus times (especially expressways operated by the A4 motorway). However, it should be noted that the original connection through Katowice was the possibility of connecting cities south of Opole with Krakow. In the current timetable, when routing "koniecpol prosthesis" such alternative was very limited (up to 3 trains in the day). Connections through Opole, Katowice (variant 1.2) despite the limitations in number of connections show a slight increase in commercial speeds, which may translate into possible future prospects e.g. the use of both routes.

The route to Warsaw has different characteristics, related to the greater number of trains (5 variants). The only variant used in each of these timetables is option 2, where the largest qualitative shift was in 2015/16 (via Łódź). Before launching the "koniecpol prosthesis" the fastest connections were made through Poznań, where the commercial speed was

maintained at about 87 km / h. The use of another railway corridor, the Central Railway Line, was related to option 5, which was used until 2014. High commercial speeds for the above mentioned variants allowed them to ride the highest category trains.

The greatest quality change, however, was visible from the 2014/15 timetable, together with the opening of the "koniecpol prosthesis" (variants 3,4), which allowed a significant increase in commercial speed compared to the route through Łódź. In the next layout 2015/16 variant 3 was characterized by similar commercial speed, significant increase (by 35%) occurred in variant 4. In terms of length of passage routing by "koniecpol prosthesis" allowed to shorten the driving time by more than 02h: 30 min.

Reducing the average driving time to 4 hours, has allowed for the increase of competitiveness of rail transport, which seems particularly important in the aspect of the existing express road S8 connecting Wrocław with Warsaw. Improving rail transport offers may encourage travelers to use public transport. It should be noted that the "koniecpol prosthesis" in case of connection with Warsaw affected two transport routes: Wrocław - Częstochowa - Piotrków Trybunalski - Warsaw and Wrocław - Opole - Częstochowa - Warsaw through Central Railway. Trains by Piotrków Trybunalski increase the potential accessibility of travelers to higher class trains (IC and EIC). It seems that the current transport offer on this route using three communication lines is at the appropriate level, both in terms of number of connections and quality of service.

The use of "koniecpol prosthesis" made it possible to create a substitute for high-speed rail in Poland in railway connections with Wrocław. Thanks to a relatively small investment, an efficient system of connections between Wrocław and Warsaw and Krakow was created.

However, it should be remembered that this is a temporary alternative to the larger high-speed rail project in Poland, and only thanks to its implementation, the Polish rail transport has the chance to match European standards, ensuring a high level of cohesion and competitiveness of the areas with the highest potential. In addition, it is worth noting that the "koniecpol prosthesis" typically affects long-distance, interglacial connections, connected to the highest category of joints. They do not play the role of regional or provincial, so the role of the carrier is to supplement this network of connections in such a way not to cut off other cities with high potential that were not on the route mentioned as Łódź.

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