Large-Scale, Economically Feasible and Safe Rearrangement of the Warsaw Rail Transport System

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Abstract Warsaw agglomeration rail transport comprising of tram and metro lines ensuring transport within Warsaw and suburban railway connections ensuring transport between a number of satellite cities and main Warsaw railway stations can be rearranged to achieve much better rail transport offer without enormous financing. The article proposes creation of a new services and points necessary investments showing that much better rail transport service is not only technically possible but also economically reasonable and feasible in relatively short time. Safety challenges associated with the proposed rearrangement are pointed and described together with the ways to meet them. The proposed solution allows operational improvement together with not only keeping rail transport high safety level but even lowering risk associated with different types of failures during extended rail service in future.

Keywords Sustainable transport · Development of rail services · Rail transport safety · Control command · Rail service improvement feasibility

Introduction

Using individual transport means, especially private cars, is associated with traffic congestion, parking difficulties and long everyday travel times for citizens. It has been already proved that developing of the public transport is the best way to solve or at least minimize undesirable consequences of the growing mobility in agglomerations. To ensure the high use of public transport, local authorities must attract citizens offering fast, frequent, punctual and comfortable connections between residential areas and all other usual destinations. Different modes of transport can be used: road, rail, water or even monorail. Different transport means

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can be used within each mode; for example, rail transport can be based on trams, rail busses, light rail vehicles or trains, while road transport can be based on public bicycles, public minicars, busses, trolleybusses or long articulated busses. Rearrangements of the public transport can be extremely successful if it takes into account, in an appropriate way, all important local circumstances. Differentiation of the local circumstances is so high that the only universal true can be summarized as 'sustainable well suited to local circumstances transport attracts citizens to use public transport'. Further analysis is therefore dedicated to chosen case—Warsaw agglomeration.

Warsaw Public Transport Overview

Public transport in Warsaw is based on the two transport modes: road transport and rail transport. Water transport is offered only occasionally for tourists.

Road Public Transport in Warsaw

Over one thousand and seven hundred road busses operated by five public transport service providers ensure connections between nearly one thousand and four hundred bus stops [1]. Bus network is so complicated as it is presented in Internet on an assembled map, which in practice allows the Internet users to see city borders and to choose one of the twenty-two smaller street maps showing public transport (see Fig. 1).

Growing congestion and public healthcare challenges requesting pollution reduction resulted in a large number of public bicycles. Over 200 bicycle stations (see Fig. 2) operated by one service provider offer over three thousand bicycles, which can be used 20 min for free (1 h for 0.25 euro, etc.) [2]. The public bicycle story in Warsaw started in 2012. It is young, but quickly developing, strongly welcomed by citizens and supported by the local society and by the local administration. The length of the bicycle roads is still not satisfactory (slightly below 460 km), but it is constantly increasing.

Rail Public Transport in Warsaw

Warsaw agglomeration has quite well-organized rail transport comprising of tram and metro lines ensuring transport within Warsaw and suburban railway connections ensuring transport between a number of satellite cities and main Warsaw railway stations. Electric trams are present in Warsaw since 1908. Many different suburban and regional railway connections are offered since the middle of the

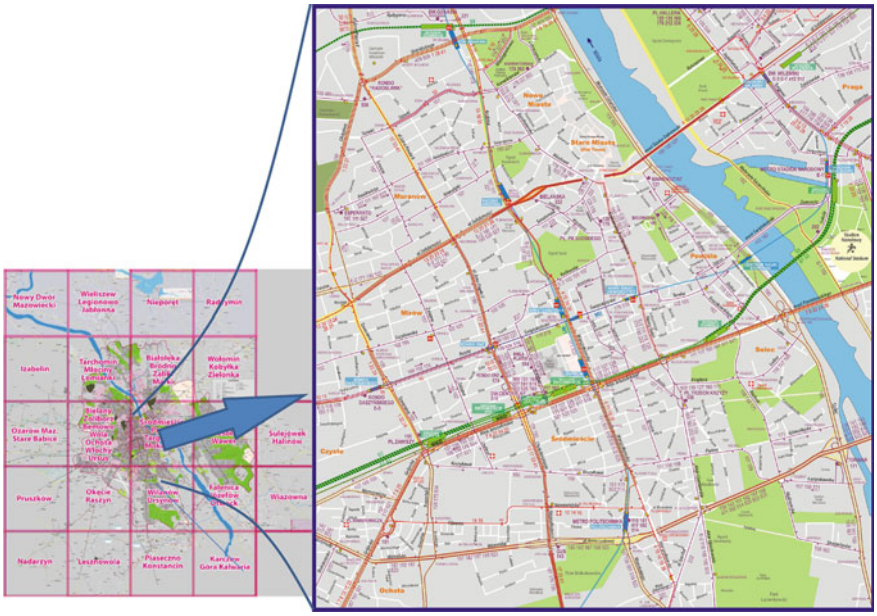

Fig. 1 Warsaw public transport Internet guide. *Source* www.ztm.waw.pl

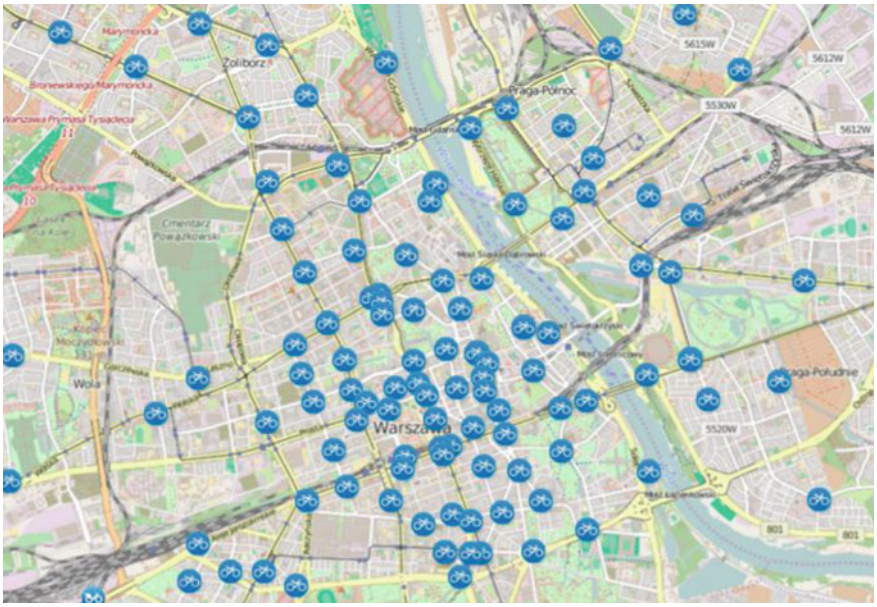

Fig. 2 Bicycle stations in the centre of Warsaw. *Source* www.veturilo.waw.pl

twentieth century. Presently, trams are operated by one service provider owned by the city of Warsaw, while suburban and regional train connections are operated by two local service providers using the same railway infrastructure.

The first section of the first metro line is in operation since 1995. The operation of the first section of the second metro line started twenty years later in 2015. Construction works started in 2010 and took five years and one and a half billion euro for 6 km and seven stations [3]. That makes 250 million euro per 1 km. Presently, it is foreseen to continue second line construction. The first section is about one quarter of the second line. However, financing is not ensured.

Rail transport network is shown in Fig. 3 where tram lines (thin colour lines), metro lines (M1—thick dark blue line and M2—thick red line) and railway lines (thin grey lines) are shown [1].

Fig. 3 Warsaw rail transport network. *Source* www.ztm.waw.pl

Warsaw Public Transport Challenge

Agglomeration is growing. New city quarters with modern office buildings, shopping centres and residential areas have to be connected in a way that ensures easy access. Streets will not be wider. New bicycle roads will rather make them narrower. Although office buildings and shopping centres are constructed with parking places, the amount of cars is significantly growing faster than the amount of parking places.

Traffic and parking congestion can be minimized, thanks to the public transport if it offers regular, fast and relatively comfortable service. Therefore, dedicated bus lanes and modern busses are already in use. Moreover, some schools, especially along first metro line, start lessons at 7:45, some at 8:00 and some at 8:15 to distribute pupils' add on to congestion in metro trains just before eight o'clock.

Achieving competitive public transport is still a challenge. Public transport means should not be affected by traffic jams on roads, which are full of private cars. Public transport services should be regular, frequent and fast. It has to be comfortable and ensure as far as possible door-to-door connections.

Construction of additional metro lines is a perfect solution, but it is theoretical in case of Warsaw. Long-lasting and costly solution cannot be the only one being applied. Therefore, other rail transport possibilities have to be taken into account. New tramways have to be constructed especially for connecting additional city quarters to tram network. Regional, suburban and local railway services should be used to ensure the better support for agglomeration transport services.

Warsaw Rail Transport System's Rearrangement Proposal

An idea to create a railway city ring in Warsaw has been proposed several times (see Fig. 4). It was seen, however, as not feasible due to the rail traffic congestion on suburban tracks between Warsaw East (Warszawa Zachodnia) and Warsaw West (Warszawa Wschodnia) railway stations.

Fig. 4 Warsaw railway city ring idea (author's own elaboration)

Existing Railway Tracks and Stations

The main railway connection between Warsaw West and Warsaw East stations is formed by tracks dedicated for long-distance trains (railway line no 1: Katowice–Warsaw West–Warsaw Central and railway line no 2: Warsaw Central–Warsaw East–Terespol) and tracks dedicated for suburban trains (railway line no 448: Warsaw West–Warsaw Ochota–Warsaw Downtown (Śródmieście)–Warsaw Powiśle–Warsaw Stadion–Warsaw East and further to Warsaw Rembertów). Long-distance trains use four platforms at Warsaw West, four at Warsaw Central and five at Warsaw East. Suburban trains use two platforms at Warsaw West, three at Warsaw Downtown and two at Warsaw East. Long-distance and suburban tracks are interconnected with switches forming train routes which are used only in case of serious traffic disturbances. Generally, suburban trains are running only on suburban tracks. It is proposed to use railway line no 20 (Warsaw Praga–Warsaw Gdańska–Warsaw Towarowa) and a section of railway line no 9 (Warsaw East–Gdansk Main station) and their interconnection numbered as railway line no 501 to create a railway city ring. As a result, it will be based on the existing tracks.

The proposed ring includes three stations used for long-distance and suburban traffic: Warsaw West, Warsaw East and Warsaw Gdańska and seven stopping points: Warsaw Ochota, Warsaw Downtown (Śródmieście), Warsaw Powiśle, Warsaw Stadion, Warsaw Zoo, Warsaw Koło and Warsaw Kasprzaka and omits station Warsaw Central. Three of them are connected with Warsaw metro stations.

Additional Tracks and Stations

Adding additional tracks between Warsaw West and Warsaw East is not possible due to the city planning constraints. Railway tracks are partly within a cut, partly in tunnel, partly on viaduct, partly on the bridge and partly on the embankment. Track geometry, substructure and superstructure changes are blocked by existing buildings, metro line situated below, main drinking water pipes, multifloor watershed for rainwater and other city infrastructure. Adding additional tracks to other sections is first of all a question of necessity.

Trains scheduled on line no 20, which is a double-track line, leave enough space for additional ones. The same applies to the section of the railway line no 9, although tracks forming this section will be used for long-distance, suburban and local trains at the same time. Interconnection between railway line nos 20 and 9 (railway line no 501, see Fig. 5) contains two single tracks constructed independently, but used as a double-track line from the operational point of view. Trains running counterclockwise will have longer route.

Additional stopping point on a double-track line can be added by constructing two single-edge platforms without touching tracks. Platforms shall be constructed taking into account the applicable requirements including adaptation for people

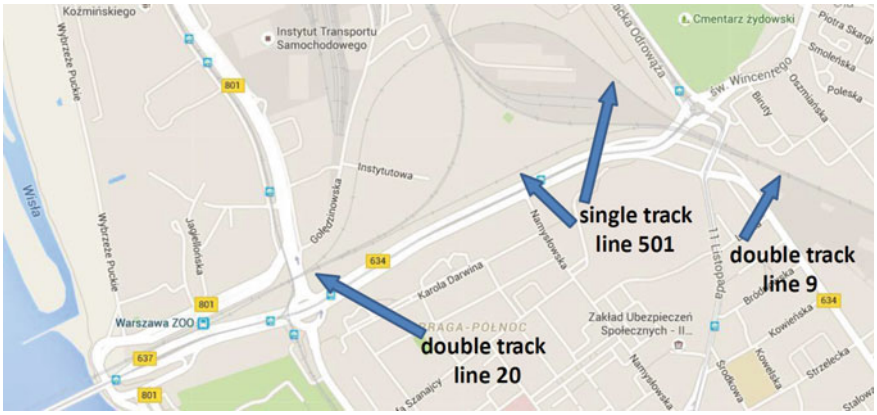

Fig. 5 Warsaw zoo station (north-east corner of the proposed railway ring) (author's own elaboration)

with reduced mobility. From the public transport point of view, five additional stopping points serving big outbound streets are reasonable. They should be constructed at the crossings with the following streets: Solidarności, Św. Wincentego, Św. J. Pawła II, Powązkowska and Obozowa.

Required Cross-Connection Railway Viaduct at Warsaw West Station

Railway line no 448 is entering Warsaw West station from the east via the east station head. Railway line no 20 is entering Warsaw West station from the north, directly to the west station head. Two platforms are used for suburban trains running through Warsaw agglomeration on line no 448: platform 2 with two tracks for trains running in the east direction and platform 3 with two tracks for trains running out of Warsaw. One platform is used for suburban trains running through Warsaw agglomeration on line no 20: platform 8.

As a result, station layout, shown in Fig. 6, does not allow trains to run from line no 20 to line no 448 and vice versa without changing train's head and occupying outgoing tracks of the west station head during shunting. That is not acceptable not only from the point of view of Warsaw railway ring capacity, but also from the point of view of the long-distance railway service. Even individual trains, occupying tracks of six double-track lines leaving Warsaw agglomeration, would cause enormous operational disturbances. That would take place in the case of constructing and using suburban tracks crossing outgoing long-distance and suburban existing tracks at the same level using switches and crossings. Therefore, creating Warsaw railway ring is possible only if a dedicated railway viaduct for two tracks will be available.

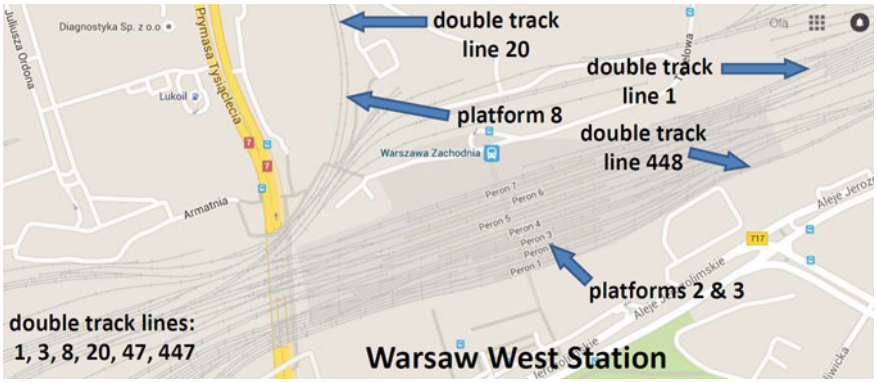

Fig. 6 Warsaw West station (south-west corner of the proposed railway ring) (author's own elaboration)

Fig. 7 Railway viaduct along Gdańsk airport at the PKM line (photograph by article's author)

Construction of a long railway viaduct has just took place in Gdansk for sub-urban railway service between Gdansk and Gdynia [4]. Just constructed railway line no 248 (Pomeranian Metropolitan Railway Line (PKM)) with 800-m-long double-track railway viaduct (see Fig. 7) along Gdansk Airport eases judgment of the construction challenges including time, cost and technical difficulty.

Sample technical solutions solving quoted difficulties shown above in Fig. 7 are non-ballasted tracks equipped with guard rails and rail adjustment switches. Guard rails are placed parallel to regular running rails for keeping the wheels of rolling

stock in alignment in case of derailment to minimize damage to the structure in case of restrictive clearance. Rail adjustment switches ensure the compensation of the rail length required due to temperature changes [5].

Control Command—Increasing Capacity While Keeping Safety

Railway viaduct at Warsaw West station will ensure closing Warsaw railway ring using tracks dedicated to suburban railway services. However, public transport minimizes congestion if it ensures regular, fast, frequent, punctual and comfortable connections between usual destinations. The following question is therefore whether closing ring allows the introduction of such service without reduction of the suburban services already in use.

Presently, daily, over five hundred trains are using two tracks dedicated for suburban trains between stations Warsaw West and Warsaw East. That makes 5 min 45 sec average headway between trains running in the same direction. Adding six Warsaw railway ring trains per hour increases traffic by half (nearly 50%). This means that signalling system must be capable to ensure safety for trains running with two and a half minute headway. That requires implementation of the communication-based traffic control system.

Many European railways are using that kind of systems supporting drivers by cab signalling and automatic braking intervention when necessary. That kind of system was not in use in Poland up to December 2014. Now, such system is used for high-speed trains on a section of the Central Trunk Line allowing trains to run 200 km/h. Introduced system is defined by publicly owned European specifications of the European Train Control System (ETCS) [6].

ETCS level 2 configuration, shown in Fig. 8, can be used to ensure safety for trains running with so small headways. Tracks have to be equipped with spot transmission devices sending data used for distance measurement (Eurobalises in case of ETCS), and trackside area control system (Radio Block Centre in case of ETCS) interconnected with interlocking on one side and with wireless communication system (GSM-Rail in case of ETCS) on the other. Traction units have to be equipped with spot transmission receivers (Eurobalises antennas in case of ETCS), wireless communication (GSM-Rail) and on-board processing unit (European Vital Computer in case of ETCS) interconnected additionally with distance measurement system (odometer) and braking system of the train and with cab signalling (Euro-cab).

Such trackside configuration is installed and commissioned on the PKM railway line dedicated for suburban railway services [4]. It is not in use yet, as on-board equipment installed in multiple units used on this line is not commissioned at the moment (see Fig. 9).

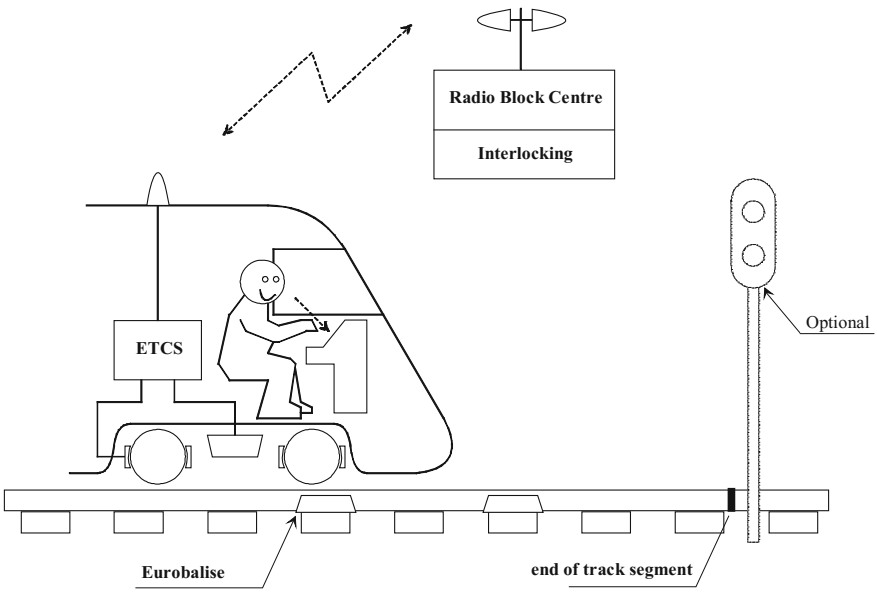

Fig. 8 European train control system level 2 equipment. *Source* ETCS system requirements specification 2.3.0

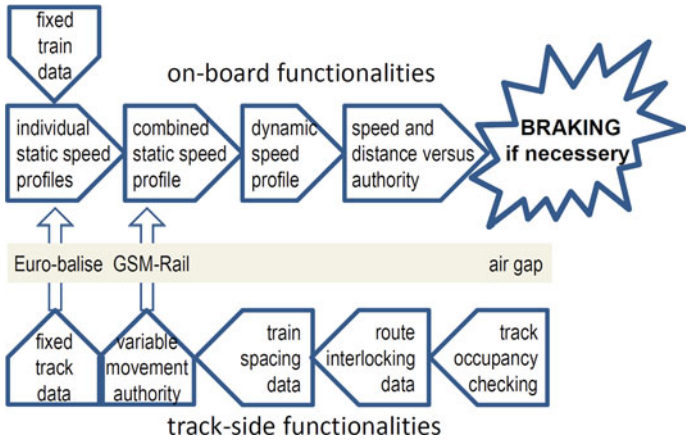

Fig. 9 European train control system level 2 functionalities (block diagram based on ETCS system requirements specification 2.3.0)

Track is subdivided into sections. Each section can be allocated for a train only if it is not occupied by another train. Sets of sections are used for setting routes at stations and defining train spacing on sections between stations. Tracks along stopping points are treated as a part of section between stations. Movement

authority, which is defining maximum distance and maximum speed the train is allowed to run, is sent via wireless data connection. Fixed track data, e.g. track geometry, are sent via spot transmission devices, which are used also as reference points. Train data entered before journey by train driver together with received data are used to define several applicable speed profiles named 'static' as they do not take into account train running dynamics. Static speed profiles are stepwise speed restrictions in relation to distance. The most restrictive combined static speed profile is calculated and used as a basis for calculating exact points where automatic braking intervention must be imposed. Dynamic envelope is used to ensure respecting speed and distance limits. If for any reason driver drives a train in a way that does not ensure respecting limits, on-board equipment intervenes and slows down the train and stops the train if necessary.

Safety During Construction Phase

Constructing railway viaduct requires special care when works are conducted near and over tracks on which trains are running. Appropriate set of rules have to be elaborated, accepted and applied. Such sets of rules are always used, when construction works take place on railway properties. Operational rules define the ways used to protect construction sites. Obviously, work safety regulations are also applicable.

Implementing ETCS is more challenging.

Traction units have to be removed from operation for ETCS on-board equipment installation. On-board equipment commissioning can take place only on equipped track. Such tracks, which can be used without introducing any traffic disturbances, exist in Poland. This is a railway test ring located halfway between Poznan and Wroclaw, which is being equipped with ETCS just now.

Trackside equipment directly mounted on tracks comprises Eurobalises and GSM-Rail antennas. Special care is required during the installation of the so-called distributed antennas in tunnels. Such technical solution using concentric cable has to be used in railway tunnel from Warsaw Ochota via Warsaw Downtown (Śródmieście) to Warsaw Powiśle station. Set of rules, conceptually similar to those applicable in case of viaduct construction, have to be elaborated, accepted and applied. Trackside equipment commissioning requires using traction units already equipped with positively verified ETCS equipment. Such traction units already exist in Poland.

Introducing additional trains, on a busy railway line no 448, requires equipping with ETCS also trains, which are presently serving suburban traffic using this line. Shortening train headways is possible only between equipped trains. Mixed traffic with equipped and unequipped trains will not ensure capacity for new service based on Warsaw railway ring.

As railway lines in question are managed by Polish Railway Lines S.A. and transport service is provided now by two companies and may be provided on the ring by another one, detailed planning and restrictive execution will be critical.

Cost Assessment and Financing Possibilities

As already stated, construction of the totally new double-track metro line took 5 years and one and a half billion euro for 6 km and seven stations equipped with signalling, communication-based train control and communication systems, which makes 25 million euro per 1 km.

Construction of the already mentioned totally new double-track PKM railway line took two and a half year and 250 million euro per 17 km and eight stations equipped with signalling, communication-based train control (ETCS level 2) and communication systems, which makes 15 million euro per 1 km.

Direct cost comparison cannot be used for simple decisions but allows easy general comparison as the influence on public transport can be seen as generally comparable.

Warsaw railway ring (WRR) cost can be estimated on the basis of the values of the assets of the Pomeranian Metropolitan Railway Line (PKM). Respective comparison using PKM asset values made available by PKM Ltd is shown in Table 1.

Construction of the Warsaw railway ring formed by existing double-track railway lines (no 9, 20, 448, 501) will probably take around two and a half year and 125 million euro per renewal of the 20 km of lines, construction of five new stations and renewal of three existing ones and equipping that infrastructure with signalling, communication-based train control (ETCS level 2), and communication systems, which makes six and a quarter million euro per 1 km.

Two and a half year is assumed to be required for the construction of the Warsaw railway ring similarly to two and a half year used for construction of the PKM line. This is because on one side construction of the PKM line took place in an area where there was no railway traffic, but on the other side scope of works to be done for Warsaw railway ring is significantly smaller. This two and a half years of construction cannot start immediately as they have to be preceded by half year for the preparation of the feasibility study procurement, one year for feasibility study including the preparation of the design and construction procurement, half year for design and construction procurement and half year for design.

Summary of cost and time:

- Warsaw metro—250,000,000 euro per 1 km, 5 years for preparatory works for 6-km metro line and 5 years for construction works;
- PKM line—15,000,000 euro per 1 km, 2.5 years for preparatory works for 17-km railway line and 2.5 years for construction works;

Table 1 Estimation of the value of the assets required for WRR based on the PKM asset values

	Value of the main assets (million euro)	
	PKM line	WRR ring
Track substructure and superstructure PKM → construction of 30 km of ballasted track WRR → renewal of 40 km of ballasted track	60.00	12.00
Civil engineering structures with ballast-less track PKM → 800 m estacada and two 200-m viaducts WRR → 500-m viaduct	50.00	22.00
Railway stations (stopping points) with associated infrastructure PKM → construction of 8 new stopping points WRR → construction of 5 new stopping points and renewal of 3 existing stopping points	12.00	10.00
Control centre (building and its infrastructure) PKM → local control centre serving 17-km line WRR → local control centre serving 20-km line	4.00	4.00
Control command, signalling and communication PKM → interlocking, ETCS l2, GSM-R (17 km) WRR → interlocking, ETCS l2, GSM-R (20 km)	10.00	13.00
Bus stops and pavements with sheds and lighting	4.00	4.00
Telematic systems at stations PKM → passenger info (voice and visual), security monitoring (video and access), etc. WRR → passenger info (voice and visual), ticketing, security monitoring (video and access), etc.	4.00	6.00
Noise barriers (WRR may require more barriers)	1.00	2.00
SUM	145.00	73.00

Author's own elaboration

– Warsaw railway ring—6,250,000 euro per 1 km, 2.5 years for preparatory works for 20-km railway ring and 2.5 years for construction works.

Financing for the construction of the further sections of the second metro line in Warsaw is not ensured. Improving the public transport is required. The 125,000,000 euro required for Warsaw railway ring is much more probable.

European support for the implementation of the ETCS (European Train Control System) makes 80% European cofinancing of eligible costs highly probable. The 25,000,000 euro of the required Polish cofinancing which will be distributed into five years should be affordable. Decision, however, has to be taken on political level in cooperation with European Commission.

Summary

Warsaw railway ring idea can only be implemented if some basic requirements are fulfilled. First of all, a relatively long viaduct has to be constructed to close railway ring formed by railway lines nos 9, 20, 448 and 501. The place where viaduct must be constructed is marked in a left bottom part of the map shown in Fig. 10.

Secondly, whole ring has to be equipped with centralized signalling, communication-based train control (namely ETCS level 2) and communication systems. If all trains running on the ring, including of course these trains which are running between Warsaw West and Warsaw East stations on suburban tracks, will be equipped, smaller headways between trains will be possible. Smaller headways will increase the capacity by 50% and allow the introduction of additional frequent and regular (e.g. every 10 min) connections along Warsaw railway ring.

Thirdly, limited amount of stopping points along the ring have to be enhanced by constructing five additional stopping points binding road-based public transport serving big outbound streets with new railway transport service. That will create railway ring with fifteen stops (railway stations and stopping points), out of which three are directly interconnected with metro stations (marked with red points on the map shown in Fig. 10).

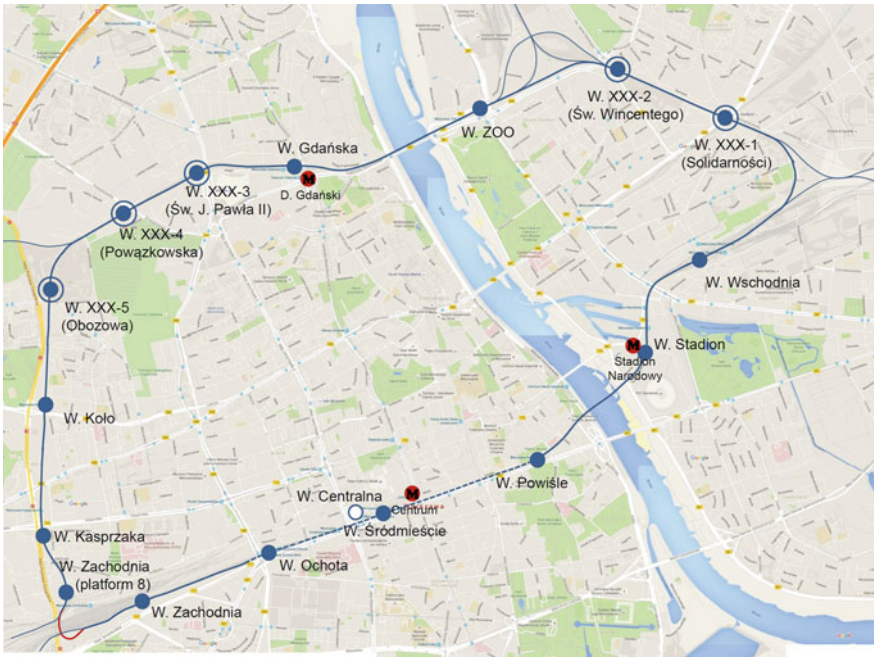

Fig. 10 Warsaw railway city ring proposal (author's own elaboration)

Last but not least, all stops have to be prepared for easy interconnections between road-based public transport and rail-based public transport. Infrastructure shall be constructed taking into account adaptation for people with reduced mobility. Construction possibility and necessity of park and ride infrastructure at new road–rail transport nodes have to be analysed.

Large-scale, economically feasible and safe rearrangement of the Warsaw rail transport is possible. In case of implementation, it will significantly improve the Warsaw public transport system. The proposed rearrangement does not exclude the construction of foreseen additional sections of the second Warsaw metro line.

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