Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2019, 59 (131), 43–52
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/351

Received: *24.05.2019*
Accepted: *12.09.2019*
Published: *30.09.2019*

Elimination of modal collision: railway bridge over the Regalica River

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Key words: elimination, collision, railway bridge, inland navigation, transport, systems

Abstract

This study aims to identify and quantify the economic benefits of eliminating collisions between two transport systems: rail and inland waterway transport. The collision between transport systems is caused here by the obsolete structure of a railway drawbridge, which constitutes an element of the railway line used by freight and passenger transport and is located on the main inland waterway used by inland waterways freight transport. Railway transport results in limitations of inland waterway transport and, vice versa, inland waterways transport blocks railway transport during lifting of the bridge span. In the case of railway transport, the low capacity of the single-track railway bridge constitutes an additional limitation of the development of transportation. There are plans to eliminate the collision in the regional transport system by constructing a new railway bridge in place of the old drawbridge. The effects of the transportation infrastructure improvement were measured directly for both rail and inland water freight systems as well as the result of the interaction between passenger rail and car and bus transport. In order to compare the different types of impact, the effects of different actions were valued in monetary terms. The planned intervention, as investigated here, will lead to reductions in the cost of time of inland waterways freight transport and costs of time of rail passenger and freight transport and a decrease in the external costs of transport. This will make possible transportation services that are both cheaper and more reliable.

Introduction

In the West Pomeranian region (north-west Poland) there is an obstacle in the transport system, in the form of a railway drawbridge. The drawbridge is located on the Regalica River at Eastern Odra, the main waterway for the inland waterway vessels and the inland waterway freight transport that is concentrated on the Polish-German border. This location also includes the section of railway line 273, which is part of the TEN-T comprehensive network and the international combined transport line C-E 59 (AGTC). This railway line is used for transport of freight to and from the hinterland of ports and sea terminals of the region as well as for regional passenger rail transport. The section of railway line 273 also forms part of the connections under the fast, metropolitan railway currently under construction to ensure efficient public rail communication for commuters in agglomeration transport.

The location of the railway drawbridge and inland waterways and railway connections in the West Pomeranian region is shown in Figure 1.

The low vertical clearance (2.96 m) of the fixed span of the railway drawbridge on the Regalica River excludes the possibility of waterway transport moving underneath it. To ensure the passage of barges under the bridge, it is necessary to lift the drawbridge span. This lifting operation is labour-intensive and time-consuming. The width of the navigable route under the drawbridge is only 12.73 m, but the required width of the navigable route is

Figure 1. Location of the railway drawbridge in the regional transport system

50.0 m. The frequency of opening the drawbridge span for inland waterway transport is low at five or six times a day, each time for 20 minutes, due to the trains running on the bridge.

Rail transport on railway line 273 through the railway drawbridge and inland waterway transport on the Regalica River under the bridge limit each other because of the outdated construction of the drawbridge and the insufficient technical parameters of the navigable bridge span. The movement of trains must be stopped for the duration of the opening of the drawbridge span to allow the movement of inland waterway vessels under the bridge. Conversely, the movement of barges under the bridge is stopped while the bridge span is lowered to enable railway transport. Railway transports result in the limitation of inland waterway transport and, vice versa, inland waterways transport blocks railway transport during the lifting of the bridge span. In the case of railway transport, the low capacity of the single-track railway bridge constitutes an additional limitation of the development of transport.

There are plans to eliminate the collision in the regional transport system by constructing, in place of the old drawbridge, a new bridge with a vertical clearance of 6.20 m and a 50.0 m wide navigable span, equipped with two rail tracks with an admissible axle load of 221 KN.

This investment project concerns the removal of the bottleneck in two transport systems, inland navigation and rail transport. The planned intervention in the regional transport system will ensure free inland navigation under the bridge and increase the capacity of the section of the railway line on which the railway bridge is located.

Methodology

Intervention in the transport sector either concerns capacity improvements of the multi-modal nodes or relates to the network by adding new links or enhancing the capacity of the existing links. Either way, these interventions make it possible to offer transportation services that are cheaper, more reliable, or both (Lakshmanan & Anderson, 2002). In the inland waterways sector, infrastructure is rarely improved and, as far as we know, no studies related to the microeconomic assessment of this type of infrastructure investment have been published. In inland transport, as a rule, there are reserves in the capacity of waterways that can be used to support increased freight. Few cases relate to restoration of the navigability of the inland waterway links in the regional network (Bernacki & Lis, 2019b). More often, intervention is focused on improving the capacity of infrastructure facilities, in the form of locks, bridges over the waterway, or barge service areas in seaports. In these cases, limited capacity leads to queues of barges and ships waiting to raise the bridge with too low clearance for free navigation, and service in locks or seaports (Van der Horst, de Langen, 2008; Bernacki, 2013). The few studies on the inland transport sector in terms of estimating the marginal costs related to infrastructure use, congestion, accidents and noise, and environmental effects presented the pilot cost accounts for selected sections of the Western European inland waterways system (ECORYS, 2005; IMPRINT-NET, 2008; Bernacki, 2011).

It is assumed that the structure of the feasible direct (determined for the transport system) effect changes depending on the type of intervention in the inland transport sector, whether it is aimed at improving the integrity and capacity of the transport network or the capacity of nodal infrastructure facilities. In the first case, the benefits associated with the reduction of operating costs of inland waterway operators prevail, as confirmed by Bernacki & Lis (2019b). There are savings in the time of inland freight transportation, and in turn, improving the capacity of inland infrastructure node facilities should primarily lead to savings in transport time, and to a lesser extent to lower operating costs for transport operators.

The aim of this study is to identify and quantify the economics benefits of enhancing the capacity of the bi-modal rail and inland waterway transport node, the railway bridge crossing the waterway. The research results will be subject to comparative analysis with the economic effects of improving the capacity of the inland waterways link in the regional network.

The economic analysis was carried out using the cost-benefit analysis (CBA) method, i.e. the method of quantifying direct economic benefits and benefits, including external transport costs. The analysis was carried out using the differential method, by calculating the net difference in transport effects and the socio-economic effects that appear in the variants with the construction of the new railway bridge (the investment variant of WI, below) and without the construction of the railway bridge (the non-investment variant of W0, below), i.e. in the differential formula WI–W0. The conditions for satisfying the demand for inland waterway transport and for rail passenger and freight transport in the variant without a new bridge and in the variant with the new bridge were compared, and then the differences in transport time, transport performance and the operation of means of transport were quantified. When the difference in the economic account WI–W0 has a negative value, it is interpreted as an advantage related to the reduction (savings) in transport performance resulting from the implementation of the investment project.

Forecast of demand for the capacity of the railway bridge

The forecast of demand for the results of the investment project, i.e. for the capacity of the railway bridge on the Regalica River, was developed at follows:

- Forecasts of demand for transhipments in the port of Szczecin, developed according to the assumptions included in the feasibility study prepared for assessing the investment project related to the modernization of the Świnoujście–Szczecin fairway to the depth of 12.5 m (Feasibility study, 2017).
- Forecasts of demand for rail transport used for the assessment of the investment project related to the creation of the Szczecin Metropolitan Railway (Feasibility study, 2016).
- Forecasts of demand for inland waterway transport services on the Odra Waterway in connection with the provision of conditions of the class III waterway (Malczyce–Widuchowa section) (Kotowska, Mańkowska & Pluciński, 2017). The forecast demand for cargo transport by inland navigation will arise in connection with the commissioning of the shipping sluice on the water stage in Malczyce; however, it was conservatively assumed that the forecast volumes of freight transport by inland waterway will remain unchanged until 2030 and only after 2030 will reach the target forecast volume.
- Forecasts of demand for inland waterway transport services developed for the seaports of Świnoujście, Police and sea terminals located in the region (Bernacki & Lis, 2019a).

The forecast number of inland waterway vessels moving in the Regalica railway bridge direction was determined with the following assumptions:

- The dead-weight of a pushed train of barges (push-boat + 2 × pushed barge of 500 tons each) is 1000 ton, and the dead-weight of a motor barge is 650 ton.
- The share of motor barges and the pushed trains of barges (push-boat + 2 × pushed barge) in the total movement of barges amounts is 30% and 70%, respectively.

The total forecast demand for freight transport by inland waterways navigation is shown in Table 1.

Table 1. Complete forecast of demand for inland waterway transport in the Regalica railway bridge direction (tons, pcs/year)

Year	Mass of cargo transported under the railway bridge (tons)	Number of inland waterway vessels passing under the railway bridge
2023	3 768 777	4675
2025	3 905 570	4950
2030	4 257 038	5225
2035	5 386 657	6600
2040	5 736 091	7150
2045	6 048 776	7425
2049	6 303 155	7700

For the 12-hour daily budget of navigation time assumed for inland waterway vessels, the rate of using the capacity of the waterway on the analysed section in the investment variant will amount to 66.6%.

Complete forecast of demand for transport by rail on the section of railway line 273

The demand for rail transport services was estimated in relation to the investment project consisting in the establishment of a passenger agglomeration system (Feasibility study, 2016). The research results made it possible to forecast the number of passenger trains (regional and agglomeration trains) and the number of commuters, as well as the number of freight trains on railway line 273.

For railway line 273, the movement of passenger trains was forecast for the Szczecin Główny–Gryfino section and the movement of freight trains was forecast for the Szczecin Port Centralny SPA–Podjuchy railway station section. It is important that in both cases passenger trains and freight trains pass through the railway bridge over the Regalica River, located along the line.

Analysis of the capacity of the railway bridge with one track proves that after the commencement of agglomeration transport in 2023 there will be restrictions on the movement of passenger trains, and from 2026 there will be restrictions on the movement of freight trains. This shows that it is necessary to equip the new railway bridge with two rail tracks to support the forecasted railway traffic. The capacity used of railway line 273 in the investment variant will amount to 54.6%.

Table 2 presents a forecast of the annual passenger and freight train traffic on railway line 273.

Forecasts of passenger transport for the Szczecin Główny–Gryfino section (passenger agglomeration transport within the framework of the Szczecin Metropolitan Railway) and the volume of transport of cargo on the Szczecin Port Centralny SPA–Podjuchy railway station section were prepared. These used the elaborated average daily forecast of passengers carried on the Szczecin Główny–Gryfino section (Feasibility study, 2016) and the weighted average

Table 2. Forecast of train traffic on railway line 273 sections Gryfino–Szczecin Główny (passenger trains) and Szczecin Port Centralny SPA–Podjuchy railway station (freight trains, pcs/year) (Feasibility study, 2016)

Year	Trains in total	Passenger trains	Freight trains	Passenger trains WI–W0	Freight trains WI–W0
2023	19 440	15 120	4 320	3240	0
2025	19 440	15 120	4 320	3240	0
2030	20 520	15 120	5 400	3240	1080
2035	20 520	15 120	5 400	3240	1080
2040	21 240	15 120	6 120	3240	1800
2045	21 240	15 120	6 120	3240	1800
2049	21 240	15 120	6 120	3240	1800

Table 3. Forecast of the volume of passenger transport on the Szczecin Główny–Gryfino section of railway line 273

Year	Number of passengers		
	W0	WI	WI–W0
2023	905 143	1 152 000	246 857
2025	888 171	1 130 400	242 229
2030	927 771	1 180 800	253 029
2035	933 429	1 188 000	254 571
2040	939 086	1 195 200	256 114
2045	893 829	1 137 600	243 771
2049	887 040	1 128 960	241 920

Table 4. Forecast of the volume of freight transport on the Szczecin Port Centralny SPA–Podjuchy railway station section of railway line 273

Year	Freight transport (tons)		
	W0	WI	WI–W0
2023	3 103 920	3 103 920	0
2025	3 103 920	3 103 920	0
2030	3 103 920	3 879 900	775 980
2035	3 103 920	3 879 900	775 980
2040	3 103 920	4 397 220	1 293 300
2045	3 103 920	4 397 220	1 293 300
2049	3 103 920	4 397 220	1 293 300

weight of loads per freight train, assuming that during the forecast period the average freight load per freight train will amount to 718.5 tons and will not change.

Analysis of the socio-economic benefits of the project

The economic benefits identified in direct connection with the implementation of the investment project are as follows:

- time savings for inland waterways freight transport, resulting from reductions in the time of waiting to navigate under the railway bridge;
- time savings for rail freight transport and reduced environmental externalities, resulting from shortening the distance of rail transport;
- savings in passenger travel time related to the use of high-speed metropolitan railways;
- reduced environmental externalities related to the limitation of car use by individual passengers and bus transport in favour of the agglomeration rail transport.

The structure of the feasible microeconomics effects of the intervention is shown in Figure 2.

The equation of total socio-economic benefits related to the construction of a new railway bridge can be presented as the sum of individual savings obtained jointly over the lifetime of the investment project:

$$TB = \sum_{i=1}^{k}\sum_{t=1}^{n} TB_{it} = \sum_{t=1}^{n} CT_t(IW) + \sum_{t=1}^{n} CT_t(R) + \\ + \sum_{t=1}^{n} \text{Ext } T_t(R) + \sum_{t=1}^{n} CT_t(PaxR) + \sum_{t=1}^{n} \text{Ext } R_t(PaxM) \tag{1}$$

where:

$$\sum_{t=1}^{n} CT_t(IW) = \sum_{t=1}^{n} L_t(IW)\cdot E_t \cdot c_t(IW) \tag{2}$$

$$\sum_{t=1}^{n} CT_t(R) = \sum_{t=1}^{n} L_t(R)\cdot \Delta T(R)\cdot c_t(R) \tag{3}$$

$$\sum_{t=1}^{n} \text{Ext } T_t(R) = \sum_{t=1}^{n} L_t(R)\cdot \Delta D\cdot c_t(A) + \\ + \sum_{t=1}^{n} L_t(R)\cdot \Delta D\cdot c_t(AP) + \sum_{t=1}^{n} L_t(R)\cdot \Delta D\cdot c_t(CC) + \\ + \sum_{t=1}^{n} L_t(R)\cdot \Delta D\cdot c_t(N) = \\ = \sum_{t=1}^{n} L_t(R)\cdot \Delta D\cdot \left[c_t(A) + c_t(AP) + c_t(CC) + c_t(N)\right] \tag{4}$$

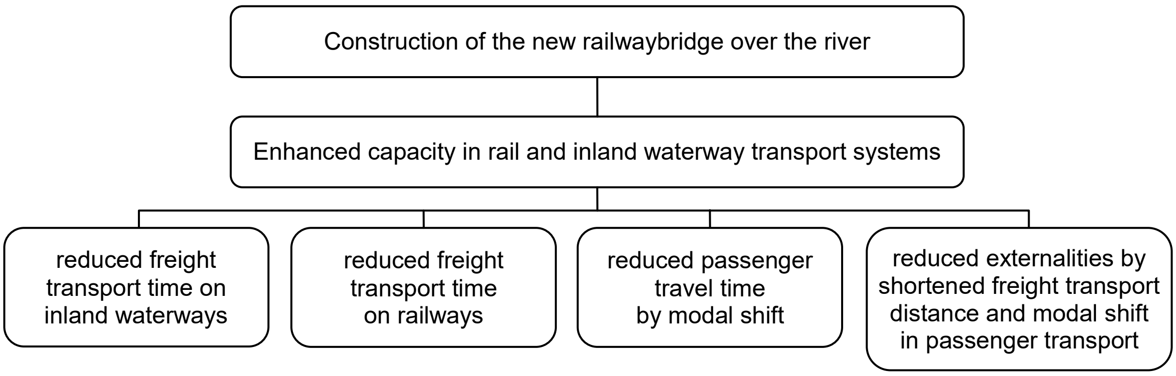

Figure 2. Feasible effects of construction of a new railway bridge over the inland waterway

$$\sum_{t=1}^{n} CT_t(PaxR) = \sum_{i=1}^{2}\sum_{t=1}^{n} Pax_t \cdot u_i \cdot \Delta T_i \cdot c_{it} \tag{5}$$

$$\sum_{t=1}^{n} \text{Ext } R_t(PaxM) = \sum_{j=1}^{3}\sum_{t=1}^{n} Pax_t \cdot u_j \cdot D_j \cdot$$
$$\cdot\left[c_{jt}(A) + c_{jt}(AP) + c_{jt}(CC) + c_{jt}(N) + c_{jt}(CG)\right] \tag{6}$$

where:

TB – total socio-economic benefits of the project;

TB_{it} – i-th socio-economic benefit received in the t year of project exploitation;

$CT_t(IW)$ – savings in the costs of time of freight transport by inland waterway in t-th year;

$CT_t(R)$ – savings in the costs of transporting freight by rail in t-th year;

Ext$T_t(R)$ – savings in external costs caused by shortening the distance of rail transport in the t-th year;

$CT_t(PaxR)$ – savings in passenger travel time costs associated with the use of high-speed metropolitan railways in the t-th year;

Ext$R_t(PaxM)$ – savings in external costs related to the reduction of individual passenger and bus transport use by rail passengers in favour of agglomeration rail transport in the t-th year;

$L_t(IW)$ – forecasted volume of freight carried by inland waterway transport under the railway drawbridge in tonnes in t-th year;

E_t – total waiting time of barges under the railway drawbridge in t-th year in ton-hours;

$c_t(IW)$ – the cost of a ton-hour in carriage of cargo in inland navigation in t-th year;

$L_t(R)$ – forecasted volume of freight in rail transport through the Szczecin Dąbie railway station in tons in t-th year;

$\Delta T(R)$ – increase in the time of freight transport by railway in the W0 variant through the Szczecin Dąbie railway station in hours;

$c_t(R)$ – the cost of a ton-hour in freight transport by rail in t-th year;

ΔD – increase of distance of freight transport by rail in the W0 variant through Szczecin Dąbie railway station in km;

$c_t(A)$ – unit cost of accidents in freight rail transport per 1 tkm;

$c_t(AP)$ – unit cost of pollution of the lower atmosphere layers in rail freight transport per 1 tkm;

$c_t(CC)$ – unit cost of climate change in freight rail transport per 1 tkm;

$c_t(N)$ – unit noise cost in freight rail transport per 1 tkm;

Pax_t – forecasted number of passengers transported by rail on the Szczecin Główny–Gryfino section in persons;

u_i – share of the i-th alternative mode of transport in passenger transport;

$\Delta T(A)$ – increase of passenger travel time on an alternative means of transport (A – bus);

$u(A)$ – share in passenger transport of an alternative means of transport (A – bus);

c_{it} – unit cost of passenger travel time on i-th means of transport per 1 pkm in t-th year;

$\Delta T(V)$ – increase of passenger travel time on an alternative means of transport (V – passenger car);

$u(V)$ – share in passenger transport of an alternative means of transport (V – passenger car);

Pax_{jt} – number of passengers served by the j-th means of transport in t-th year;

u_j – share of the j-th means of transport in passenger transport for the purpose of determining external costs;

D_j – passenger travel distance on j-th means of transport in km;

$c_{jt}(A)$ – unit costs of accidents in passenger transport caused by the j-th mode of transport per 1 pkm in t-th year;

$c_{jt}(AP)$ – unit costs of pollution of the lower atmosphere in passenger transport caused by the j-th mode of transport per 1 pkm in t-th year;

$c_{jt}(CC)$ – unit costs of climate change in passenger transport caused by the j-th mode of transport per 1 pkm in t-th year;

$c_{jt}(N)$ – unit noise costs in passenger transport caused by the j-th mode of transport per 1 pkm in t-th year;

$c_{jt}(CG)$ – unit costs of congestion in passenger transport caused by the j-th mode of transport per 1 pkm in t-th year.

Reduction of inland waterway vessels' time of waiting for the possibility of navigating under the railway bridge

In the non-investment variant, the navigation of inland waterway vessels is possible at the raised span of the railway drawbridge. The span is raised six times over a 12-hour navigation period each day.

In the investment variant, the construction of a railway bridge will allow for unrestricted inland navigation under the bridge. In the variant WI–W0, the time budget expressed in barge-hours and in ton-hours was determined for the whole period of the analysis and is related to the waiting time of barges for navigation under the railway bridge. On the basis of the inland waterway transport forecast, the average daily number of barges passing under the drawbridge was established. These values changed from 17 to maximum of 28 in different forecast periods. At a maximum 28 barges, six barges await passage under the drawbridge from the previous day and pass one by one in six consecutive bridge opening cycles, without limiting the possibility of four barges passing on the run in a single bridge opening cycle.

This means that in the variant without a new bridge, the forecast number of barges will pass under the bridge, but this will be at the cost of an ever-extending queuing time for the barges.

To determine the economic benefits resulting from reducing the waiting time of barges for passing under the railway drawbridge and unit time values for inland freight transport in Poland, average values for lock-in time were used and indexed for the period of the analysis (Cost-Benefit Analysis, 2016). In 2018, the value of time (VOT) in freight inland navigation was 0.45 PLN/ton-hour. The unit time values in freight inland navigation applied in the study were originally estimated in the Netherlands with application of stated preferences and willingness to pay (De Jong et al., 2014). It includes both the time cost of transport (carrier component of VOT) and time costs related to cargo (shipper component of VOT).

Savings in the costs of freight rail transport time and decreasing external costs caused by shorter transport distances

In the non-investment variant, the forecast train traffic on the section of railway line 273 is limited by the capacity of the drawbridge equipped with one rail track.

Conversely, in the investment variant, the increased capacity of the railway bridge equipped with two rail tracks will enable unrestricted movement of trains on the Szczecin Port Centralny SPA–Podjuchy railway station section. Freight trains, in the W0 variant (i.e. with the existing limitations in the capacity of the railway drawbridge) on the Szczecin Port Centralny–Podjuchy railway station section will be directed via railway line 251, bypassing the railway drawbridge on the Regalica River. Freight trains will be directed from Szczecin Port Centralny SPA station to Szczecin Dąbie station using another railway bridge, and then will be shunted to Podjuchy railway station, from where they will be able to continue their further transit to the south of the country on railway line 273.

Using a detour in railway traffic will increase the transit time per freight train from Szczecin Port Centralny SPA to Podjuchy railway station from 8 minutes in WI to 43 minutes in W0 (travel time will increase by 35 minutes for WI–W0) and will increase the distance from 1,634 km in WI to 14 km in W0 (transit distance will increase by 12,366 km for WI–W0).

To determine the economic benefits associated with the implementation of the investment project, average values of unit costs of time in rail transport in Poland indexed for the period of the analysis were used (Cost-Benefit Analysis, 2016). In 2018, the value of time (VOT) in freight rail transport amounted to 2.75 PLN/ton-hour. VOT for rail freight transport gives quoted time costs in freight transport from a perspective of railway carriers (Niebieska Księga, 2015).

In the case of savings in external costs (costs of accidents, costs of pollution of the lower atmosphere layers, costs of climate change, costs of noise), the calculations were based on the values of appropriate external cost categories for rail transport in Poland per 1000 tkm, indexed for the period of the analysis. In 2018, the value of external costs in freight rail transport per 1000 ton-km were as follows: cost of railway accidents 0.56 PLN; costs of pollution of lower atmosphere layers 3.06 PLN; cost related to climate change (greenhouse effect related to CO_2 emissions) 1.34 PLN; and cost of noise in rail transport 2.78 PLN. For external costs of freight railway transport, the unit cost indicators were adopted from the update study of external transport costs in Europe (ECT, 2011).

Economic benefits resulting from the savings of commuting time of passengers using agglomeration rail services

The 21.498 km Szczecin Główny–Gryfino section of railway line 273 is part of the Szczecin Metropolitan Railway and is intended for servicing rail agglomeration transportations. The travel time of passengers by a high-speed train on the Szczecin Główny–Gryfino section will be 23 minutes. In the non-investment variant, the forecast transit of passenger trains and size of passenger transport on the Szczecin Główny–Gryfino section will be limited by the capacity of the railway bridge. Conversely, in the investment variant, the increased capacity of the railway bridge will enable an unrestricted agglomeration rail transport on the Szczecin Główny–Gryfino route.

It is assumed that out of the total number of passengers that will not be transported on agglomeration railway transport (WI–W0), half will choose individual transport (passenger car), while the remaining half will use buses.

Travel times by passenger car and by bus on the route Szczecin Główny–Gryfino are 36 minutes and 48 minutes, respectively. The extensions of the travel time by car and by bus between Szczecin Główny and Gryfino in relation to the time of agglomeration rail transport (set at 23 minutes) will be 13 minutes and 25 minutes, respectively. The distances covered by a passenger car and by bus on the route Szczecin Główny–Gryfino are 31.5 km and 28.2 km, respectively. In the case of agglomeration rail transport, the distance between Szczecin Główny and Gryfino is 21.498 km. The extension of the distances on the Szczecin Główny–Gryfino route covered by passenger car and by bus in relation to the rail agglomeration transport will amount to 10.0 km and 6.7 km, respectively.

It is assumed that the motivations in passenger travel will be as shown in Table 5 and Table 6.

Table 5. Motivations for travelling by passenger cars in the urban area (Blue Book, 2015)

All categories of roads	Home–work–home	Business	Other
	35%	10%	55%

Table 6. Motivations for travelling by bus in the urban area (Blue Book, 2015)

All categories of roads	Home–work–home	Business	Other
	35%	5%	60%

To determine the economic benefits associated with the reduction of passenger travel time, unit time costs for passenger travel in Poland per passenger-hour were used and indexed for the period of the analysis. In 2018, the costs of time per business trips, home–work–home travel and other trips amounted to 89.50 PLN, 36.30 PLN and 33.71 PLN, respectively, and these were averaged for transport modes and estimated regardless of travel distance. Original VOTs were estimated using a cost-savings approach with adopted gross wage rate (wage plus employee – related overheads) and in line with harmonized European approaches for transport costing and project assessment (HETACO, 2006). The unit costs of passenger travel time were multiplied by the differences between agglomeration rail services travel time and passenger car and bus travel times, respectively, on the Szczecin Główny–Gryfino route.

Savings in external costs related to the development of agglomeration rail services

The economic benefits of this kind arise due to the shorter distance of transporting people on the Szczecin Główny–Gryfino route with the use of agglomeration rail services as compared with individual and bus transports, and through greater use of fast rail connections by commuters. In the latter case, this is due to the shorter travel time by train as compared to by car or bus. For the number of passengers forecast in the WI–W0 differential variant, calculations were made for passenger-kilometres in individual car and bus transport and of passenger-kilometres in railway agglomeration transport. The determined passenger transport performance was multiplied by appropriate external cost indicators for road transport and rail transport, and then indexed for the period of the analysis. External unit costs for passenger transport were adopted from the update study of external transport costs in Europe (ECT, 2011) and assumed for Poland as presented in Table 7.

Table 7. The values of unit external costs in passenger transport in Poland in 2018 (PLN/1000 passenger-kilometres)

Type of external effect	Road transport		Railway transport
	Passenger cars	Buses	
Accidents	92.15	35.09	1.71
Pollution of the lower layers of the atmosphere	15.69	17.12	7.42
Climate change (lower scenario)	21.57	11.50	2.16
Noise	4.85	4.56	3.42
Congestion (costs of delays)	57.80	24.85	0.00

In the last stage of calculations, the difference between individual types of total external costs for cars/buses and rail transport was established.

Results of the research

The total and discounted (at a 5.0% discount) benefits of the investment project are presented in Table 8.

The implementation of the investment project will contribute to the socio-economic benefits to the total

Table 8. Total discounted economic benefits of the investment project (PLN)

Benefits	Discounted total value	% of total benefits
Savings resulting from shortening the waiting time of barges for passing under the railway drawbridge	124 930 156.82	44.2%
Time savings in freight transportation by rail due to shortening transport distances	20 656 763.00	7.3%
Decreasing external costs of freight transport by rail due to shortening the transport distances	1 504 460.93	0.5%
Savings in passenger travel time in rail transport	73 399 155.18	26.0%
Reduction of external transport costs resulting from the development of passenger rail transport	19 732 838.58	7.0%
Residual value	42 587 689.91	15.1%
Total	282 811 064.42	100.0%

value of 282,811,064.42 PLN. This includes savings in the costs of freight transport time by inland waterways amounting to 124,930,156.82 PLN (44.2% of the total economic benefits of the investment project), in the costs of travelling time of rail passengers amounting to 73,399,155.18 PLN (26.0% of the total economic benefits of the investment project), and in the costs of freight transport time by rail of 20,656,763.00 PLN (7.3% of the total socio-economic benefits of the project). Total savings in external transport costs amounted to 21,237,299.51 PLN (7.5% of the total socio-economic benefits of the project).

Conclusions

Table 9 summarizes the results of studies on the economic effects that are expected from the implementation of two investment projects, namely as a result of adding a new link to the local waterways network (Bernacki & Lis, 2019b) and as a result of enhancing capacity of the (bi-modal rail and inland waterways) transport node.

Improving the integrity and capacity of the inland transport network by adding a new link induces considerable savings in the operating costs of inland waterways transport operators. This results from reduced transport distances between origins and destinations and enhanced velocity of inland ships and barges. The time savings in inland freight transportation originates, in this case, from the shorter transport distances. Savings in external costs are very limited because they are only a consequence of shorter transport distances, not a reduction of externalities per se.

When intervention is aimed at enhancing the capacity of node facilities, the main economic benefit is savings in time of transportation. Enhanced capacity of the node reduces congestion and thus make the transport services cheaper and more reliable. While capacity improvements relate to multi-modal node, savings in time multiplicate for another modes and freight or passenger transports. Intervention in multi-modal nodes often results in modal shifts of freight and/or passenger transports, which may lead to substantial savings in externalities. In this project, shifts occurred in passenger transport from road (private and public) to rail, which was the main source of the reduction of external costs.

Finally, it is worthwhile discussing the values of external costs in freight rail and inland waterways. External unit costs for freight transport were adopted from the updated study of external transport costs in Europe (ECT, 2011) and assumed for Poland as presented in Table 10.

Table 10 shows that the unit external costs for freight are higher in inland waterway transport than in rail transport. This is mainly due to the large amount of exhaust gas emitted into the atmosphere by barges and other inland waterway vessels. Therefore, the expected savings in environmental costs that would arise in connection with the shifting of

Table 9. The structure of the direct effects depending on the type of intervention in the inland transport sector (% of total benefits)

Type of intervention	Adding new link to the waterways network (Bernacki & Lis, 2019b)	Enhancing capacity of the (bi-modal rail and inland waterways) transport node
Operating cost-savings in inland navigation	49.8	0.0
Time savings in inland freight transportation	37.1	44.2
Time savings in freight and passenger rail transportation	0.0	33.3
Savings in external transport costs	1.3	7.5

Table 10. The values of unit external costs in freight transport in Poland in 2018 (PLN/1000 ton-kilometres) (ECT, 2011)

Type of external costs	Inland waterways	Railway transport
Accidents	0.00	1.71
Pollution of the lower layers of the atmosphere	15.41	7.42
Climate change (lower scenario)	4.31	2.16
Noise	0.00	3.42
Congestion (costs of delays)	0.00	0.00

cargo from rail to inland waterway transport are questionable.

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