Actual utilisation of maximum line speed - Polish and Ukrainian experience

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Abstract. The overall condition of the Polish railway infrastructure has been recently improved. The condition of railway infrastructure and the level of its technical equipment are reflected in the maximum train speeds allowed on particular sections of railway lines. The analysis covers the utilisation of the maximum line speed by the long-distance trains in Poland in the 2018/2019 timetable. The database has been prepared, covering start-to-stop runs of Express Intercity Premium (EIP) trains). The analysis shows that typical value of speed utilisation ratio for EIP trains operated with ED250 EMU is approximately 0.82-0.83. The correlation ratio between the average maximum line speed and the train commercial (start-to-stop) speed is rather good. The data from the Polish railways have been compared with Ukrainian ones. The results of the research show clearly, that the selection of passenger rolling stock for particular route can have significant impact on its day-to-day operation.

1 Introduction

The European railways have recently been significantly transformed through implementation of the EU legislation imposing “unbundling”, i.e. strict separation of infrastructure management and operation of passenger and freight services.

The Directive on the interoperability of the rail system within the European Union states, that the quality of rail services depends, inter alia, on excellent compatibility between the characteristics of the network (in the broadest sense, i.e. the fixed parts of all the subsystems concerned) and those of the vehicles (including the on-board components of all the subsystems concerned) [1]. Performance levels, safety, quality of service and cost depend upon that compatibility. Performance of the rail system can be evaluated according to numerous criteria and described through various parameters, like capacity, speed, accessibility.

Overall performance of railway system in Poland was evaluated by Wróbel [2]. This assessment was focused on the integration of timetables for passenger trains co-financed by competent authorities in the framework of Public Service Contracts (PSC). The examples of parameters used for this particular assessment were: number of connections in the directions specified in the Transport Plan, average waiting time and average connection time for stations and for individual directions.

The issue of performance evaluation is valid in case of all transport systems. It is very important to develop methods for selection of optimum system suited to specified local conditions. For example there numerous works comparing light rail systems (LRT) with bus rapid transit systems (BRT). One of the key features of particular transit system is its commercial speed. Therefore it is necessary to investigate factors influencing that speed. According to works by Kühn [3], in case of LRT systems, the direct relation exists between percentage of separated right-of-way and commercial speed. For completely (or almost completely) segregated LRT routes, the typical commercial speeds of 29-32 km/h can be achieved. If only 50% or less right-of-way is separated, the commercial speed usually does not exceed 20 km/h (data from Cologne) [3]. The commercial speed influences the service that can be provided for customers, but also determines the number of vehicles and drivers that will be needed. The commercial speed is also related to the maximum speed of the vehicle, and to braking and acceleration characteristics. However, TRL/INRETS field surveys revealed little difference between electric trains and buses. Research using multiple regression analysis for such factors as station spacing (i.e. the distances between stations), suggests that the inherent difference between busways and LRT is not statistically significant. [3].

Various aspects of railway transport system have been assessed by the European Court of Audit (ECA). For example in 2016, ECA evaluated rail freight transport across Europe [4]. The poor performance of rail freight transport in terms of volume and mod-al share in the EU is not helped by the average commercial speed of freight trains. On some international routes freight trains run at an average speed of only around 18 km/h. This is due to weak cooperation between the national infrastructure managers. In Central and Eastern

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European Member States, the average speed is between 20 and 30 km/h. The analysis o ECA showed, however, that the situation is significantly better in some freight corridors, where the average is speed is around 50 km/h. This values is closer to the average speed of trucks (around 60 km/h). [4].

A comprehensive performance audit on the long-term strategic planning of high-speed lines in the EU, on the cost-efficiency (assessing construction costs, delays, cost overruns and the use of high-speed lines which received EU co-funding), and on the sustainability and EU added value of EU co-funding was carried out in 2018 [5]. The analysis was focused on the speed on the audited high-speed lines. It shows, that, on average along the course of a line, trains run at only around 45 % of the line's design speed (in European conditions usually at the level of 300 km/h). Only two lines operate at average (commercial) speeds of more than 200 km/h, and no lines operate at an average speed above 250 km/h. The lowest speed yield on a completed high-speed line is on the Madrid-León high-speed line (39 % of design speed). The cross-border Figueres - Perpignan section also only operates at 36 % of its design speed, because it accommodates mixed traffic. Average speed so far below the design speed indicates that an upgraded conventional line would have been enough to achieve the objectives set, at a much lower cost [5].

Important aspect influencing performance of railway system is the quality of transport offer and its structure. The problem was investigated by Żurkowski, who proposed classification of passenger services. The following categories have been distinguished: intercity, interregional, regional and agglomeration. [6].

Charkina developed the proposal for new classification of passenger trains in Ukraine taking into account the working period, the territory of service, the maximum distance of movement, average journey speed, time of a trip, a type of a rolling stock and sources of financing [7].

Organisational aspects of implementation of accelerated passenger train services in Ukraine have been investigated by Matusevich [8]. Their introduction is treated as a mean of improvement of efficiency of passenger transport. The practical result of the research study was an algorithm for the introduction of new economic classification of passenger trains.

The aim of the present research is to verify method for evaluation of actual utilisation of the maximum line speed. Another goal is to identify factors having influence on utilisation of the maximum line speed in case of long-distance passenger trains on the Polish railway network.

2 The railway infrastructure in Poland

The vast majority of railway lines in Poland is managed by PKP Polskie Linie Kolejowe S.A. (PKP PLK). According to the Annual Report of the company, the total length of railway lines forming PKP PLK network is 18513 km (December 2017). The total length of tracks at that time was 35967 km, 27120 km of which were route tracks (i.e. tracks on open sections) and principal main tracks at stations and 8847 km were other station tracks.

The total length of electrified railway lines is 11816 km and total length of tracks equipped with overhead catenary lines is 24697 km [9]. This means, that approximately 63.8% of railway lines in Poland are electrified.

The technical condition of the railway network in Poland is not uniform. It is noteworthy, however, that as a result of the maintenance and repair works as well as performed investment tasks, the overall condition has been recently improved. The length of railway line tracks graded as good in terms of technical condition (as at 31 December 2017) represented 58.9% of the total track length, which is almost 23% increase in comparison to the status from 31 December 2010, when only 36% of tracks were in a good condition (tracks in good condition – tracks operated in line with the assumed parameters, only maintenance work is required).

Simultaneously the percentage of railway line tracks graded as unsatisfactory has been reduced from 29% in 2010 to 15.6% in 2017. Tracks in unsatisfactory condition are tracks characterised with significantly lower operation parameters (low timetable speed, large number of local speed limits, lower permissible loads), which qualify railway tracks for comprehensive replacement.

The condition of railway infrastructure as well as the level of its technical equipment are reflected in the maximum train speeds allowed on particular sections of railway lines. The maximum speeds on all operated railway lines managed by PKP PLK are presented in Fig. 1.

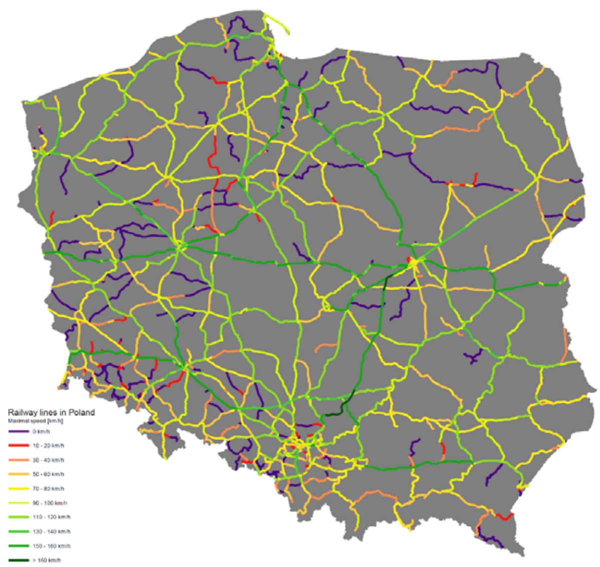

Fig. 1. Maximum speeds on railway lines in Poland (2017). Source: Own elaboration of IK

It should be noticed, that the structure of maximum speeds on the Polish railway network has been significantly changed recently. In December 2010 only 20.2% of main tracks were cleared for operation at the speed of 120 km/h or more. In 7 years, till December 2017, the share of main tracks with the maximum speed of 120 km/h or more has been increased to 37.8%. Moreover, since December 2014 the maximum speed of 200 km/h is in force on the part of line 4 Grodzisk Mazowiecki – Zawiercie (Central Trunk Line). In the 2014/2015 timetable, the total length of line allowed for 200 km/h was 87 km (i.e. the total track length was 174 km). Four years later, in the 2018/2019 timetable, two sections on the Central Trunk Line are operated at this speed and located between Grodzisk Mazowiecki and Zawiercie (76.7 km) and between Wloszczowa Polnoc and Zawiercie (58.3 km). The total length of tracks for 200 km/h is approximately 271 km.

Simultaneously, the percentage of main tracks with the maximum train speed lower than 80 km/h has been reduced from 43.8% in 2010 to 29.5% in 2017. The key issue is, however, to what extent the maximum line speeds are reflected with the train commercial speeds, i.e. the speeds which are perceived by the end-users of railway transport – the passengers.

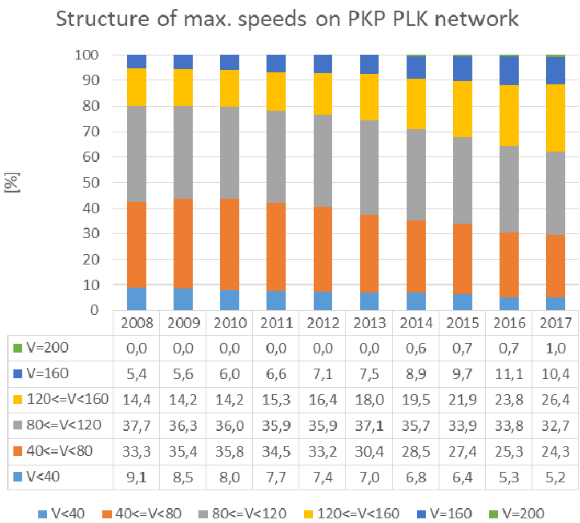

Fig. 2. Changes in structure of maximum speeds on railway lines in Poland from December 2008 till December 2017. Source: Author's own elaboration on the basis of PKP PLK data

3 Express train services in Poland

In Poland comprehensive network of express trains was implemented in early 1960s. The essential role of these daytime trains was to establish the fastest possible connections between Warsaw and regional administrative centres. In 1984 the operation of the express trains making use from newly built Central Trunk Line (CMK) was started. Initially the offer included one pair of non-stop trains between Warsaw and Cracow as well as one pair of trains from Warsaw to Gliwice via Katowice. For the first time in the history of the Polish railways the maximum speed of these trains was set as 140 km/h. In the following few years (until 1989) the network of express trains running non-stop (or at least with very limited number of stops) was expanded. Moreover, in 1988 the maximum speed of passenger trains on CMK line was increased to 160 km/h.

In December 2014 the new ED250 Pendolino electric motor units (EMUs) were introduced on the Polish railway network [10]. Generally they serve the main north-south axis from Gdynia and Gdansk through Warsaw to Cracow and Katowice. Moreover selected trains between Warsaw and Wroclaw through Opole are also operated with these EMUs. These trains make good use of the modernised and revitalised infrastructure.

Table 1 shows changes in journey times between Warsaw and the largest cities in the country. Three milestones have been selected: 1989 - start of political and economic transformation in Central-Eastern Europe, 2004 – accession of Poland into EU, 2019 – present year (journey times according to the timetable valid from December 2018 till March 2019).

Table 1. Evolution of journey times in Poland [hh:mm]

Section	Length [km]	Time 1989	Time 2004	Time 2019
Warsaw - Cracow	293	2:45	2:45	2:17
Warsaw - Lodz	133	1:30	1:50	1:18
Warsaw - Wroclaw	422	5:08	4:50	3:36
Warsaw - Poznan	302	3:01	2:47	3:26
Warsaw - Gdansk	328	3:34	4:00	2:51
Warsaw - Szczecin	515	5:27	5:32	6:28
Warsaw - Bydgoszcz	288	3:40	3:40	3:19
Warsaw - Bialystok	183	2:33	2:21	2:17
Warsaw - Katowice	298	2:42	2:27	2:19

It is clear the in majority of cases the journey times have been significantly reduced in comparison with the year 1989. The most notable shortening of journey time (more than 1 1/2 hours) is in the case of Warsaw – Wroclaw route. The journey time between Warsaw and Poznan, however, is much longer than in 1989. The reason is ongoing modernisation of the line, requiring deviation of all trains (they are operated through Gniezno).

4 Utilisation of maximum speed – the case of the Polish railways

The analysis covers the utilisation of the maximum line speed by the long-distance trains in Poland in the 2018/2019 timetable. The database has been prepared, covering 46 start-to-stop runs of Express Intercity Premium (EIP) trains). All involved trains are operated by PKP Intercity on commercial basis.

The official infrastructure data of PKP PLK were used to calculate exact distances and mean maximum speeds for all sections.

To characterise maximum train speeds it is necessary to adopt some statistical measures. The most important parameter seems to be the highest maximum speed on the section in question (V_{max}). This value defines the requirements for rolling stock making the full use from the infrastructure capabilities [11].

The differentiation of the maximum speed along the line has significant influence on journey time and, consequently, on line capacity. It is taken into account with the harmonic weighted mean $V_{0\ max}$, calculated according to the formula (1):

$$V_{0\ max} = \frac{\sum_{i=1}^{n} l_i}{\sum_{i=1}^{n} \frac{l_i}{V_{i\ max}}} \quad (1)$$

where $V_{i\ max}$ is maximum speed on section of track i, and l_i is the length of (sub)section i. Harmonic weighted mean is a quotient of the total length of the line (or the network) and the sum of theoretical journey times on particular (sub)sections with the constant speed. It is clear, that $V_{0\ max} \leq V_{max}$.

In the case of Central Trunk Line the maximum speed of 200 km/h is allowed on two sections (total length approximately 135 km), whereas the maximum speed of 160 km/h is in force on the remaining part of the line (see Fig. 3). The only exceptions are the station of Idzikowice (from km 80.2 to 82.4) and the final 2 kilometres at the end of the line close to Zawiercie station. As a result the weighted mean value of maximum speed for that line is $V_{0\ max}$=180.6 km/h.

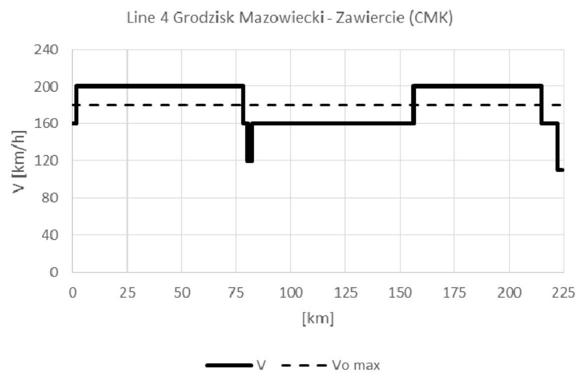

Fig. 3. Example of the speed profile with long sections passed at uniform maximum speed. Source: Author's elaboration on the basis of official data of PKP PLK S.A.

The journey times have been collected for all start-to-stop sections. They were extracted from official public timetables and from working timetables valid from 9 December 2018 [12].

Practical measure for assessment of railway offer in passenger traffic is the value of commercial speed V_c, which is calculated according to the formula (2):

$$V_c = \frac{l}{\sum t_r + \sum t_S} \quad (2)$$

where l is the length of train route, t_r are the journey times on consecutive sections and t_s are the stopping times. It should be noticed, however, that for the analysis of utilization of the maximum line speed, the start-to-stop average speeds V_s are more convenient measure. Start-to-stop average speed was commonly used for presentation of the fastest train services in professional journals before World War II. Good example was the series of articles "British Express Train Services" in the Railway Magazine [13]. Similar analyses were also compiled for express train services in other European countries. It is noteworthy that the start-to-stop train speeds are the basis for train classification in the World Speed Survey, published bi-annually in Railway Gazette International until now [14].

As the parameter characterising the utilisation of the maximum line speed, the speed utilisation ratio I_s has been defined (3):

$$I_S = \frac{V_S}{V_{0\ max}} \quad (3)$$

where V_s is the start-to-stop average speed of the train on particular section and $V_{0\ max}$ is the weighted average maximum line speed on the same section.

In general, the values of start-to-stop average speeds of EIP trains show very good correlation with (harmonic) mean maximum speeds (Fig.4).

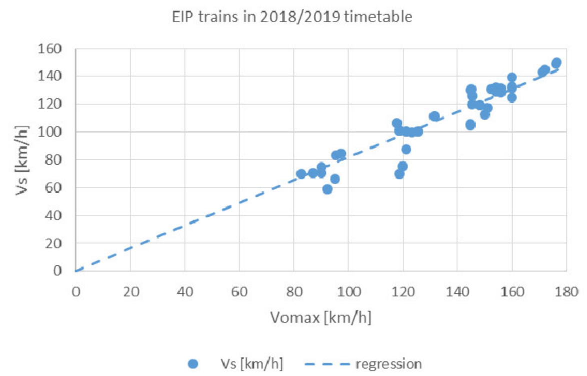

Fig. 4. Correlation between average maximum speeds and start-to-stop speeds for EIP trains in the timetable valid from 9 December 2018

In case of 46 runs of these trains (served with ED250 EMUs) the correlation coefficient r equals to 0.942. The regression equation for this group of train services can be written as follows (4):

$$V_S = 0.818\, V_{0\ max}\ . \quad (4)$$

It should be noted, that neglecting a few sections affected with track works results in even better correlation and in higher values of speed utilisation ratio.

There are several sections with particularly favourable utilisation of maximum line speed, for example: Warszawa Wschodnia – Ilawa Glowna (I_s=0.900) and Lebork – Slupsk (I_s =0.903).

For the start-to-stop runs of EIP trains, covering Central Trunk Line (at which 200 km/h is achieved) the speed utilisation ratio is also quite good: Warszawa Zachodnia – Krakow Glowny (I_s=0.858), Krakow Glowny - Warszawa Zachodnia (I_s=0.859).

5 Acceleration of passenger train services in Ukraine

Novelty on the Central-Eastern European railways is the gradual replacement of overnight trains (composed of couchette and sleeping cars) by EMUs operated as daytime trains. The best examples can be shown in Belarus and Ukraine.

In Belarus such restructuring of passenger offer was possible after electrification of selected lines of BC network and simultaneous raising the maximum speed. up to 140 km/h. The central location of the capital city of Minsk. at the intersection of main railway lines in Belarus. makes it very easy to start new daytime connections.

In the year 2002, the first fast daytime Intercity services were implemented on the Kyiv – Kharkiv route in Ukraine (branded as Stolichny Express). They were composed of the new passenger open-saloon cars and operated at the maximum speed of 140 km/h. In the following years similar intercity services were introduced also on other important routes.

Since 2012 several intercity trains in Ukraine are operated with modern EMUs manufactured by Hyundai and Skoda (Fig.5). They serve routes linking Kyiv with major regional centres as Lviv, Dnipro, Kharkiv.

Fig. 5. HRCS2 EMU of Ukrainian Railways serving the Lviv – Kyiv Intercity+ train (2012)

Table 2 shows the changes in journey times between Kyiv and major regional centres valid for 1989, 2004 and 2019 timetables. It is noteworthy that the numbers from the year 2004 reflect the significant improvement on Kyiv – Kharkiv and Kyiv – Dnepropetrovsk (now Dnipro) routes thanks to implementation of Stolichny Express.

Table 2. Evolution of journey times in Ukraine [hh:mm]

Section	Length [km]	Time 1989	Time 2004	Time 2019
Kyiv - Kharkiv	486	9:44	5:50	4:45
Kyiv – Dnipro	532	9:18	5:45	5:45
Kyiv – Kryvyi Rih	448	9:08	9:04	5:36
Kyiv – Lviv	572	9:19	8:30	5:09
Kyiv – Mariupol	1032	19:35	17:23	17:54
Kyiv – Mykolaiv	526	9:22	8:22	6:27
Kyiv – Odessa	654	9:29	9:35	7:15
Kyiv - Zaporizhia	657	13:32	10:16	7:18

Using the maximum speed and journey time data from the 2013/2014 timetable it was possible to calculate the average maximum speeds and start-to-stop speeds for a few sections:

1) Kyiv – Mirgorod, 246.5 km, V_{0max}=133.6 km/h, V_s=122.2 km/h, I_s=0.915;
2) Darnitsa – Mirgorod, 232.4 km, V_{0max}=138.5 km/h, V_s=127.9 km/h, I_s=0.924;
3) Mirgorod – Poltava K., 88.4 km, V_{0max}=121.9 km/h, V_s=110.5 km/h, I_s=0.906.

All above runs were made by trains operated with HRCS2 EMUs. It should be noticed, however, that the present journey times on respective sections are a few minutes longer than in the year 2013.

6 Conclusions

Quality of rail services depends, to large extent, on excellent compatibility between the characteristics of the infrastructure and the rolling stock. Good example of such compatibility is adjustment of speed characteristics of EMU or loco hauled train to the maximum speeds allowed on the route and to their differentiation.

Comprehensive data base including the runs of long-distance trains in Poland in the 2018/2019 timetable has been prepared. The analysis shows that typical value of speed utilisation ratio I_s for EIP trains operated with ED250 Pendolino EMU is approximately 0.82-0.83. The correlation ratio between the average maximum line speed V_{0max} and the train commercial (start-to-stop) speed V_s is rather good.

The differences between start-to-stop average speeds and average maximum speeds result from time losses due to train acceleration and braking at the beginning and the end of each run but also in all locations, where maximum speed changes. It should be remembered that timetable recovery margins are added to guarantee timekeeping.

The highest values of the speed utilisation ratio are observed for the longest sections passed without intermediate stops. On such sections the influence of acceleration and braking is relatively minor. I_s values at the level of 0.9 have been identified for some runs of EIP trains, operated with ED250 trainsets, for example between Warszawa Wschodnia and Ilawa Glowna stations (distance 204.7 km).

The utilisation of maximum speed is negatively influenced by significant differentiation of the speed profile (frequent and large changes of speed along the line). The most effective utilisation of line capabilities is in the case of Electric Motor Units with distributed power and high power-to-weight ratio.

Similarly good results have been achieved by the Ukrainian Railways (UZ) thanks to the implementation of new generation of rolling stock, in particular modern EMUs. Despite numerous changes in maximum speeds on route, these trains are able to reach start-to-stop speeds in the range of 120 km/h without exceeding the maximum speed of 160 km/h.

The results of the research show clearly, that the selection of passenger rolling stock for particular route can have significant impact on its day-to-day operation.

Therefore it is very important to take the infrastructure characteristics (gradients, maximum speed profile) into account at the stage of drafting specifications for the rolling stock to be used on particular route. Similarly it is important to carry out in-depth analysis of rolling stock performance as a part of feasibility study for construction of the new railway infrastructure or modernisation of existing one [11]. This is important field of applicability of the method and the results of the study as the tool to compare large number of various variants of the future infrastructure investment. The method allows to check, how the speed profile for designed alignment will be "consumed" in practice with the rolling stock to be used and with the planned stopping pattern.

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