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DOI: 10.35117/A_ENG_23_06_07_08_02

Traffic organization and transport forecast for the proposed Otwock – Karczew railway line

Abstract: The article concerns the concept of building a new railway line between Otwock and Karczew. Proposed variants of the railway line are presented and the organization of railway traffic for each variant presented in the concept is proposed. It is assumed that the existing route of Fast Urban Railway line would be extended or a new circle line would be launched. Transport forecasts were developed using the Polish Integrated Traffic Model. Results indicate that the proposed line has a large transport potential, and in the most developed variant, it would open up new travel opportunities around the Warsaw agglomeration.

Keywords: Railway Transport;traffic ; Karczew

Introduction

Karczew is one of the four cities in the Warsaw metropolitan area (alongside Konstancin-Jeziorna, Łomianki, and Marki) that lacks direct access to the railway network. The concept of a new railway line connecting Otwock with Karczew, as a means to integrate the second of these cities into the railway network, was presented in an article in issue 1/2023 of the "Przegląd Komunikacyjny" [1]. The article outlined the main functional assumptions for the new line and preliminary routing in three variants. Implementing this concept would represent an important step toward enhancing the role of suburban rail in passenger transport within the capital's agglomeration and would align with the strategy of the national infrastructure manager – PKP Polskie Linie Kolejowe S.A. [2]. Most importantly, it would significantly improve the transport accessibility of Karczew, which is situated peripherally relative to the main communication routes. In this article, which can be considered a continuation of previous discussions [1], the results of analyses concerning the proposed organization of train traffic and the anticipated passenger volumes on the proposed new segment of the railway network are presented. This includes a discussion of traffic forecasts developed using the Integrated Traffic Model.

Considered Variants of the Railway Line

In the railway line construction concept for Karczew presented in January 2023 [1], three variants are considered, each with sub-variants differing in the number of tracks (single-track or double-track line). The characteristics of the variants, which are the subject of the analysis, are provided in Tab. **1.**

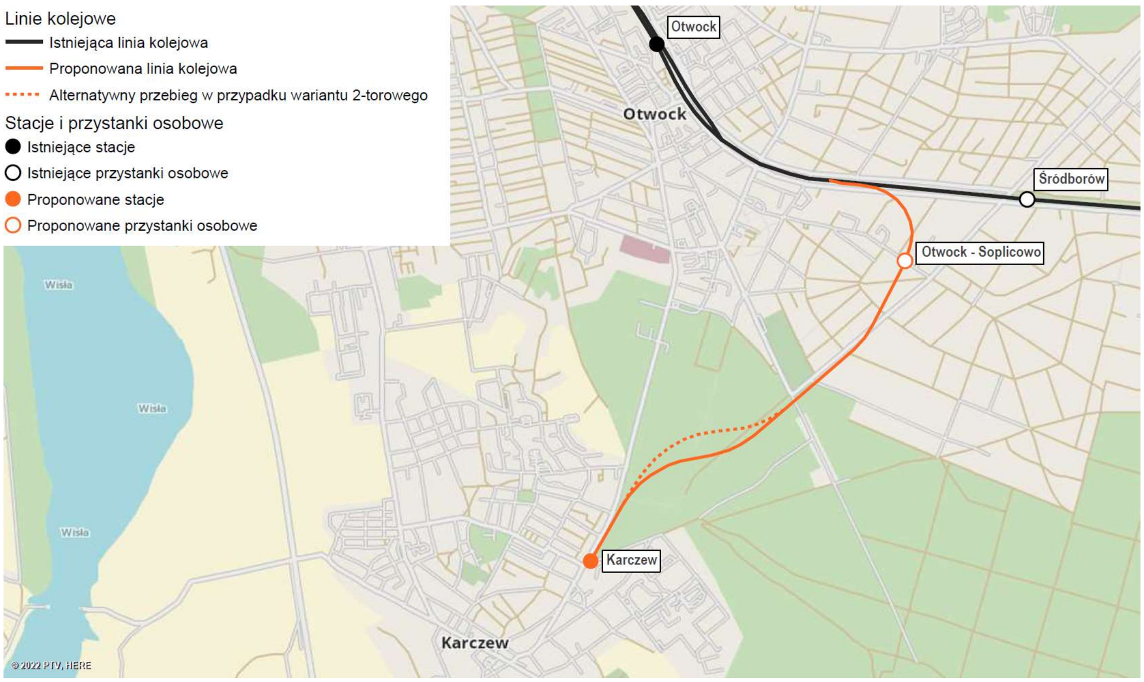
Tab. 1. Characteristics of the railway variants to Karczew

Feature/Variant	**W1A / W1A+**	**W1B+**	**W2**
Line length	approx. 4,7 km	approx. 4,8 km	approx. 6,4 km
Number of tracks	1 (W1A) or 2 (W1A+)	2	2
New stations and stops	Otwock Soplicowo, Karczew	Otwock Soplicowo, Otwock-Ługi, Karczew	Otwock Soplicowo, Karczew-Ługi, Karczew
Maximum speed	80 km/h	80 km/h	120 km/h

Possibility of extending the line	NO	NO	YES

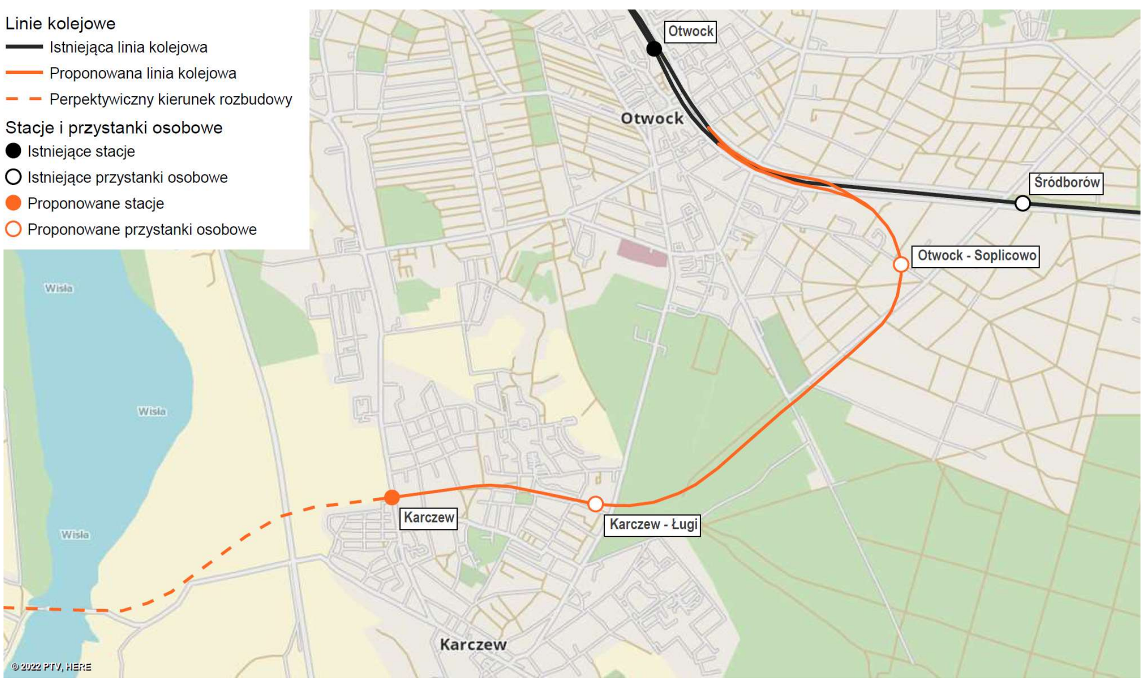
Source: Own study based on [1]

Variants W1A (W1A+) and W1B+ are characterized by a "dead-end" termination of the line in Karczew, whereas variant W2 allows for its extension, via a new bridge over the Vistula River, towards the west. All variants can be implemented without significant technical or terrain obstacles. The route of the line in each variant is presented in the diagrams (Fig. **1**, **2**, and **3**). Detailed aspects related to the routing of the line were described in the previous article [1].



1. Diagram of the proposed railway line to Karczew in variant W1A (single-track line) and W1A+ (double-track line); Source: [1]

2. Diagram of the proposed railway line to Karczew in the W1B+ variant (double-track line); Source: [1]



3. Diagram of the proposed railway line to Karczew in variant W2 (double-track line); Source: [1]

Methodology

For each of the analyzed railway line variants, assumptions regarding the organization of rail traffic along with a model timetable were developed. These assumptions were then incorporated into the Integrated Traffic Model along with other necessary modifications (as described later in the article). The next steps involved performing calculations and developing results. For comparative purposes, calculations were also carried out for the so-called baseline variant, which represents the situation where there is no new railway line.

Integrated Traffic Model

To develop passenger transport forecasts for each variant, the Integrated Traffic Model (hereafter: ITM) developed by the Center for European Transport Projects (CETP) was used. The primary objective of developing the ITM is to support ministries and other institutions in the planning process and in making investment decisions related to transport [4]. The license for the model granted by CETP allows its use for non-commercial purposes, thus providing support to research institutions in carrying out their statutory activities.

The ITM is a classical four-stage travel model, encompassing the stages of trip generation, trip distribution, mode split, and network assignment. The four stages of the model, which effectively constitute a demand model, are defined based on the supply model, which consists of: the transport infrastructure network model (road, rail, water, and air), the transport regions layer, and the public transport network model (communication lines of all public transport modes with timetables). The model was developed using PTV VISUM software version 18. In the further part of the article, based on a 231-page technical report [4] and the model file, the basic features of the ITM are characterized.

Representation of Transport Infrastructure in the ITM

In the model, all roadways from motorways to county roads were represented as network segments. In special cases, segments of municipal and city roads were mapped. In selected cities, the street network was detailed further. The parametrization of road segments was done considering: road category, technical parameters of the road, and technical class of the road (in the case of urban areas). This resulted in a division into 7 main types of segments, within which 57 subtypes of segments were defined (differentiated by road cross-section, maximum speed, and capacity). For each main type, a separate segment resistance function was determined. Additionally, 5 types of intersections were defined (differentiated by location in built-up areas or the presence of traffic signals) and 12 types of turning movements (differentiated by travel time and capacity). Bus stops were defined on segments representing roadways, but aggregated at the locality level. An exception was made for cities, where a higher level of detail was adopted.

For the railway network, 8 types of segments were defined. The classification considered the following criteria: track width, electrification, and type of voltage. A separate type was designated for the WKD and PKM suburban lines. The main parameters for railway network segments are the maximum train operating speed, the length of the segment, and the railway line number.

4. Illustration of the transport infrastructure mapped in ZMR; Source: own study based on [5]

Mapping of Communication Regions in the ITM

Communication regions are understood as the averaged points of origin and destination of trips by model travelers [4]. Since the model encompasses the entire country, the authors decided to divide the communication regions at a level of detail corresponding to municipalities. A total of 2,875 communication regions [5] were modeled, corresponding to individual municipalities (or districts for larger cities with at least 170,000 inhabitants), as well as airports, seaports, inland ports, and intermodal terminals. The pool of communication regions also includes so-called external regions corresponding to areas outside the territory of Poland, allowing the model to account for international traffic. It should be noted that the largest set of regions corresponds to municipalities (districts), diversified sufficiently to distinguish 13 types of regions. Individual regions were connected to the transport infrastructure network using connectors (9 types were defined).

Mapping of Communication Lines in the ITM

Based on the transport infrastructure network encoded in the model, the routes of communication lines were defined. According to the report [4], "for rail transport, the train routes were accurately mapped along the existing railway network, maintaining the travel times between individual stops as per the timetables." The model includes connections from all carriers in the e-podróżnik database (556 carriers). Due to the method of mapping stops and the very large size of the database, the encoding of bus connections was simplified. Nevertheless, the model contains approximately 27,000 bus stops. Urban public transport was also encoded in a simplified manner using the so-called auxiliary transport mode (type PuT-AUX). Based on actual ticket prices, several types of fare tariffs were defined and subsequently assigned to individual communication lines.

Demand Model in the ITM

The demand model in the ITM is a classical four-stage model. A detailed description of the model's assumptions is provided in the CUPT report [4], while this article presents only its basic assumptions in an illustrative manner.

Trips described by the model were analyzed considering the following characteristics: trip motivation, age group, access to a car, type of municipality of residence, and functional type of municipality of residence. Based on motivation, trips were defined as obligatory and non-obligatory, significantly differing in terms of frequency and the decision criteria used by travelers. Obligatory trips include home–work, home–school, and home–university (and vice versa), while non-obligatory trips include home–other, home–business, business unrelated to home, and other trips unrelated to home. The adopted division of trip motivations can be considered typical. Additionally, trips were analyzed separately for three age groups: pre-working age, working age, and post-working age. The combination of age and place of residence characteristics resulted in 39 traveler groups, to which different mobility coefficients were assigned based on collected data, depending on motivation, creating 208 demand segments. Certain travel segments were not considered by assumption and were assigned a mobility of 0 (e.g., business trips of individuals in the pre-working age or school trips of retirees). The explanatory variables adopted in the model are: population size, average household size, number of workplaces, number of school pupils, number of students, number of overnight accommodations, utilization of overnight accommodations, and motorization rate. The mode split was modeled discretely using a polynomial logit model. The adopted model divides trips into: car trips, public transport trips, and walking trips. This model is based on a suitably defined generalized cost function for transport and selected calibration constants. For individual transport, the generalized cost function takes into account: travel time and the value of this time, road tolls, vehicle operating costs, travel distance, and average vehicle occupancy. For public transport, the generalized cost function considers: travel time, time spent departing and arriving, waiting time, transfer time, penalty for transfers, and fare. The unit of the generalized cost is the minute—the monetary variables are converted into time by dividing them by the value of time.

The final stage of the demand model, namely the assignment of trips to the transport network, was implemented as follows: for car transport, the "Equilibrium Assignment Bi-conjugate Frank-Wolfe" procedure was used, while for public transport, a "headway-based assignment" was applied, based on service frequency. Detailed parameters for these procedures are presented in the technical report on the ITM [4].

Forecast Development – Adjusting the ITM

Developing passenger transport forecasts for the proposed Otwock–Karczew railway line required adjusting the ITM. It was decided to use the baseline model for the year 2019 for calculations, and all conclusions would be drawn on the basis of "what the interest in the new railway line would be if it suddenly appeared." Therefore, passenger forecasts were not developed in the sense of predicting the future but as a study of the hypothetical reaction of the transport system to the introduced modifications, as if the new railway line had appeared "overnight" in 2019.

Due to the lack of data that could be used to further detail the model, the original demand model from the ITM was left entirely unchanged. This approach is justified by the fact that the developed forecast is preliminary, and any decisions about the implementation and design of the investment would still require detailed analyses, for example, within the framework of a feasibility study. No changes were also made to the layout of the communication regions and the explanatory variables. From the perspective of passenger forecasts for this line, a division of Karczew into 2-3 regions and Otwock into 3-5 regions would be desirable. However, there is a lack of easily accessible data necessary to describe the divided regions with appropriate values of the explanatory variables.

Supply-side modifications to the model include:

- Adding and parameterizing new railway network segments, corresponding to the individual variants of the proposed investment,
- Adding railway stops (on new segments),
- Adding missing and modifying existing connectors (connecting new railway stations/stops),
- Modifying the layout of communication lines and train timetables (to reflect the base or assumed train traffic organization in each variant),
- Comprehensive correction of bus line networks operating in the Otwock County area.

As previously stated, the mapping of the bus network in the ITM is simplified due to the scale of the model, which had a specific effect in the case of Otwock. All bus lines that actually pass through the periphery of Otwock (the so-called Lublin Highway and the S17 road) and do not play any role in serving the city functioned in the model as services serving Otwock on par with the railway or local buses, which play a real role in serving the region. Therefore, all these lines had to be rerouted, along with the removal of the stop in Otwock. Due to the cancellation of many bus connections in 2020–2021, the model was also verified in this regard (primarily by removing the frequently running private bus line Karczew–Otwock–Warsaw corresponding to the discontinued MiniBus company line). Connections launched in 2022 were also added (primarily county lines D1, O1, and K2 connecting Otwock and Karczew with neighboring municipalities, as well as bus line L51 Karczew–Otwock).

In addition to the aforementioned modifications to the bus network, the timetable for regional trains on the Dęblin–Otwock–Warsaw section was updated. The defined timetable for long-distance trains was left unchanged.

Baseline and Variants Adopted for Analysis

The baseline scenario adopted for the analyses considered a demand model consistent with the ITM model for the year 2019, while the supply model (in terms of lines running through the Otwock County area) was consistent with the year 2022. Based on this, models were created for the individual investment variants (W1A, W1A+, W1B+, W2 – Stage 1, W2), in accordance with the assumptions presented in the next paragraph. Using the same demand model for all variants (including the baseline) ensures the comparability of the obtained results.

Assumed Organization of Rail Traffic

One type of data encoded in the ITM is the timetable of public transport vehicles. Therefore, for each variant, it was necessary to assume what the predicted organization of rail traffic on the new railway line segment would look like and how it would affect traffic on the existing railway network.

In principle, it was assumed that the launch of services on the railway line to Karczew would interfere as minimally as possible with the existing rail traffic on railway line No. 7 and No. 448 (the suburban circumferential line), partly due to the exhausted capacity of the latter.

Therefore, as much as possible, an extension of the services terminating in Otwock is anticipated.

For the single-track sub-variant W1A, it is assumed to extend SKM S1 line trains to Karczew. For the double-track sub-variant W1A+, it was additionally assumed to extend selected regional trains (Mazovian Railways) to Karczew, while slightly increasing the number of trains on the Otwock–Warsaw segment, without changing the service offer on the Otwock–Dęblin segment.

For variant W2, the analysis was conducted for two investment stages. The first stage assumed terminating the line at Karczew station, while the ultimate goal is to create a connection with Konstancin-Jeziorna and Warsaw crossing the Vistula River via a new bridge. In the first case, the service offer analogous to variants W1A+ and W1B+ was assumed, i.e., extending the SKM S1 line to Karczew and extending from Otwock or launching additional Mazovian Railways trains. In the second case, it was proposed to launch a circular SKM S0 line running in both directions on the route: Konstancin-Jeziorna – Karczew – Otwock – Józefów – Warsaw – Piaseczno Północ – Konstancin-Jeziorna (and simultaneously shortening the S1 line from Pruszków to Warsaw East station). Since the calculated travel time for the entire "ring" was 1 hour and 46 minutes, to maintain a 30-minute frequency of the line, an extended stop (14 minutes) was assumed in Konstancin-Jeziorna. The placement of the stop in this location does not extend the travel time to Warsaw from either Karczew (via Otwock) or Konstancin and maintains the possibility of direct trips in any direction between points on the circular SKM line route. The schematic of the S0 line is shown in Fig. **5.**

The assumed number of connections and train travel times are presented in Tab. **2** and **3**.

Tab. 2. Estimated number of train pairs on the Karczew – Warszawa Wsch. section [train pairs/day]]

Section/ Variant	**W0**	**W1A**	**W1A+**	**W1B+**	**W2 – Etap I**	**W2**
Warszawa Wsch. – Otwock	79	79	82	82	82	82
Otwock – Karczew	0	39	51	51	51	51

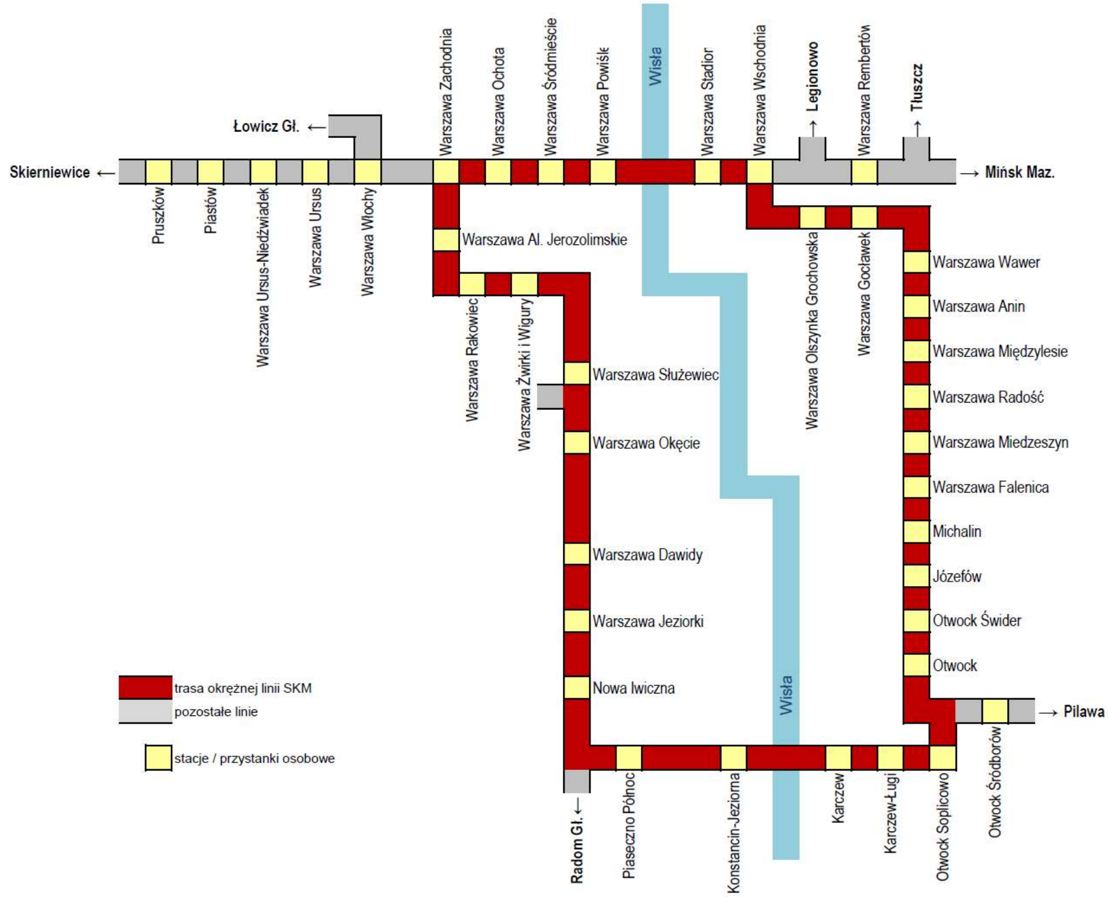
Source: own study

Tab. 3. Estimated train travel time on the Karczew - Warszawa Wsch. section [min]

Section / Variant	**W0**	**W1A**	**W1A+**	**W1B+**	**W2 – Etap I**	**W2**
Warszawa Wsch. – Otwock	33	33	33	33	33	33
Otwock – Karczew	n.d.	6	6	6 - 8	6,5-9	6,5-9

Source: own study

Train travel time (which is one of the input data in the forecasting model) for existing segments of the railway network was adopted in accordance with the 2021/2022 train timetable. For new segments, travel time was calculated using a simplified method described in [3]. Differences in travel times from Otwock to Karczew between the individual variants result from the alignment of the line and the locations of passenger stops/stations.



5. Schematic diagram of the proposed SKM S0 circular line in variant W2;
Source: own study

Forecast Results

The results of the calculations performed in the Integrated Traffic Model (ITM) are presented in the subsequent tables. The most significant output data selected are:

- **Public transport travel time** (including transfers) from Karczew to downtown Warsaw (Tab. **4**);
- **Perceived public transport travel time** from Karczew to downtown Warsaw (Tab. **5**);
- **Daily passenger flows** on selected sections of the railway line (Tab. **6**);
- **Daily passenger flows** on selected travel routes, carried out by individual and public transport (Tab. **7**);
- **Number of railway passengers** in Karczew and Otwock (Tab. **8**).

Tab. 4. Travel time by public transport from Karczew to Warsaw (city centre)) [min]

Section / Variant	**W0**	**W1A**	**W1A+**	**W1B+**	**W2 – Etap I**	**W2**
Karczew – Warszawa (center)	67	56	56	56,5	55,5	55,5

Source: own study based on the results obtained in ZMR

Tab. 5. Perceived travel time from Karczew to Warsaw (city centre) [min]

Section / Variant	W0	W1A	W1A+	W1B+	W2 – Etap I	W2
Karczew – Warszawa (centrum)	117	73	72	72,5	72,5	72,5

Source: own study based on the results obtained in ZMR

Train travel time (Tab. **4**) is the time that includes both the travel time by transport means and the time spent on transfers. Perceived travel time (Tab. **5**) takes into account additional factors such as the timetable (frequency of service) and the associated waiting time, as well as the time required for boarding and alighting.

Based on the obtained results, it can be concluded that the longest travel time from Karczew to Warsaw occurs in the absence of a railway line (variant W0). The initiation of railway services, even in the least developed variant (W1A), results in a radical reduction of perceived travel time (by 38%) and a decrease in actual travel time by 16%. Differences in subsequent variants are minimal:

- **Variant W1A+**: There is a slight reduction in perceived travel time compared to variant W1A, despite having the same actual travel time. This improvement is due to increased frequency of connections.
- **Variant W1B+**: This variant results in a slight increase in both actual travel time and perceived travel time compared to variant W1A+. The increase is caused by an additional commercial stop of the train.
- **Variant W2**: Due to a different line alignment and its parameters, the train travel time is slightly reduced. However, the perceived travel time remains unchanged because of the different locations of stops and stations, which results in an increased length of the line.
-

Tab. 6. Daily passenger flow on selected sections of the railway line [passenger/day]]

Cross section (both directions)	W0	W1A	W1A+	W1B+	W2 – Etap I	W2
Konstancin Jez. – Karczew	n.d.	n.d	n.d	n.d	n.d	1 064
Karczew – Otwock Soplicowo	1 047*	1 968	1 985	1 990	1 986	2 692
Otwock Świder – Józefów	12 244	13 100	13 124	13 147	13 157	12 977
* a stream of buses on the section between Otwock and Karczew						

Source: own study

Tab. 7. Daily passenger flow on selected travel routes [pass./day]

Trip Direction (Outbound/Inbound)	W0	W1A	W1A+	W1B+	W2 – Etap I	W2
Karczew – Warszawa (car)	5 231	4 935	4 918	4 922	4 902	4 671
Karczew – Warszawa (publ. tr.)	651	1 400	1 409	1 411	1 409	1 362
Karczew – Warszawa (total)	**5 882**	**6 335**	**6 327**	**6 333**	**6 311**	**6 033**
Karczew – Otwock (car)	644	556	556	557	551	536
Karczew – Otwock (publ. tr.)	167	187	188	188	186	177
Karczew – Otwock (total))	**811**	**743**	**744**	**745**	**737**	**713**

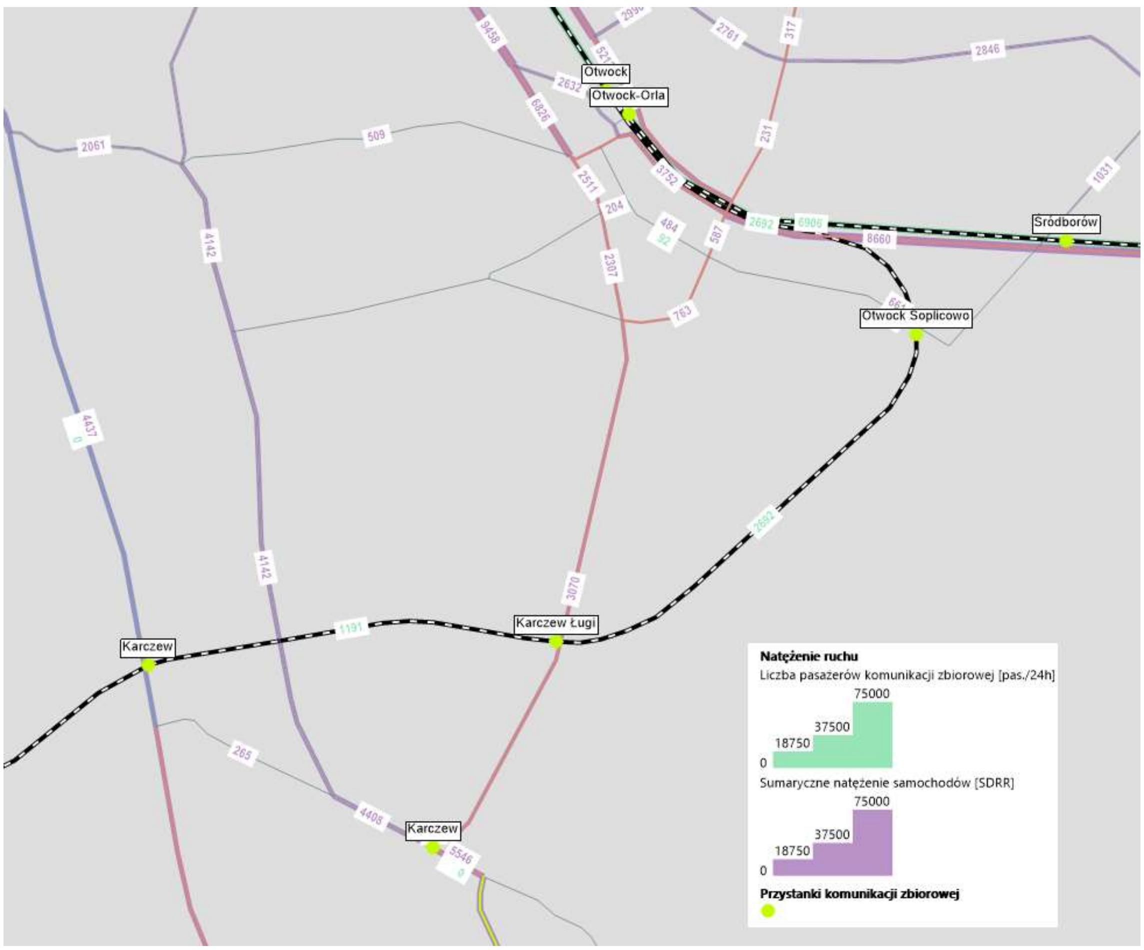
Source: own study

Tab. 8. Number of railway passengers [passengers/day]]

Communication area	**W0**	**W1A**	**W1A+**	**W1B+**	**W2 – Etap I**	**W2**
Karczew city	0	1 968	1 985	1 990	1 986	2 032
Otwock city	7 134	6 706	6 752	6 760	6 780	7 453
Karczew + Otwock cities	**7 134**	**8 674**	**8 737**	**8 750**	**8 766**	**9 485**

Source: own study

The daily passenger flow on the section between Otwock and Karczew is just under 2,000 people in all variants except variant W2 (Tab. **6**). The lack of significant differences in the results is due to the model being a national model, making it difficult to reflect effects arising from differences within a single municipality. The obtained results show that launching additional regional connections (variants W1A+, W1B+, and W2 – Stage 1) that reinforce the existing 30-minute frequency SKM line (variant W1A) brings virtually no effect in terms of passenger flow size. In variant W2, the passenger flow is significantly larger, amounting to nearly 2,700 people per day (Tab. **6**). As an example of a graphical presentation of the forecast results, Fig. **6** shows a cartogram of passenger flows for variant W2.



6. Distribution of Passenger Flows on the Transport Network for Variant W2 Source: Own elaboration based on results obtained in the ITM model

Since in variant W2 the passenger flow exiting Otwock towards Warsaw slightly decreases, it should be assumed that part of the trips from this city are directed towards Konstancin-Jeziorna or Piaseczno. This is evidenced by the increased number of passengers using rail transport in the city of Otwock in variant W2 (Tab. **8**).

Regarding passenger exchanges within the cities of Karczew and Otwock (Table 8), it can be stated that the highest number of passengers uses rail transport in Otwock in variant W0. This is due to the fact that passengers from Karczew reach the train by bus, and thus physically appear on the railway network only in Otwock. In each of the investment variants, the total number of people using the railways in Otwock and Karczew is higher compared to the baseline variant W0. This difference ranges from 16% to 33% (the highest in variant W2).

The initiation of rail services in Karczew (so far only in the model) results in more than a twofold increase in the number of people using public transport on the Karczew–Warsaw route and approximately a 10% increase in the number of trips on the Karczew–Otwock route. In variant W2, the number of trips on these routes is lower than in variants W1A, W1A+, and W1B+, as trips to Konstancin-Jeziorna and Piaseczno are carried out instead (some of them interchangeably instead of trips to Warsaw).

Summary

The anticipated passenger traffic volume is one of the criteria that should be taken into account when selecting a variant or determining the feasibility of a particular investment. The passenger transport forecasts developed and presented in this article should be considered preliminary, as they were performed using the national ITM model and thus do not fully account for local trips (in practice, trips that occur within municipalities are not modeled at all, and it can be assumed that the new line would increase railway usage, for example, in trips within Otwock itself). The obtained results indicate a high potential for the railway line to Karczew. In each of the investment variants, compared to the baseline variant, the number of people using rail transport, as well as public transport in general, increases, while the number of people using private cars decreases. Additionally, the new railway line significantly shortens the travel time from Karczew to Otwock, and such a trip can be made without a transfer. Variant W2 appears promising, as it would eliminate the negative impact of the natural geographical barrier posed by the Vistula River, opening up new opportunities for residents of both Karczew and Otwock to engage in activities and efficiently travel towards Konstancin-Jeziorna and Piaseczno (as well as the southern districts of Warsaw). By launching the proposed circular Fast Urban Railway (Szybka Kolej Miejska) line, direct train trips between several cities in the capital's agglomeration (Józefów, Karczew, Konstancin-Jeziorna, Otwock, Piaseczno, Warsaw) would be possible, including some that would not require unnecessary travel through the center of Warsaw or transfers, as is currently the case.

Source materials

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