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Target network of high-speed railway lines in Mazovia

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ABSTRACT

High-speed rail (HSR) can bring rail back to an advantage over road and air transport in interurban passenger transport. For this reason, creating a coherent network of high-speed rail lines in Poland and Mazovia makes sense, and the first step in this direction should be the development of a target, comprehensive program for the construction of these lines. Meanwhile, the hitherto arrangements for the construction of HSR in the Mazovian region are fragmentary and controversial in many aspects.
In this situation, this study aims to identify the strengths and weaknesses of the findings of the existing HSR development plans in the region, to indicate other ways to solve the already detected weaknesses of these plans, to analyze and evaluate the basic decision-making alternatives, and to select optimal solutions for the Mazovia area.
Currently, there are two HSR lines in Mazovia, leading from Katowice and Gdańsk towards Warsaw. Development plans provide for their further modernisation and extension to Warsaw and also provide for the creation of two more lines from Białystok and Łódź to Warsaw. At the same time, the planning documents do not include the construction of HSR exit lines from Warsaw in other geographic directions, although there are also many large cities in these directions. In order to determine whether this omission is justified, the author made a simplified analysis of the passenger traffic generation population for all possible exit directions from Warsaw to other cities, the conclusions of which lead to the legitimacy of supplementing the HSR network in Mazovia with four additional lines from Terespol, Lublin, Kielce and Toruń to Warsaw.
Based on preliminary location analyses, the author stated that these additional lines should be essentially new routed lines independent of the existing conventional lines, and only for the Warsaw – Radom section it is possible to route the HSR line in the corridor of the existing conventional line there. There were no significant ecological and natural obstacles in the construction of these lines identified.
The author supports creating a strictly radial system of HSR lines with a midpoint in the centre of Warsaw, which will be in accordance with the central role of Warsaw in the agglomeration. He considers the plans to build a "second Warsaw" at the planned Solidarity Transport Hub – STH (Centralny Port Komunikacyjny – CPK) unrealistic and calls for a return to the old concept of the Central Airport (Centralny Port Lotniczy – CPL) with rail services based only on one or two HSR lines.

Key words: rail transport, high-speed rail, railway lines, technical parameters, optimization of the location of transport investments, environmental protection, Mazovia

Introduction

In the 19th century, as a result of the construction of dense railway line networks, rail gained a dominant role in mass land transportation on a continental scale, especially in highly developed countries. The 20th century brought further ground-breaking

inventions in form of the automobile and the aeroplane. Strong competition for rail transport emerged, which led to the loss of its dominant role, especially in passenger transport.

The construction of a new subsystem within rail transport in the form of high-speed rail (HSR) is the answer to this. Just as the construction of a network of highways (i.e. freeways and expressways) gave road transport an advantage over the rail in intercity passenger transport, the construction of a sufficiently dense network of HSR lines will lead to regaining this advantage. However, this does not occur within the old conventional rail CR system, but thanks to the new HSR system.

The HSR significantly reduces not only road travel but also air travel, despite the fact that the latter mode of transport is characterised by travel speeds three times higher than those of the HSR. The main reason for this phenomenon is the distant location of airports from city centres and time-consuming administrative procedures at check-in for passengers at airports. Meanwhile, the HSR network, just like the CR network, uses main stations in city centres. These train stations are usually two-system, connected to both CR and HSR, which ensures easy transfers.

A current example of the process of regaining the former role of rail in passenger transport (thanks to HSR) is the collapse of the Italian airline Alitalia, which was caused, among other things, by competition from carriers operating within HSR. For example, a train journey on the HSR line from Rome to Milan currently takes slightly more than 3 hours, and by plane – about 3.5 hours, if the necessary connections to the airports and pre-flight check-in time are included. Such time ratios resulted in the volume of high-speed rail transport increasing from 1.0 million passengers in 2008 to 3.6 million passengers in 2018 [Dybiński 2021]. The situation is similar in other directions where HSR lines were also created (usually with design speeds of 300 kph), e.g. Rome – Naples or Milan – Turin.

Other European countries are also creating or have already created coherent networks of HSR lines. The French network deserves particular attention; it consists mainly of new HSR lines radiating from the Paris agglomeration, with maximum train speeds of up to 320 kph. In Eastern Europe, coherent HSR networks have not yet been developed, but the first sections of these lines have already been built, e.g. in Russia between St. Petersburg and Moscow with maximum speeds of up to 250 kph. On a global scale, the greatest achievements in HSR development have been made by China, where a dense network of HSR lines has already been created, usually newly built, with consistent train speeds of up to 350 kph over their long sections.

In light of the achievements made so far in the development of the HSR system on a global scale, it should also be assumed that a coherent network of HSR lines of an appropriate density will eventually be built in Poland, i.e. one that would guarantee the advantage of the new rail system over road and air transport, particularly in passenger transport between large cities. The first step should be the development of a comprehensive programme for the construction of these railway lines, as well

as determining the location of the new lines. A network created in Mazovia should be a part of the planned network. However, the current provisions of the HSR construction plan in this area are fragmentary and controversial in many aspects. Therefore, there is a concern that these provisions are not appropriate, which may lead e.g. to the implementation of wrong investments, i.e. construction of lines that will not be used by a sufficient number of passengers.

Consequently, this study aims to identify the strengths and weaknesses of the findings of the existing HSR development plans in the Mazovian region, to indicate other ways to resolve the already identified weaknesses of these plans, to analyse and evaluate the basic decision-making alternatives and to select optimal solutions for Mazovia.

Definition of HSR

The most general definition of HSR is provided by the *Glossary of Transport Development Strategy* [*Słownik pojęć strategii rozwoju transportu* 2012], in which HSR is defined as *a subsystem of rail passenger transport characterised by a significantly higher commercial speed of trains than other types of transport*. A more precise definition is given in the EU Directive on the interoperability of the rail system in the Union [Dyrektywa... 2008; Annex I, point 2.1]. It states that the railway lines of the HSR system include the following sections:

a) *specially created high-speed lines generally suitable for speeds equal to or greater than 250 kph* (hereinafter: Category I lines),
b) *specially upgraded high-speed lines intended for speeds of approximately 200 kph* (hereinafter: Category II lines),
c) *specially upgraded high-speed lines which have special features characterised by topographical, terrain or town planning constraints, on which the speed must be adapted to each instance. This category also includes the lines connecting high-speed and conventional networks, lines crossing through stations, accesses to terminals, railway roundhouses, etc., which are used by high-speed rolling stock travelling at conventional speeds* (hereinafter: Category III lines).

The above definitions mention three terms concerning the speed of rail traffic: speed, commercial speed and conventional speed, which need to be clarified. According to the above-mentioned *Directive*, conventional speed refers to the speed of trains on the conventional rail network, i.e. not classified as HSR. Commercial speed (hereinafter: $V_ś$) is the average speed of trains that is the *quotient of the distance between the start and final points of a journey made by a means of transport and the time that this journey took* [*Prędkość handlowa*, wikipedia.org]. When referring to rail lines, "speed" (without adjective) is either a maximum operating speed (hereinafter: V_e) according to § 3.8 of the Regulation [Rozporządzenie... 1998] on technical conditions, which should be met by railway structures or a maximum design speed (also referred to as road, line or geometric speed, hereinafter: V_p), defined as the maximum speed for which a given section of a railway line was designed [*Prędkość maksymalna*, wikipedia.org].

Technical specifications

According to the *Directive* mentioned above, the HSR system may operate at different speeds V_p. However, the term "high-speed" refers to the speed of 200 kph or higher. The current design approach for new interurban HSR lines (cat. I) usually assumes $V_p = 350$ kph and for existing interurban lines to be upgraded and integrated with HSR (cat. II) $V_p = 200$ kph. An exception to this rule are sections running in urban agglomerations, where due to dense housing development V_p can drop to 160 kph or even 120 kph (cat. III). Ideally, V_p should be kept constant for sections of a line between cities (stations), but then $V_ś$ would be lower than V_p anyway. It is because trains must accelerate when leaving a station and then brake before reaching a next one. In terms of the spatial planning of HSR networks, the lowest difference between V_p and $V_ś$ can be achieved by limiting the number of stations (e.g. to one in each large urban agglomeration) and by reducing the length of HSR sections in agglomerations with $V_p < 200$ kph. The conclusion is that cat. I and II lines should be completely separated from conventional lines on long interurban sections and should only connect to them (directly or via cat. III lines) near junctions or branches.

In the spatial planning of HSR lines, the minimum admissible horizontal curve radius for a given speed V_p is also important. A distinction is usually made between the minimum radius used exceptionally (hereinafter: R_w) and that used regularly (hereinafter: R_n); according to § 32.2.1 of the aforementioned *Regulation*, the following values are used – for newly built main lines ($V_p > 160$ kph) $R_w = 4{,}000$ m, and for modernised lines, $R_w = 2{,}000$ m. This *Regulation* fails to specify the parameters for HSR and the R_n values, which is why it is advisable to refer to the design standards used in other countries. For example, in Spain $R_w = 6{,}500$ m and $R_n = 7{,}250$ m are used for $V_p = 350$ kph [Kraśkiewicz 2015, p. 156]. Design standards recently developed by the Solidarity Transport Hub (STH) (Centralny Port Komunikacyjny – CPK) company can also be followed [*Standardy techniczne*… 2021].

These regulations and guidelines indicate that HSR lines should be designed to be straight where possible, and the curvature between any subsequent straight sections should be as smooth as possible. The decision whether to build a new HSR line or to upgrade an existing conventional line is crucial in planning the HSR network. It can be made at the preliminary planning stage based on a rough (simplified) collision analysis of the required smoothing of the curvature on the existing conventional line, selected for the HSR integration.

In highlands and mountain areas an important technical parameter in designing HSR lines is also the maximum acceptable longitudinal gradient of a line. It can be categorised as either exceptional (hereinafter: I_w) or regular (hereinafter: I_n). According to point 4.2.3.3 of the *Annex to the Commission Regulation (EU) on the technical specifications of interoperability of the subsystem "Infrastructure" within the rail system in the European Union* [Rozporządzenie Komisji 2014] for passenger HSR lines travelling at $V_p = 250$–350 kph,

I_w = 35‰ and I_n = 25‰ are used. In addition, it is mandatory that the average longitudinal gradient of a track along each 10 km section of a line is not greater than I_n and that the maximum length of the uninterrupted gradient equal to I_w does not exceed 6 km. These requirements can also apply in lowland areas, e.g. when planning a longitudinal profile of a deep HSR line tunnel beneath dense urban development.

Current state

According to the *Open railway map* [Open] and the detailed data of the PKP Polskie Linie Kolejowe (PKP PLK) company, there are currently two high-speed railway lines in Poland, both running radially from Warsaw and crossing, among others, Mazovia; they are as follows:

Line no. 4 Grodzisk Mazowiecki – Zawiercie, also known as Central Railway Main Line (Centralna Magistrala Kolejowa – CMK); designed in 1970–71 as a high-speed line (V_p = 250 km; R_w = 4,000 m); built in 1971–1977; modernised between 1993–2017; currently on the Mazovian section (Grodzisk Mazowiecki – Idzikowice, with a length of approx. 80 km) passenger trains (more precisely: train ED250 "Pendolino") travel at a constant speed V_e = 200 kph (cf. Fig. 1); there are plans to increase this speed to V_e = 230 kph [*Linia kolejowa 4*].

Line no. 9 Warsaw East Passenger Station – Gdańsk Main Station; built in sections between 1850 and 1877; thoroughly modernised between 2006 and 2014 and adapted to a speed of V_p = 200 kph; at present, on the Mazovian section (Warsaw – Działdowo, length ca. 140 km), "Pendolino" passenger trains run at V_e = 200 kph along the majority of this line; in few places the track geometry limits this speed to V_e = 90–130 kph (e.g. in the area of Modlin, Pomiechówek and Nasielsk, Fig. 2) [*Linia kolejowa 9*].

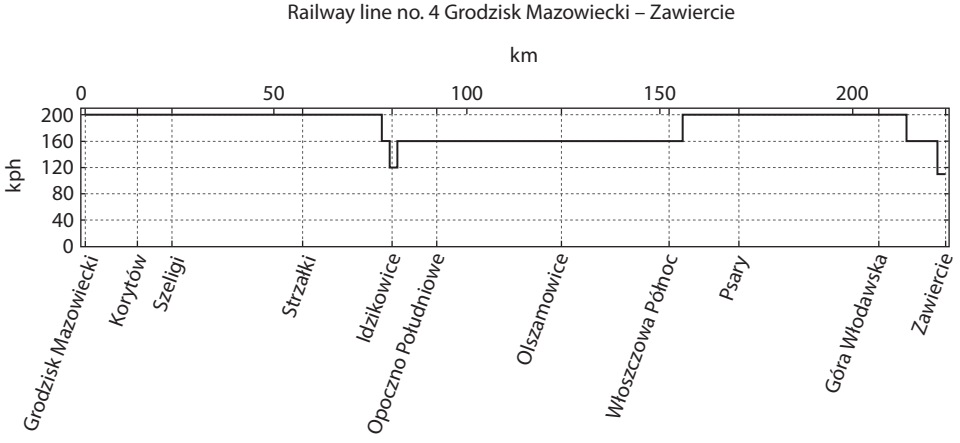

Fig. 1. V_e speeds for railway line no. 4 in 2017/2018
Source: based on: *Linia nr 4*, https://pl.wikipedia.org/wiki/Linia_kolejowa_nr_4

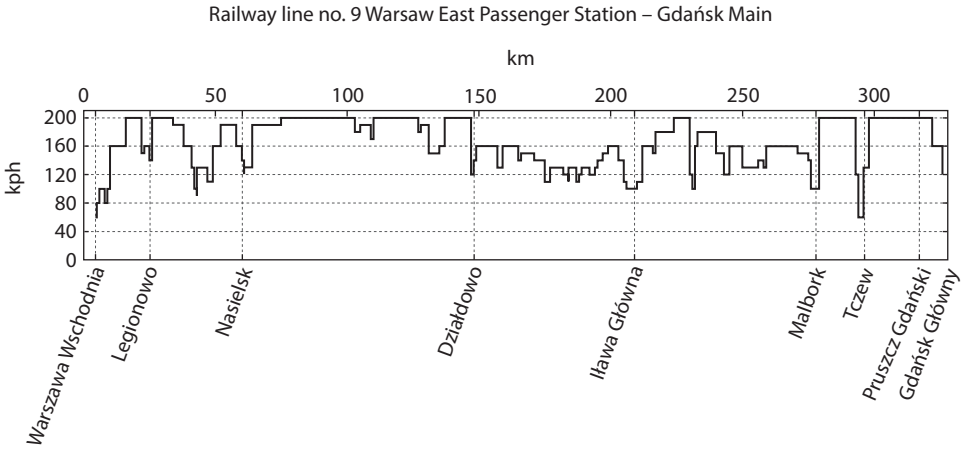

Fig. 2. V_e speeds for railway line no. 9 in 2020/2021
Source: based on: *Linia nr 9*, https://pl.wikipedia.org/wiki/Linia_kolejowa_nr_9

Current development plans

According to the *Concept for Spatial Development of the Country 2030* (Koncepcja przestrzennego zagospodarowania kraju KPZP 2030), the following HSR lines will be created in the Mazovian region by 2030 [*Koncepcja*... 2030, Fig. 8, p. 43]:

- Warsaw – Katowice (existing CMK);
- Warsaw – Łódź (new line), continuing to Kalisz and separating there into lines to Wrocław and Poznań, shaped like a "Y" letter, hence referred to as the "Y" concept;
- Warsaw – Gdańsk (new line), running through Płock, Włocławek, Toruń.

Moreover, a new connection line between Łódź and CMK, following an estimated route of: Łódź – Piotrków Trybunalski – Opoczno (CMK), is planned in close proximity to Mazovia.

The HSR network does not include the existing Warsaw – Gdańsk line (via Działdowo), even though at the time (in 2011) it was planned to be upgraded to V_p = 120–200 kph. This results from the definition of HSR outlined in the KPZK 2030 as a line with V_p > 200 kph, which excluded from the network the lines upgraded to V_p = 200 kph.

The latest version of the *Spatial Development Plan for the Mazovian Voivodeship* (Plan zagospodarowania przestrzennego województwa mazowieckiego PZPWM) anticipates the construction of the following new HSR lines in the voivodeship [*Plan*, Fig. 11, p. 31]:

- Warsaw – STH – Łódź – < Poznań / Wrocław;
- CMK (Korytów) – STH, as an extension of CMK to Warsaw, utilising the above mentioned STH – Warsaw line;
- Legionowo – Nasielsk (Świercze), as a connector straightening the existing line no. 9 Warsaw – Gdańsk;
- Warka – Grójec – STH – Płock – Włocławek – Gdańsk.

What draws attention in this new version of the PZPWM is above all the loss of Warsaw's role as the main node in the HSR network in Mazovia; the former clear radiating layout with the central point in Warsaw has changed into a bipolar layout with its second pole located in the planned Solidarity Transport Hub (STH). PZPWM describes the new second pole as an "*international transfer hub*" [*Plan*, Fig. 11] and locates it along with the Warsaw – Łódź HSR line in the area of Baranowo in the Grodzisk County.

Such a fundamental change in the Mazovian HSR layout is not the idea of the authors of the PZPWM, but a consequence of the introduction of new national planning and development documents. In particular, the approval and construction of STH in accordance with the Act on STH [Act]. A special-purpose STH company was established under the Act. In addition to its primary task, which is the construction of an international airport called the Central Airport (STH Airport), it is also in charge of creating new railway lines to ensure fast access to the future airport. The STH company has already developed a preliminary STH railway programme, the so-called "spokes" concept (Fig. 3). It includes the *Strategic Location Study for the Central Transport Port investment* (Strategiczne studium lokalizacyjne inwestycji centralnego portu komunikacyjnego, 2020 SSL CPK). The findings of this work are being gradually introduced into many spatial programme documents and their updates, including the above-mentioned PZPWM.

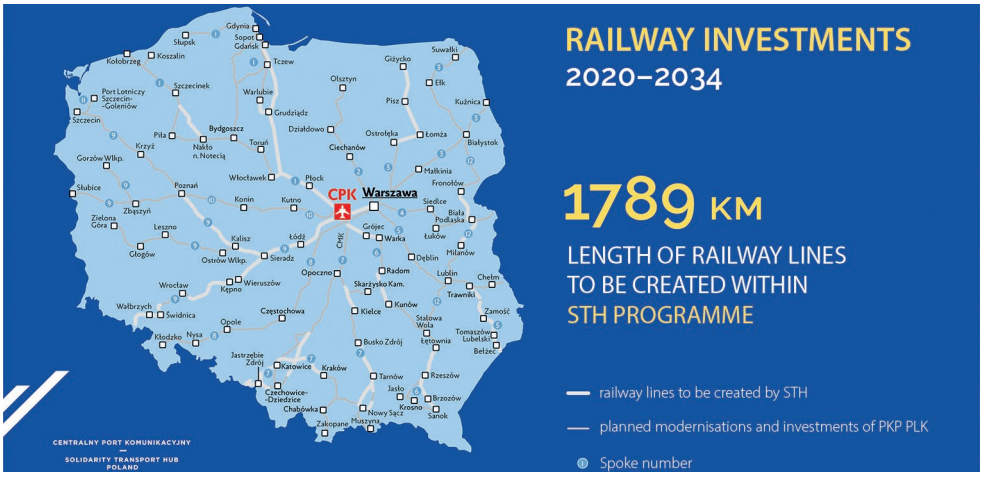

Fig. 3. The "spokes" concept for STH, 2021 version
Source: Inwestycje, https://www.cpk.pl

The STH company has recently started preparing technical-economic-environmental studies (STEŚ) for the particular railway lines (including HSR). The results of these studies will provide detailed identification of the possible variants of the new railway lines routes and the selection of the optimal ones. In Mazovia, the work on the routing of the Warsaw – STH – Łódź HSR line (line no. 85) is the most advanced.

Public consultations were held to determine alternative locations for the line (see Fig. 4). Once the STEŚ has been prepared, the next step will be to submit an application for an environmental conditions assessment.

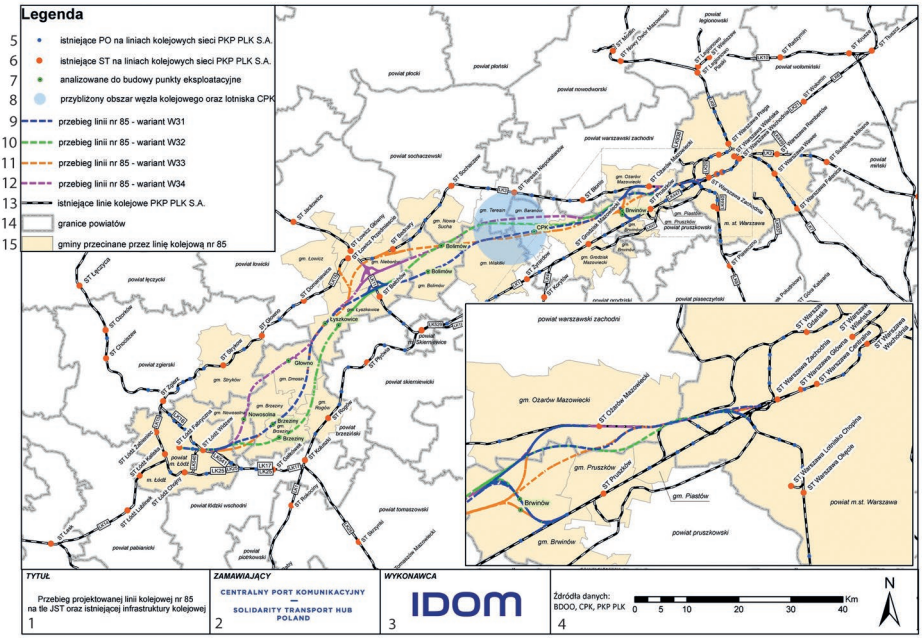

Fig. 4. Alternative lines currently under assessment for the planned line no. 85 Warsaw – Łódź

Translation: 1. Title: The route of the planned railway line no. 85 in relation to JST and the existing rail infrastructure; 2. Ordering party; 3. Conractor; 4. Data sources 5. Existing POs on the PKP PLK S.A. network railway lines; 6. Existing STs on the PKP PLK S.A. network railway lines; 7. Operation points analysed for construction; 8. Approximate area of the railway hub and STH Airport; 9. route of the line no. 85 – variant W31; 10. route of the line no. 85 – variant W32; 11. route of the line no. 85 – variant W33; 12. route of the line no. 85 – variant W34; 13. Existing PKP PLK S.A. network railway lines 14. counties boundaries; 15. municipalities crossed by the railway line no. 85

Source: *Przebieg*, https://www.cpk.pl/

The "spokes" programme fallaciously assumes that all of Poland will commute (e.g. by high-speed rail) to STH Airport for international flights, including intercontinental flights. Whereas, other major cities in Poland have airports suitable for international air traffic (e.g. Gdańsk, Cracow, Katowice) and are planning their further development. With such competition present, flows of passengers from those cities to STH Airport may be too limited to justify the construction of separate HSR lines directly to STH/STH Airport bypassing Warsaw. The author believes that we should return to the old concept of an unipolar radial HSR network with the central point in Warsaw. STH Airport

should be connected to one HSR line Warsaw – Łódź (and possibly Warsaw – CMK). According to planning documents related to the construction of STH, the HSR travel time from the centre of Warsaw to STH Airport will be as short as 15 minutes [*Strategiczne studium*… 2020, p. 27]. Therefore it is better to establish the main HSR transportation hub in the centre of Warsaw, from where passengers travelling to STH will be able to easily reach the airport.

The current map of the trans-European transport network (TEN-T) shows, apart from the HSR lines included in the KPZK 2030, one more HSR connection between Ełk – Suwałki and the state border [*Koncepcja*... 2011, Fig. 5], which is in line with the plans to build a high-speed railway through the Baltic states from the Polish border through Kaunas, Riga to Tallinn (the so-called *Rail Baltica*). The absence of a fast connection between Warsaw and Elk needs to be treated as inconsistency of these plans. The elimination of this planning error implies that this section should operate on the speed of at least $V_p = 200$ kph. This should be achieved through the modernisation of the existing lines Warsaw – Białystok (line no. 6) and Białystok – Ełk (no. 38). A recent feasibility study commissioned by the PKP PLK company increased the maximum speed on the latter line from 130–160 kph to 200 kph (*Rail Baltica*). Therefore, a perspective of one more HSR line being created should be assumed for Mazovia: Warsaw – Białystok.

In summary, given the existing state of affairs, selected planning documents, and the assumption that there will be a single convergence point for HSR lines created in Warsaw, one should consider the construction/development of only the following four HSR lines in the Mazovia region, radiating away from Warsaw (following successive geographical directions, moving clockwise, starting from the north, N):

- **NE line** from Warsaw to Białystok and further to Ełk, Suwałki and Kaunas (the modernised Warsaw – Bialystok line);
- **SW1 line** from Warsaw to Katowice (new exit from Warsaw + CMK), with a possible stop at STH Airport;
- **SW2 line** from Warsaw to Łódź and further to Wrocław and Poznań ("Y" concept), with a possible stop at STH Airport;
- **NW line** from Warsaw to Gdańsk (existing Warsaw – Gdańsk line with a new "straightening" section Legionowo – Nasielsk);

At the same time, the planning documents omit the construction of HSR lines exiting from Warsaw in other geographical directions, even though there are numerous cities in those directions which might benefit from high-speed rail service. In order to determine whether the omission is justified, a simplified analysis of passenger traffic generated in all possible outbound directions from Warsaw to other cities (or rather groups of cities located in the same or a similar geographical direction) is presented below.

Fig. 5. Planned TEN-T network in Central Europe in terms of passenger railway lines

Translation: 1. Comprehensive Network: Railway lines and airports; Core Network: Railway lines (passenger) and airports; 2. Conventional rail/completed; 3. Conventional rail/to be developed; 4. Conventional rail/planned; 5. High-speed rail/completed 6. High-speed rail/to be developed; 7. High-speed rail/planned; 8. Airports

Source: *Transeuropejska sieć transportowa – TEN-T*. Ministerstwo Infrastruktury, https://www.gov.pl/

Spatial and transport analysis (generation of passenger traffic)

The assumption of a radiating layout of HSR lines in Mazovia having a central point in Warsaw is well-founded by the spatial and urban planning system of the region and the country. Warsaw is the biggest agglomeration in Mazovia and the second biggest in Poland after the Upper Silesian conurbation. It is, however, the centre of the agglomeration which is predominantly single-centred. According to Eurostat analyses [*Urban Audit* 2012–2013], the agglomeration has approximately 2,660,400 inhabitants and dominates over the other Mazovian agglomerations – the second largest agglomeration in the region is Radom with a population of approximately 372,000 people according to Eurostat [*Urban Audit* 2012–2013].

The law of gravitation may be applied to the volume of passenger traffic on HSR lines. After simplifications resulting from the study of gravitational pull towards a single city ("Warsaw") and abstracting from specific traffic flows (measured in passengers per day), it can be expressed as follows:

$$F = M \times d^2$$

where:

- F – stands for the index of the gravitational pull of a given agglomeration towards Warsaw
- M – represents the population of a given agglomeration
- d – is the distance of a given agglomeration from Warsaw.

Table 1 below shows the calculation of the index of the gravitational pull of major agglomerations in Poland and neighbouring countries – F, assuming a minimum population of an agglomeration of 50,000 and a maximum distance to Warsaw of 500–700 km which results from the advantage of air transport over HSR on longer distances. In this approach, the index F expresses the relative gravitational force of a given city towards Warsaw, and its value should be directly proportional to future HSR traffic flows between those cities. However, it is based on the undisturbed target perfect condition, i.e. it assumes the existence of the HSR lines between the cities in question and it makes no assumptions regarding any specific time period, spatial-environmental conditions, political situations, etc.

The agglomerations listed in the table above may be grouped by geographic directions and one can calculate a total gravitational pull $\sum F$ towards Warsaw for every direction (sector). When selecting the sectors, one can take into account the existing HSR system, the current HSR development plans and the spatial layout of agglomerations. The results of such calculations are presented below, whereas the names of agglomerations included in the calculations are listed in brackets:

- **NE sector**: $\sum F = 45.61$ (Riga, Kaunas, Vilnius, Suwałki, Ełk, Grodno, Białystok, Łomża, Ostrołęka)

Table 1. Index of the gravitational pull of the major cities towards Warsaw – *F*

No.	Name of the agglomeration	The population of the agglomeration[1] (persons)	The distance of the agglomeration from Warsaw[2] (km)	Index of the gravitational pull of the agglomeration towards Warsaw
1	Berlin	4,900,000	482	21.09
2	Biała Podlaska	62,000	146	2.91
3	Białystok	524,280	177	16.73
4	Bielsko-Biała	325,000	301	3.59
5	Bratysława (Bratislava)	601,130	531	2.13
6	Brześć (Brest)	339,700	185	9.93
7	Budapeszt (Budapest)	2,453,000	544	8.29
8	Bydgoszcz	583,090	226	11.42
9	Chełm	66,500	210	1.51
10	Częstochowa	466,730	205	11.11
11	Elbląg	120,000	240	2.08
12	Ełk	64,000	199	1.62
13	Gdańsk (Trójmiasto)	1,098,380	295	12.62
14	Głogów	69,000	344	0.58
15	Gorzów Wielkopolski	188,800	396	1.20
16	Grodno (Grodna)	356,900	253	5.58
17	Grudziądz	99,500	206	2.34
18	Jelenia Góra	128,600	394	0.83
19	Kalisz	409,310	207	9.55
20	Katowice (Upper Silesia)	2,746,460	259	40.94
21	Kielce	407,320	153	17.40
22	Kijów (Kyiv)	4,200,000	712	8.28
23	Konin	142,770	188	4.04
24	Koszalin	171,470	389	1.13
25	Kowno (Kaunas)	460,560	353	3.70
26	Cracow	1,257,510	253	19.65
27	Królewiec (Kaliningrad)	493,300	282	6.20
28	Legnica	102,500	353	0.82
29	Leszno	66,500	307	0.71
30	Lubin	75,000	344	0.63
31	Lublin	651,580	154	27.47
32	Lwów (Lviv)	717,490	350	5.86
33	Łomża	65,500	128	4.00
34	Łódź	1,178,030	118	84.60
35	Mielec	65,000	218	1.37

No.	Name of the agglomeration	The population of the agglomeration[1] (persons)	The distance of the agglomeration from Warsaw[2] (km)	Index of the gravitational pull of the agglomeration towards Warsaw
36	Mińsk (Minsk)	2,645,500	512	10.09
37	Nowy Sącz	156,450	291	1.85
38	Olsztyn	283,610	176	9.16
39	Opole	266,520	276	3.50
40	Ostrawa	1,100,000	328	10.22
41	Ostrołęka	55,000	102	5.29
42	Ostrowiec Świętokrzyski	70,000	146	3.28
43	Piła	78,500	306	0.84
44	Płock	233,700	96	25.36
45	Poznań	1,011,170	279	12.99
46	Praga (Praha)	1,900,000	500	7.60
47	Przemyśl	70,000	299	0.78
48	Radom	372,000	93	43.01
49	Rybnik	526,000	294	6.09
50	Ryga (Riga)	1,000,000	588	2.89
51	Rzeszów	329,690	254	5.11
52	Siedlce	77,000	87	10.17
53	Słupsk	96,000	364	0.72
54	Stalowa Wola	76,000	199	1.92
55	Starachowice	51,500	132	2.96
56	Suwałki	82,360	245	1.37
57	Szczecin	778,060	455	3.76
58	Tarnów	269,000	247	4.41
59	Toruń	294,010	184	8.68
60	Wałbrzych	248,000	366	1.85
61	Wien	2,100,000	562	6.65
62	Vilnius	708,790	400	4.43
63	Włocławek	121,000	140	6.17
64	Wrocław	1,029,880	302	11.29
65	Zamość	68,000	230	1.29
66	Zielona Góra	206,050	378	1.44

Clarifications:

[1] – according to Eurostat [*Urban Audit 2012–2013*], or in the absence of data therein according to the author's estimated calculations

[2] – calculated in a straight line (airline) between the central points of the agglomeration, with the Palace of Culture and Science taken as the centre of Warsaw, and in the case of other agglomerations – usually the market square, central square or the centre of the main shopping street in the city centre

- **E sector**: $\sum F = 33.10$ (Minsk, Brest, Biała Podlaska, Siedlce)
- **SE sector**: $\sum F = 44.68$ (Kyiv, Lviv, Przemyśl, Zamość, Chełm, Lublin)
- **S sector**: $\sum F = 104.14$ (Budapest, Nowy Sącz, Cracow, Tarnów, Mielec, Rzeszów, Stalowa Wola, Ostrowiec Świętokrzyski, Starachowice, Kielce, Radom)
- **SW1 sector**: $\sum F = 84{,}23$ (Vienna, Bratislava, Ostrava, Rybnik, Bielsko-Biała, Opole, Katowice, Częstochowa)
- **SW2 sector**: $\sum F = 75.45$ (Prague, Wałbrzych, Jelenia Góra, Głogów, Lubin, Legnica, Wrocław, Kalisz, Łódź 50%)
- **W sector:** $\sum F = 83.77$ (Berlin, Zielona Góra, Gorzów Wlkp., Leszno, Poznań, Konin, Łódź 50%)
- **NW1 sector**: $\sum F = 55.94$ (Szczecin, Koszalin, Piła, Bydgoszcz, Grudziądz, Toruń, Włocławek, Płock)
- **NW2 sector**: $\sum F = 30.78$ (Słupsk, Gdańsk, Elbląg, Królewiec, Olsztyn)

When comparing the above sectoral gravitational pull towards Warsaw, it can be seen, firstly, that values of the northern directions are generally lower than the southern ones (which results from the higher population density in the south). Secondly, the HSR lines converging radially in Warsaw, which were omitted from the plans, do not significantly differ in terms of traffic potential from those already existing or the planned lines. However, a lower potential of the NW2 sector/line (from Gdańsk) in comparison with the omitted sectors, e.g. SE Lublin, is notable.

Moreover, the value of $\sum F$ indicates how urgently a given HSR line should be developed, and thus the order in which they should be completed. For example, according to the current plans, the Łódź – Warsaw HSR line (sectors SW2 + W) is a priority. The next most important direction is the Radom – Warsaw line (sector S), which is not in line with those plans.

In summary, nine HSR lines should eventually converge in Warsaw. Their routes should be determined by both the current plans and the aforementioned division of the sectoral gravitational pull. The most urgent Mazovian investments seem to be HSR lines from Łódź, Radom, and Katowice (CMK), less urgent are lines from Toruń (Płock), Białystok, and Lublin, and the least urgent are lines from Brześć (Siedlce) and Gdańsk.

Environmental conditions

New or modernised HSR lines should not interfere with areas of high environmental value. Since the level of environmental protection varies between different types of areas protected by law, not all of them need to be protected in their entirety. In simple terms, it can be assumed that HSR lines may cross through nature parks (OChK) and natural landscape parks (large-scale protection). However, the crossing of a new HSR line through a national park or nature reserve is in principle not permitted. In the case of Natura 2000 areas, the best solution is to avoid them. Occasionally, it is possible to route a line through such areas after it has been demonstrated, on basis of a detailed

natural analysis, that the impact on protected areas will not be significant. In some spatial situations it is impossible to avoid areas of special nature protection, e.g. in the case of linear layout of protected areas, such as e.g. in the Vistula, Liwiec and Bug valleys. The borders of particular types of nature protected areas are easy to identify if one uses the Geoservice of the General Directorate for Environmental Protection [http://geoserwis.gdos.gov.pl].

The principle of protecting the environment applies not only to protecting nature but also to human living conditions. New HSR lines should therefore avoid densely populated areas where possible, so as not to worsen the quality of life of local communities. In the case of modernised HSR lines, the crossing of such lines through densely populated areas may be allowed on the condition that appropriate protective measures are implemented, especially concerning noise (tunnels, noise barriers, etc.). The HSR line located in the main cities should, as a rule, run through the city centres. This is when the largest number of potential passengers (i.e. the best service for residents) is reached; in certain spatial situations, it is not reasonable (technically, economically, socially, etc.) to run HSR through a city centre. Therefore, such a line should be routed next to a city, through its suburbs, where a separate HSR station/stop would be located to serve a city.

Optimal routes of HSR lines (preliminary locations)

Taking into account the results of the aforementioned analyses, one may attempt at a preliminary determination of the intended layout of the HSR lines through Mazovia. The following simplified analysis of optimal routes of particular lines is based on two criteria discussed above, i.e. functional-technical criterion (measured by the straightness of a railway line) and the criterion of environmental conditions (measured by the number of cases of the route interfering with the areas of high natural value).

NE line to Bialystok (Tallinn)

According to the current plans of PKP PLK company (cf. Fig. 5) the HSR line was projected to run inside the existing railway line no. 6 Zielonka – Białystok. Provided that eventually, a separate HSR track will have to be built inside the existing line to separate high-speed traffic from local and freight traffic; within this railway corridor, there is enough available space (usually 60–70 m wide) to accommodate such an investment. The line is almost straight so there is practically no need to straighten it in order to meet the standards of the HSR cat. I (V_p = 350 kph; R_n > 7,250 m). Such a location means that the negative environmental impact of further HSR line modernisation should be considered insignificant (provided that adequate protection measures are implemented).

E line to Brest (Minsk)

No such HSR line was planned in the previous development plans. The STH company listed this direction as passageway no. 4, stating that "no investments in the construction

of new lines are anticipated" [*Strategiczne studium*… 2020, p. 47], which in fact means maintaining the status quo: V_e = 100–160 kph. The existing line no. 2 Warsaw Central – Terespol cannot be upgraded to a high-speed line as it is too windy and has small horizontal curves radiuses (particularly in the section between Mrozy and Siedlce, R_w = 800–1,200 m). In addition, its central section (ca. 25 km long) between Siedlce and Łuków heads not eastward but southward.

Therefore, the construction of a new HSR line has been assumed. It is to be located north of the existing line no. 2, crossing through the centre of Siedlce and Biała Podlaska, using the in-city sections of line no. 2 there (which will presumably require the construction of tunnels on the HSR exits from these cities). The most likely route of this new HSR line is: Wesoła (exit from the corridor of line no. 2 to the north, into the military area) – Sulejówek – Nowa Miłosna/Okuniew – Budziska (near Okuniew) – Ładzyń (DK50) – Falbogi (near Kałuszyn) – Sługocin – Czarnowąs – Opole-Świerczyna – Siedlce (HSR station, Ujrzanów – Karcze (near Zbuczyn) – Krzewica – Woroniec (DK2) – Prosiuki/Sławacinek – Biała Podlaska (HSR station, interlocked with existing railway station) – Hola – Dobryń Mały – Koroszczyn-Fort – Terespol (a tunnel under the city, with possible HSR border crossing) – Bug river (a tunnel?) – West Brest/Zapadnyy (a tunnel under Brest Fortress?) – Brest Central/Centralnyj station.

This route will result in three interferences with the special protection Areas: Warsaw, Siedlce-Węgrów and Bug Landscape Park, as well as two interferences of the HSR with Natura 2000 areas: "Kostrzyn Valley" (near Sługocin) and "Ostoja Nadliwiecka" (a part in the Muchawka valley near Opole-Świerczyna), which are unavoidable if the new line is to be routed towards the Siedlce railway station. If crossing through these protected areas will lead to significant damage to nature, much more expensive solutions will have to be implemented, such as building either overpasses above these valleys or tunnels beneath them.

SE Line to Lublin (Lviv/Kyiv)

The current development plans did not include the construction of an HSR line from Warsaw to Lublin. The STH company listed this direction as route no. 5, stating that it will comprise, among others, the existing railway line no. 7 Warsaw-East – Lublin [*Strategiczne studium... 202*0, p. 49]. This would mean the maintaining of the status quo, possibly with an increase in train speeds as a result of further modernisation from the current V_e = 100–140 kph to V_p = 160 kph (except for stations and tighter curves). The existing railway line no. 7 on the section Otwock – Nałęczów is not suitable for high-speed rail as it is too windy with the small horizontal curves radiuses (mostly R_w = 800–1,000 m); the only exception is the straight section Warsaw – Otwock. Therefore it is proposed to build a new HSR line in the Otwock – Lublin section on the western side of the existing line no. 7 in the Otwock – Dęblin section and on its eastern side on the further Dęblin – Lublin section. The optimal route with the least impact on the valuable natural areas would be as follows: Otwock (PKP station) – Tabor (DK50) – Rudnik (near Osieck)

– Ewelin (near Garwolin) – Sośnika (near Łaskarzew) – Wola Życka – Kleszczówka (near Dęblin) – Niecziecz (on the Wieprz River) – Witkowice (near Końskowola) – Ludwinów (near Nałęczów) – Moszna – Motycz – Konopnica – Węglinek/Stasin (near Lublin). In addition to interference with the special protection areas (Warsaw and "Pradolina Wieprza"), this HSR route would only interfere with the Mazovian Landscape Park. It would be necessary to build a tunnel under the residential buildings of Otwock on the section PKP station – Partyzantów / 3 Maja street, about 1,400 m long. No stations are planned on this HSR line between Warsaw and Lublin as the cities located there have too low population potential (hence they are not included in Table 1).

S line to Radom and Cracow (Budapest)

The current development plans did not assume the construction of the HSR line from Warsaw to Cracow via Radom and Kielce, since this direction was expected to be operated by CMK. However, given this direction's high traffic potential, it seems reasonable to create a separate HSR line for it (with the CMK being used only for the SW1 direction to Katowice). The STH company's decision is also supported by the adoption of a separate direction to passageway no. 6, connecting Rzeszów and Ostrowiec Świętokrzyski with Radom and later not with Warsaw, but with STH/STH Airport. Following the author's thesis that Warsaw is more significant than STH in terms of traffic potential, this S line should be directed to the centre of Warsaw (from where less numerous passengers will be able to reach STH Airport via another HSR line).

According to the STH company, this direction within Mazovia will primarily include the existing line no. 8 between Warsaw West – Warka – Radom [*Strategiczne studium*… 2020, p. 52], which essentially means maintaining the status quo, with a possible increase in train speeds as a result of further modernisation from the current V_e = 80–130 kph to V_p = 160 kph (except for stations and tighter curves). The existing line no. 8 between Warsaw Służew and Radom Stara Wola due to its straightness is suitable for upgrade into a high-speed line. The only exception might be the crossing of Warka (western ring road for HSR?). The sections adjacent to Warsaw and Radom have far too tight horizontal curve radiuses (most often R_w = 500–800 m) and are located in densely built-up areas. Therefore, it is best to construct tunnels for HSR there, diverging from the route of the existing line. In order to increase and standardise travelling speeds, e.g. to V_e = 250 kph, a separate high-speed track for passenger trains is being proposed along the entire length of the line no. 8 Warsaw – Radom. However, this will require additional land and buildings to be demolished (the rail corridor there is narrow, usually 20–40 m wide). Nevertheless, it is estimated that the environmental impact of this project will not be high if appropriate protection measures are implemented.

Contrary to the STH company's plan, the new line no. 88 STH – Warka is recommended to be abandoned, while construction of a new line no. 84 Radom – Kunów is considered reasonable, as it would shorten and straighten rail traffic in the Rzeszów direction. The construction of the HSR line between Radom and Rzeszów is not

anticipated but the planned line no. 84 in this direction should be designed as a high-speed one. According to the *Strategy for Sustainable Transportation Development until 2030* (Strategia Zrównoważonego Rozwoju Transportu do 2030 roku – SZRT 2030), line no. 84 is to be an HSR line with V_p > 200 kph [*Strategia*... 2019, Fig. 16]. Unfortunately, all the possible route options of this line proposed by the STH company [*Strategiczne studium*... 2020, Figure Section, Tract no. 6, Line no. 84] will not qualify this line for HSR (R_w = 800 m, R_n = 3,500 m). Therefore, when including this line in the Mazovian HSR network, it seems that it is optimal to follow the most straight route through the vicinity of Iłża (V_p = 300 kph) with the following specific route: Radom Godów – Ciborów – Gębarzów – Wilczna – Walentynów – Krzyżanowice – Iłża (eastern part) – Błaziny Górne/Kotlarka – Koszary/Maziarze – Puszcza Iłżecka – Kolonia Inwalidzka – Janik – Boksycka/Wymysłów – PKP Ostrowiec Świętokrzyski. This route presents interference only with the Iłża – Makowiec and Kamienna Valley Landscape Parks.

However, the HSR is mainly routed from Radom via Kielce to Cracow and possibly further to Budapest (via Kosice?). In Mazovia, adapting the existing line no. 8 between Radom and Skarżysko Kamienna into the HSR line should be considered. This section of line no. 8 is too windy: there are numerous tight horizontal curves present with radiuses of R_w = 700–1,000 m, and wide turning angles, which is also due to the large gradients. Thus, it is recommended that a new HSR line be created in this section, routed independently of the existing line no. 8, located to the east of this line.

Apart from the problem of the exit from the centre of Warsaw in the S direction (as comprehensively discussed further for all directions), the optimal route of the HSR Warsaw – Kielce line through Radom remains to be solved. In order to keep standard horizontal curves within the limits of R_n = 7,000–10,000 m, an 8 km long HSR tunnel is proposed to be built under Radom. Its approximate route is to be along Energetyków and Zborowskiego streets, with an underground HSR station directly next to the existing Radom train station (in the vicinity of Mazowieckiego street) and further routed to the south under the districts of Glinice and Godów.

Keeping in mind this possible HSR tunnel under Radom, the optimal further route of the S line southwards towards Kielce and Cracow would be as follows: Radom-Godów – Trablice / Ciborów (turnouts for line 84 towards Iłża and Ostrowiec Świętokrzyski) – Parznice – Maliszów – Zalesice-Kolonia (near Wierzbica) – Rogów / Mirów Stary – Zbijów Duży – Skarżysko Kościelne – Skarżysko Kamienna (underground HSR station under Skarżysko Kamienna railway station?). Following such a route means that there will be no interference with legally protected nature areas with the exception of the "Przysusko-Szydłowieckie Forests".

Line SW1 to Katowice (Ostrava/Vienna)

All development plans include the HSR line from Warsaw to Katowice with the use of the existing line no. 4 (CMK) after its speed limit has been increased to up to V_e = 350 kph. No continuation of this line from Grodzisk Mazowiecki (Jaktorów)

to Warsaw is planned in Mazovia. The past and present plans call for the construction of a new HSR line in this direction to the north of the existing section of line no. 1 between Warsaw West and Grodzisk Mazowiecki; however, the Warsaw – Tłuste / Kłudzienko section would share its route with the HSR line in the SW2 direction. The STH company has recently announced the exact location of the new airport with the airport terminal being located between the villages of Strumiany Górne and Buszyce in Baranów municipality, Grodzisk county – preferred area. This means that it would be difficult to route the SW1 line through this terminal. Thus, the most probable straight route, avoiding the terminal, is as follows: Tłuste / Kłudzienko (excluded from SW2 line) – Zabłotnia – Izdebno Nowe (intersection with A2 freeway) – Kolonia Jaktorów – Stare Budy – Korytów (included in CMK). Along this route, almost the entire section of the line would follow a horizontal curve with an approximate radius of $R_n = 12{,}000$ m and there would be no significant environmental interferences. However, in order to provide service to STH Airport along such a route, an additional HSR connector would be necessary in the general direction of STH Airport (Buszyce) – Nowa Pułapina (excluded from SW2 line) – Stare Budy – Korytów (included in SW1 line), following a horizontal curve with an approximate radius of $R_w = 5{,}000$ m without significant environmental interferences. As a consequence, some HSR trains travelling in this direction (SW1) from Warsaw could travel along SW2 line to STH Airport (HSR station under the terminal?) and then return to the primary SW1 direction using this railway connector.

SW2 line to Wrocław (Prague) + W line to Poznań (Berlin)

The past and present development plans involve the routing of HSR lines from Warsaw to Wrocław and Poznań crossing under the centre of Łódź using the existing HSR stop at the Łódź Fabryczna station (concept "Y"). In Mazovia, i.e. between Warsaw and Łódź, both the SW2 and W directions will share a common route. Recently the STH company has presented alternatives for the route of this section of the HSR line (Fig. 4). Taking into account the two above-mentioned criteria ("straightness" and "environmental protection"), the optimal route would consist of sections of various variants W31-W34 (combined variant). Therefore, the following route of the SW2/W line to Łódź is recommended: Warsaw West – Bronisze (a tunnel under line 3) – Duchnice – Domaniew – Moszna (W33) – Biskupice – Żuków – Tłuste – STH Airport (station under the terminal?) – Aleksandrów (DK50) – Humin – Ziąbki – Podsokołów – Sypień/Łasieczniki (W34) – Nieborów – Bobrowniki – Parma – Seroki – Wrzeczko (Łyszkowice) – Pieńki Henrykowskie (W31/W33) – Tadzin/Brzeziny – Paprotnia – Helenów – Wiączyń Dolny (W33) – Łódź Widzew – PKP Łódź Niciarnia (the beginning of the existing HSR tunnel to PKP Łódź Fabryczna). The route will interfere with the "Rawka" nature reserve (an overpass over the river valley), Bolimowski Landscape Park and Łódź Heights Landscape Park, as well as with the Warsaw Landscape Park, Warsaw-Berlin Proglacial Valley, Morga and Mrożyca Landscape Parks.

NW1 line to Bydgoszcz (Szczecin)

The previous development plans did not include the construction of a direct HSR line from Warsaw towards Płock, Toruń, and Bydgoszcz. However, the regional government communicated a need the build new railway line between Modlin and Płock, but as a conventional line and not a high-speed one. The line was included in the government plans (in the first versions of the *National Railway Programme* [*Krajowy Program*... 2019, app. 2/1, item 148] and included in the PZPWM [*Plan*... 2018]. It was not included in *the Strategy for Sustainable Transport Development until 2030* (Strategia Zrównoważonego Rozwoju Transportu do 2030 roku – SZTR 2030) [*Strategia*... 2019], as shown in Fig. 14, 16 and 19. The figures of the aforementioned *Plan* indicate that the line will have a windy route and thus will not be suitable for the HSR line.

The STH company adopted a different concept, based on the idea of a large transport hub located by the new airport. This direction will be operated indirectly, i.e. by the SW2/W line from Warsaw to STH/STH Airport (a section of passageway no. 9, line no. 85), and then by a specially created new railway line from STH/STH Airport via Płock, Włocławek, Lipno, and Grudziądz to Gdańsk (passageway no. 1, line no. 5). It is not clear whether the STH company planned the construction of the new line to Gdańsk as high-speed or conventional, but the indicated travel time of 1:50 [h: min] between STH and Gdańsk [*Strategiczne studium*... 2020, Table 2, p. 38] indicates that it will be a HSR line with a $V_{ś}$ speed of nearly 170 kph (including stops at intermediate stations). SZRT 2030 assumes the future HSR line no. 5 to be a line with $V_{p} > 200$ kph [*Strategia*... 2019, Fig. 16]. Such a plan follows the former concept of extending the CMK from Jaktorów to Gdańsk. It does not, however, take into account the fact that the existing and modernised line no. 9 Warszawa – Działdowo – Gdańsk is close to HSR standards. Therefore it makes no sense to build two HSR lines to Gdańsk: via Płock/Włocławek and via Ciechanów/Działdowo.

As the idea of moving the main railway hub from the centre of Warsaw to STH is rejected, it is therefore suggested to resign from the planned new line no. 5 and replace it with the HSR line in the NW1 direction. It should run radially from Warsaw via Płock to Toruń, Bydgoszcz, and Szczecin. Taking into account its maximum straightness and environmental conditions, the following optimal route within Mazovia is proposed: PKP Warsaw Żerań – Henryków/Płudy – Las Henryka – Nowodwory/Czajka – Jabłonna (a tunnel under the palace park?) – Las Rajszew (Lasy Chotomowskie) – Janówek Pierwszy – Okunin – Modlin Fortress – Modlin Airport (a tunnel under Narew river valley and fortress + HSR station at the airport) – Henrysin – Karnkowo – Nowe Radzikowo (DK570) – Słomin/Kobylniki (DK50) – Dzierżanowo-Osada/Nakwasin – Mąkolin – Kolonia (Bodzanów) – Chełstowo – Juryszewo/Brochocinek (Rogozino) – Tchórz/Brochocin (DK60) – Nowe Trzepowo (HSR station Płock Północ) – Dziarnowo – Kamionki (DW540) – Janoszyce – Turza Wielka/Wilcza/Nowa – Bałdowo – Kolankowo (DK10) – Lipno/Okrąg – Złotopole (DK10) – Jankowo – Steklin – Jackowo (Czernikowo) – Skrzypkowo (Obrowo) – Zawały/Dobrzejowice (DK10) – Nowa Wieś (on the Drwęca River) – Toruń Kaszczorek – River Wisła (a tunnel or a bridge) – PKP Toruń Główny.

The NW1 line would replace the planned Modlin – Płock conventional line (in a way "straightening" it) and the interferences with valuable natural areas would occur when crossings the special protection areas: Warsaw, Naruszewski, Nadwiślański, "Przyrzecze Skrwy Prawej" and the Drwęca Valley, as well as with Brudzeń Landscape Park, Natura 2000 area "Drwęca Valley" connected with the nature reserve "River Drwęca" (an overpass or a tunnel) and Natura 2000 area "Lower Vistula Valley" (a tunnel or a bridge).

NW2 line to Gdańsk

As a result of to-date modernisation activities, line no. 9 between Warsaw – Działdowo – Gdańsk is close to HSR standards. Therefore, its further development is advocated. Its main element should at least be to straighten the Legionowo – Nasielsk section of the line. The STH company accepted this modernisation approach, stating that it was necessary to create a new line no. 20 Warszawa Choszczówka – Kątne [*Strategiczne studium*... 2020, p. 40], and published the preliminary optional routes of this new line [*Strategiczne studium*... 2020, string no. 2, line 20, sheets 1 and 2 + legend]. However, these designed routes include horizontal curves of R_w = 1,200–2,000 m. This shows that line no. 20 will not be a HSR line according to the aforementioned company. This contradicts the SZRT 2030, which assumes that the future line no. 20 will be a HSR line with V_p > 200 kph [*Strategia*... 2019, Fig. 16].

To correct this error, a new alternative route, almost straight (R_w = 7,000 m), is proposed along the following approximate direction: PKP Warsaw Choszczówka – Legionowo Bukowiec (beginning of a tunnel) – Legionowo Piaski – Łajski (end of the tunnel) – Kałuszyn Forest – Skrzeszew – Poddębie (a bridge over Narew River) – Dębe – Lorcin – Chrcynno – Pniewo (Nasielsk) – Pianowo – Gołębie – PKP Świercze. Such an alternative route of the NW2 line would result in natural interference only with the Warsaw and Nasielsk-Karniewski Natural Parks.

Warsaw HSR junction

The nine planned HSR lines should converge in the centre of Warsaw, and HSR trains should stop only at the central station. The current cross-town railway line (no. 2 Warsaw West – Warsaw East) cannot meet the requirements of high-speed rail traffic because it is too windy in its eastern part (R_w = 300–500 m). Given this situation, it seems reasonable to design separate, independent tunnels for HSR under the dense Warsaw development and the new Warszawa HSR central station. There are two possible spatial solutions for the HSR tunnel system:

1. A traditional layout, following the basic geometry of the present Warsaw HSR system (after it has been "straightened"), in which all HSR lines from the west and east converge in a new underground HSR station located next to the present Warsaw Central station (e.g. under Jerozolimskie Avenue). The lines running from the west to this station include S (in a tunnel running roughly beneath Żwirki i Wigury Street with a R_w = 2,000 m curve) and **SW1/SW2/W** (running jointly in a tunnel

along the current cross-city line). From the east, the following lines would converge there: **NW1/NW2** (routed in a shared tunnel beneath the line no. 9 from Warsaw Żerań railway station to Warsaw Praga railway station, followed by a new route under Nowa Praga, Stara Praga, the Vistula River and Powiśle with a final curve of R_w =4,000 m), **NE** (with a tunnel beneath the line no. 21 Zielonka – Warsaw Zacisze Wilno, followed by a new route under Targówek and Stara Praga to connect there to the tunnel of the NW1/NW2 line), **E** (running on a new aboveground line from Warsaw Wesoła railway station to Rembertów. The route turns south away from the line no. 2 and continues through a tunnel under Rembertów, the Kawęczyn and Olszynka Grochowska nature reserves, and Grochów, and then in a straight line along Waszyngtona and Jerozolimskie Avenues) and **SE** (running along a new tunnel route from PKP Warsaw Wawer to the connection with the E line tunnel in Grochów with a R_w = 6,000–8,000 m curve).

2. A cross-shaped layout with two main tunnels crossing at different levels in place of the new HSR Warsaw Central Underground Station (with platforms on two levels, initially located in the area of Zawiszy Square). The east-west tunnel would connect the **SW1/SW2/W** lines with the **NE**, **E**, and **SE** lines and would follow the route of the traditional layout. On the other hand, the north-south tunnel would connect the **S** line with the **NW1/NW2** lines. Its approximate route would be as follows: from the south roughly along Żwirki i Wigury St. and Towarowa St. and then under the Powazki cemeteries, Sady Żoliborskie, Marymont, and Żerań to PKP Warsaw Płudy (with two final reverse curves of R_w = 8,000 m).

When comparing the two layouts, one must pay attention primarily to the lack of admissible curves in the traditional layout (especially on the S line joining the new Warsaw Central HSR: R_w = 2,000 m). This would mean that formally part of the tunnels in this layout would not meet the HSR standards. Practically, trains using these tunnels would not be able to travel at the desired speed of V_p = 350 kph. For this reason, the author prefers the cross-shaped design.

Conclusions

The above analyses of the possible construction of the high-speed railway lines network in Mazovia lead to the following conclusions:

1. There are currently several sections of HSR lines in the Mazovian Voivodeship, located in the directions from Warsaw to Katowice (line no. 4, the so-called CMK) and to Gdańsk (line no. 9); therefore, their upgrade to meet the HSR network standards is advocated.
2. The modernisation of the third HSR line from Warsaw to Bialystok is the most advanced (line no. 6); this line is close to being upgraded to the HSR standards and therefore it is proposed that it should be integrated into the HSR network.

3. The construction plans for the fourth HSR line from Warsaw through STH to Łódź (line no. 85) are most advanced; therefore, it may be assumed that the construction of this line is certain and it should be included in the HSR network.
4. Given the high demographic and economic potential of Warsaw, it is reasonable to plan a radial layout of HSR lines. The central point of the line will be in the centre of Warsaw, which will be in line with the single-centred nature of the Warsaw agglomeration; therefore, plans to build the fifth HSR line in the Warka – STH – Płock direction (lines nos. 5 and 88), avoiding the city centre of Warsaw, are not justified.
5. The plan to build a second HSR node located near STH is flawed, as in the foreseeable future STH will not match the demographic and economic potential of Warsaw; this plan is tantamount to building a "second Warsaw", which is unrealistic; Therefore the former concept of STH Airport should be revisited. The service of the new airport by high-speed trains should be based on the planned line no. 85, and possibly additionally on line no. 4 after its extension through STH Airport to Warsaw; access to STH Airport from other directions would be realised through the Warsaw HSR node.
6. An analysis of the transport potential of large cities in Warsaw's area leads to the conclusion that the above-mentioned four HSR lines running radially away from Warsaw should be complemented by another four lines, running in the directions of Siedlce/Terespol, Lublin, Radom/Kielce/Cracow and Modlin/Płock/Toruń.
7. These additional HSR lines were the subject of a preliminary analysis of their possible localisations. It was concluded that they should be newly created lines, routed separately from existing conventional lines; only the Warsaw – Radom section was considered suitable for routing the HSR line along the extended corridor of the existing line no. 8; no significant environmental interferences with the construction of such lines were identified.
8. Two spatial layouts for the proposed Warsaw HSR node can be adopted for the radial convergence of all lines in the centre of Warsaw, i.e. either a traditional or a cross-shaped layout. In both cases, one central HSR station is planned, with no intermediate stations within the agglomeration (except for the large airports). It was initially located next to the existing Warsaw Central Railway Station or in the vicinity of Warszawa Główna station.
9. The simplified analysis of securing adequate technical parameters for HSR lines converging in the centre of Warsaw led to the conclusion that only the cross-shaped layout (east-west and north-south) can ensure uninterrupted fast travel of HSR trains to the central station. For all the converging lines, it would be necessary to build long HSR tunnels under the densely built-up areas of the city.

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Docelowy układ linii kolei dużych prędkości na Mazowszu

STRESZCZENIE

Koleje dużych prędkości (KDP) mogą doprowadzić do ponownego uzyskania przewagi kolei nad transportem drogowym i lotniczym w międzymiejskim transporcie osobowym. Z tego względu tworzenie spójnej sieci linii szybkiej kolei w Polsce i na Mazowszu ma sens, a pierwszym krokiem w tym kierunku powinno być opracowanie docelowego, kompleksowego programu budowy tych linii. Tymczasem dotychczasowe ustalenia planów budowy KDP w regionie mazowieckim są fragmentaryczne, a ponadto w wielu punktach kontrowersyjne.

W tej sytuacji niniejsze opracowanie ma na celu identyfikację mocnych i słabych stron ustaleń dotychczasowych planów rozwoju KDP w regionie, wskazanie innych sposobów rozwiązania ujawnionych już słabości tych planów, analizę i ocenę podstawowych alternatyw decyzyjnych oraz wybór rozwiązań optymalnych w odniesieniu do obszaru Mazowsza.

Obecnie na Mazowszu istnieją dwie linie KDP, prowadzące z Katowic oraz Gdańska w kierunku Warszawy. Plany rozwojowe zakładają ich dalszą modernizację i przedłużenie do Warszawy, a ponadto przewidują stworzenie dwóch następnych linii z Białegostoku oraz Łodzi do Warszawy. Jednocześnie dokumenty planistyczne pomijają budowę linii wylotowych KDP z Warszawy w innych kierunkach geograficznych, choć i na tych kierunkach są liczne duże miasta. Aby ustalić, czy to pominięcie jest zasadne, autor wykonał uproszczoną analizę generacji ruchu pasażerskiego dla wszystkich możliwych kierunków wylotowych z Warszawy do innych miast, z której wnioski prowadzą do zasadności uzupełnienia sieci linii KDP na Mazowszu o cztery linie dodatkowe z Terespola, Lublina, Kielc oraz Torunia do Warszawy.

Na podstawie wykonanych wstępnych analiz lokalizacyjnych autor stwierdził, że te dodatkowe linie powinny być zasadniczo nowymi liniami trasowanymi niezależnie od istniejących linii konwencjonalnych, a jedynie dla odcinka Warszawa – Radom jest możliwe wytrasowanie linii KDP w korytarzu istniejącej tam linii konwencjonalnej. Nie zidentyfikował istotnych przeszkód ekologiczno-przyrodniczych w budowie tych linii.

Autor opowiada się za stworzeniem ściśle promienistego układu linii KDP z punktem środkowym w centrum Warszawy, co będzie w zgodzie z monocentrycznym charakterem aglomeracji warszawskiej. Plany budowy „drugiej Warszawy" przy planowanym Centralnym Porcie Komunikacyjnym (CPK) uważa za nierealne i postuluje powrót do dawnej koncepcji Centralnego Portu Lotniczego (CPL) z obsługą kolejową opartą jedynie na jednej lub dwóch liniach KDP.

Słowa kluczowe: transport kolejowy, kolej dużych prędkości, linie kolejowe, parametry techniczne, optymalizacja lokalizacji inwestycji transportowych, ochrona środowiska, Mazowsze

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