Ekonomiczne Problemy Usług nr 3/2017 (128)

ISSN: 1896-382X | www.wnus.edu.pl/epu
DOI: 10.18276/epu.2017.128-05 | strony: 67–80

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Statistical estimation and prediction of Annual Average Daily Traffic (AADT) on the first/last mile road sections in the Port of Szczecin

JEL codes: O18, Q51, G00

Keywords: annual average daily traffic (AADT), infrastructure development, sea ports

Abstract: Deepening the fairway Świnoujście–Szczecin to a depth of 12.5 m will improve access to the port of Szczecin from the sea. Larger vessels will be able to call at the port of Szczecin and thus the current trends in cargo turnover will probably change. To make it possible, it is also necessary to invest in improving port access from the mainland. In the article the authors present estimates and forecasts of the annual average daily traffic of vehicles (AADT) on national road no. 10 (DK 10) and access roads to the port of Szczecin (so called the "last mile" sections). Estimation was based on the author's own traffic research carried out in September–October 2016 as part of Feasibility Study for the project *Modernization of the access roads to the port of Szczecin: reconstruction of the transport system in the area of Międzyodrze* implemented by the city of Szczecin.

Introduction

The technical depth of Świnoujście–Szczecin fairway to 10.5 m makes cargo transhipment quite limited nowadays. This is why the capital expenditure in the deepening of

the fairway up to 12.5 m is planned by Maritime Office in Szczecin. Therefore Szczecin and Świnoujście Sea Ports Authority decided to customize some selected wharfs to the deeper depth and even built two brand new deep-water wharfs in both general cargo and bulk cargo area in the port of Szczecin. The City Hall of Szczecin planned to carry out the project "Modernization of the access road to the port of Szczecin: reconstruction of the transport system in the area of Międzyodrze", in order to adjust the capacity of roads leading to the port. The project includes modernization of National Road No. 10, construction of the new bridge Kłodny and customizing the access roads to the port, also known as the First/Last Mile Roads, to the increased demand for road, rail and barge cargo transport because of the fairway deepening.

To assess the socio-economic efficiency of the project, the cost–benefits analysis (CBA) was carried out. The core issue of the study was forecasting the vehicles traffic on the roads, which is the primary goal of the authors of this paper. Original research of the vehicles movement on the road sections covered by the project had to be done. The methodology that is normally used by the General Directorate for National Roads and Motorways (see *The Method…*, 2015) has been developed and used in the research.

1. Methodology of the General Traffic Measurement

Using the method consistent with the GTM (General Traffic Measurement) some factors and conditions were taken into consideration, namely:

- the possibility of obtaining all final results that are needed,
- required accuracy of results,
- cost of traffic measurement,
- the degree of risk at a level that enables reliable results even in the case of unusual phenomena at some measurement days,
- direct measurement with the use of statistical forms for so called "last mile" road sections that connect the national road No. 10 with entrance/exit gates of the port of Szczecin,
- the use of high definition video cameras (HD 1080) for direct measurements on the national road No. 10 sections due to very high traffic,
- facilitating the organization of measurements by optimizing the location of measurement points (minimizing the number of measurement points while observing as many sections of the project as possible) – see Figure 1.

Another issue was the scope of vehicles that were taken into account in the study. The traffic structure by type of vehicle includes the following categories of vehicles:

- motorcycles,
- passenger cars,
- commercial vehicles (vans),
- trucks without trailers,
- trucks with trailers,

– buses,
– agricultural tractors, bicycles.

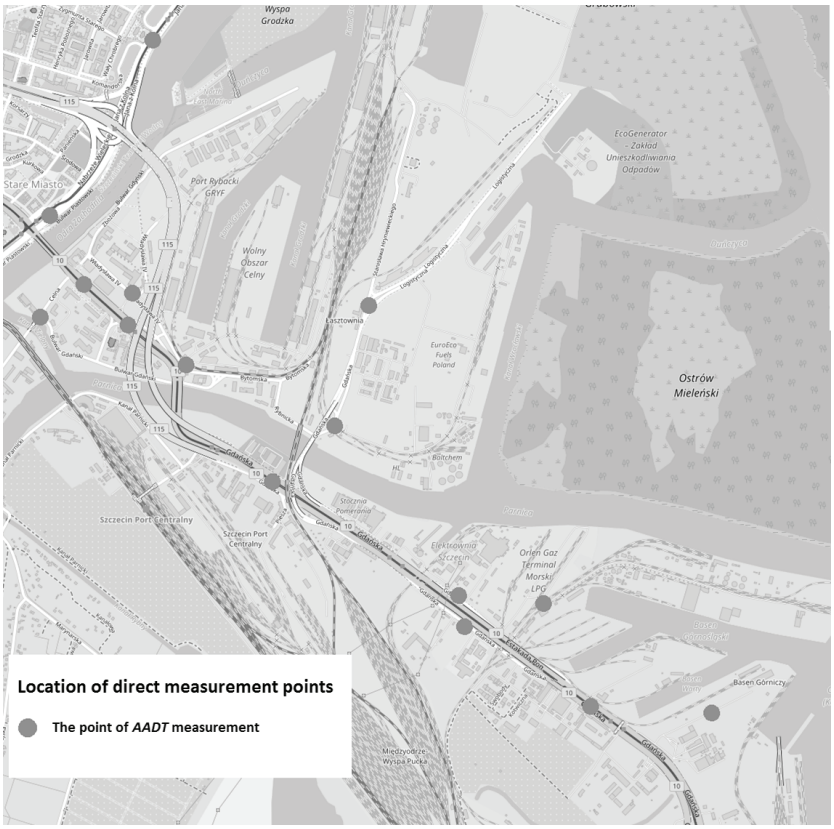

Figure 1. Location of measurement points in the research of Annual Average Daily Traffic (AADT) in the port of Szczecin in 2016

Source: own elaboration based on the OpenStreetMap.

In line with the General Directorate for National Roads and Motorways (GDDKiA) methodology motor vehicles covered by the survey were as follows:[1]

– passenger cars (SO),
– commercial vehicles, vans – (SD),
– trucks without trailers (SC),
– trucks with trailers (SCp),
– buses (A).

[1] Abbreviations come from Polish.

Motorcycles, agricultural tractors, bicycles were intentionally omitted in the survey due to the small importance of such kind of vehicle for socio-economic benefits.

Vehicle categories which can be used alternatively:

– LV – light vehicles, gross weight <3.5 tons,
– HGV – heavy goods vehicles, gross weight >3.5 tons (incl. buses).

Annual Average Daily Traffic (AADT) is a main parameter which is calculated for all road sections in the national road network in the frame of the General Traffic Measurement (GTM). GTM means the number of vehicles that are moving through a given cross-section of the road during next 24 hours on average within one year (measured throughout a year). AADT is a useful and simple measurement of how busy the road is. It shows an average 24-hour-vehicle-movement.

The product of AADT, the number of days in a year and the length of a road, is the transport activity (work) expressed in vehicle-kilometers. This is a measure of traffic flow which is usually taken as a basis for socio-economic benefits generated by the investment projects in road transport. Most of the unit costs are expressed as amount of money per 1 vehicle-kilometer.

The AADT is calculated for all measurement points according to formula:

$$AADT = \frac{M_R \times N_1 + 0.85 \times M_R \times N_2 + M_N \times N_3}{N} + R_N,$$

where:

AADT – Annual Average Daily Traffic of motor vehicles,
M_R – Annual Average Daily Traffic on working days (from Monday till Friday between 6 a.m. and 10 p.m.),
$0.85 \cdot M_R$ – Annual Average Daily Traffic on Saturday and day before holiday (between 6 a.m. and 10 p.m.),
M_N – Annual Average Daily Traffic on Sunday and holiday day,
R_N – Annual Average Traffic in the night (between 10 p.m. and 6 a.m.),
N_1 – the number of working days within a year (in 2016 – 252),
N_2 – the number of Saturdays and days just before holiday (in 2016 – 53),
N_3 – the number of Sundays and holiday days within a year (in 2016 – 61),
N – the total number of days in a year (in 2016 – 366).

Duration of measurement in each period and each check point is exactly the same, which means:

– in "daily" periods – 16 hours between 6 a.m. and 10 p.m.,
– in "night" periods – 8 hours between 10 p.m. and 6 a.m.

The General Directorate for National Roads and Motorways designates study days for entire year beforehand. Selected days are typical for traffic. Such approach allows minimizing an impact of irregularities on final results. In practice, there is impossible to wait

a whole year in order to obtain AADTs for road section of interest. This is why statistical approach was taken into account.

2. Statistical Approach in the Estimation of Annual Average Daily Traffic

The original traffic research for road sections covered by the project was carried out between 5.10.2016 and 16.10.2016, and in particular: traffic measurement on working days was conducted on 5.10.2016 (Wednesday), 6.10.2016 (Thursday), 13.10.2016 (Thursday) and 14.10.2016 (Friday – only during so-called morning peak), measurement of Sunday traffic was made on 9.10.2016 and 16.10.2016, traffic measurement within night was made on 5.10.2016, 6.10.2016 and 16.10.2016. The study lasted 12 days. Days were typical for traffic. Moreover, traffic measurement in any checkpoint and weekday was carried out with the use of statistical estimation of mean value. Day was divided into time intervals such as morning peak, afternoon peak, the interval between peaks and the time after the afternoon peak (evening calm traffic). Statistical observation was carried out for randomly selected hour in each time of day, and then results were extrapolated into next remaining hours. The identification of time intervals was based on the study of time duration for vehicle route from the port of Szczecin to the node of TEN-T core network and inversely from the node of TEN-T core network to the port of Szczecin. The typical route of vehicles with loads to the port and from the port was determined. Ends of route were set at the junction of Logistyczna Street and Hryniewieckiego Street in the port and two nodes: Klucz (A6/S3) and Kołbaskowo. Time of journey was measured by means of GPS devices thanks to logins of GSM users that were driving on selected last mile road sections connected to the TEN-T core network. The study was based on **Google Traffic** application. Observations were done between 15.09.2016 and 21.09.2016. Results were normalized with the zero unitarization method, and then the synthetic (taxonomic) congestion coefficient for arrival and departure to/from the port of Szczecin in the relation with TEN-T core network was calculated.

As final results showed, four time intervals of working day can be separated such as:

- the morning peak: 6:00–9:00,
- time between peaks: 9:00–15:00,
- the afternoon peak: 15:00–18:00,
- evening calm traffic: 18:00–22:00.

Then M_R, M_N, R_N were calculated for each road section covered by the project. In M_R calculation weighted average formula was taken into consideration, where the duration of daytime was the weight, which means for the morning peak – 3 hours, between peaks – 6 hours, the afternoon peak – 3 hours and evening calm traffic – 4 hours.

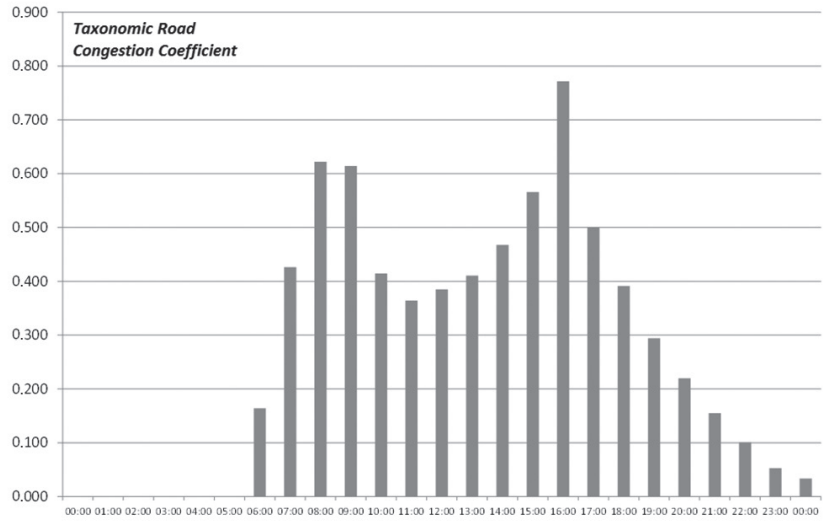

Figure 2. The aggregate congestion function for road transport in double-sided relation: core network – the port of Szczecin (working day)

Source: own research and elaboration.

Road sections in the communication system of Międzyodrze that were covered by the project were divided into three groups according the role they play in the TEN-T transport network. The first part of the table consists with the National Road No. 10 (DK 10) sections that are components of the TEN-T comprehensive network. The second part of the table covers last mile road sections and the third part – new roads and Kłodny Bridge. Instead of AADTs for trucks with trailers or semi-trailers determined on the basis of statistical observation, the traffic intensity of these vehicles was calculated as a function of cargo turnover forecasts for the port of Szczecin in 2022–2042 (see Bernacki, Lis, 2016). This refers to the roads (last mile sections) leading to the entry gates of the port of Szczecin such as: Władysława IV Street, Bytomska/Rybnicka Street, Kujota Street, Hryniewieckiego Street, Logistyczna Street, Górnośląska Street, Gdańska Street, Basenowa Street. These road sections are written in bold text in Table 2.

3. Forecasting the cargo turnover and truck traffic to/from the port of Szczecin

Forecasts of cargo turnover in the port of Szczecin were split into main categories of cargo and the modes of transport. Then following some assumptions were made:

1. Average load per 1 truck + semitrailer for 2 TEU (40' container) is 18.8 tons (mean load calculated from statistical data for the port of Szczecin in 2011–2015).
2. Load weight of dump trucks with bulk cargo is 20 tons.

3. Load weight of dump trucks with cereals is 18 tons.
4. Load weight of trucks with general cargo is 18 tons.
5. Load weight of semitrailer tanker for the transport of fuels Simatra type is 34 tons.
6. Load weight of semi-trailer (three-axis) for the transport of LPG is 25 tons.

Further detailed assumptions for cargo turnover forecasts had been described and explained in *Feasibility Study for Modernization of the access roads to the port of Szczecin: reconstruction of the transport system in the area of Międzyodrze.*

Table 1. Forecasts of truck traffic related with wharfs being under administration of Szczecin and Świnoujście Sea Ports Authority

Years	Forecasts of cargo turnover for the port of Szczecin* (in tons)	Truck traffic on the road sections covered by the project** (the number of trucks)
2016	6,856,699	297,504
2017	6,841,182	296,779
2018	6,827,216	356,852
2019	6,814,581	436,786
2020	6,803,094	516,773
2021	6,792,606	623,646
2022	7,027,075	624,256
2023	7,270,187	624,828
2024	7,522,271	625,358
2025	7,783,671	625,837
2026	8,054,742	626,245
2027	8,335,855	626,574
2028	8,627,399	626,810
2029	8,929,773	626,938
2030	9,243,397	626,950
2031	9,568,706	626,822
2032	9,906,152	629,690
2033	10,256,208	632,710
2034	10,619,364	635,884
2035	10,996,130	639,223
2036	11,387,038	642,734
2037	11,792,640	646,420
2038	12,213,513	650,291
2039	12,650,256	654,357
2040	13,103,491	658,629
2041	13,573,869	663,109
2042	14,062,065	667,814

*It concerns to wharfs being under administration of Szczecin and Świnoujście Sea Ports Authority.
**It concerns traffic being in relation with wharfs being under administration of Szczecin and Świnoujście Sea Ports Authority covered by the project. It includes truck traffic to/from the waste incineration plant and the warehouse-production centre "Waimea Logistics Park Port Morski Szczecin".

Source: Bernacki and Lis (2016).

4. Results of the AADT Estimation

The final results of AADT on road sections of interest (covered by the project) are gathered and presented in Table 2.

Table 2. Annual Average Daily Traffic (AADT) on road sections covered by the project in 2016

No.	Street/road section	The length of road section [km]	AADT					
			passenger cars (SO)	commercial vehicles (SD)	trucks without trailers (SC)	trucks with trailers (SCp)	buses (A)	total
			vehicles per day					
1	2	3	4					
DK 10								
1	Gdańska Street (from Gate 3 to Estakada Pomorska)	0.700	54,396	4,569	1,957	2,835	1,052	**64,809**
2	Estakada Pomorska	0.730	49,738	3,325	1,295	1,709	1,052	**57,118**
3	Gdańska Street (among Estakada Pomorska)	0.730	4,659	1,244	662	1,128	0	**7,693**
4	Gdańska Street (from Estakada Pomorska to Trasa Zamkowa)	0.860	61,665	5,204	1,667	1,385	899	**70,820**
5	Gdańska Street (from Trasa Zamkowa)–Portowy Brigde–Energetyków Street (to Władysława IV Street)	0.645	26,255	3,295	824	799	856	**32,029**
6	Energetyków Street (to Długi Brigde)	0.625	24,502	2,611	1,066	885	928	**29,992**
Roads leading to the port								
7	Celna Street (from Energetyków Street to Gdański Boulevard)	0.195	4,245	840	281	27	99	**5,493**
8	Gdański Boulevard	0.317	2,479	461	79	53	115	**3,188**
9	St. Florian Street (from Energetyków Street to Gdański Boulevard)	0.199	2,969	384	63	144	0	**3,560**
10	St. Florian Street (from Energetyków Street to Władysława IV Street)	0.095	5,187	425	203	295	0	**6,110**
11	Gdański Boulevard /Śląski Boulevard	0.514	5,343	414	125	188	88	**6,158**
12	Władysława IV Street/Zbożowa Street	0.660	3,094	164	63	0	0	**3,321**
13	Wendy Street	0.650	957	59	18	0	0	**1,034**
14	Wieleckie Quey – Długi Brigde	0.444	14,164	1,194	383	267	122	**16,131**
15	Jana z Kolna Street	0.357	26,086	2,436	841	521	63	**29,946**
16	Władysława IV Street	0.330	594	157	105	103	0	**960**

1	2	3	4					
17	Władysława IV Street (from St. Florian Street to Bytomska Street)	0.321	5,294	395	138	269	46	**6,142**
18	Bytomska Street (from Main Gate to Śląski Boulevard)	0.161	5,293	460	157	306	72	**6,288**
19	Bytomska Street (from Śląski Boulevard to Rybnicka Street)	0.242	1,961	227	128	253	78	**2,647**
20	Rybnicka Street	0.366	1,870	293	248	215	78	**2,705**
21	Kujota Street	1.130	334	64	10	9	0	**416**
22	Hryniewieckiego Street	0.620	2,927	525	261	542	90	**4,344**
23	Logistyczna Street	0.355	478	102	73	60	15	**729**
24	Górnośląska Street	1.150	399	132	47	66	0	**644**
25	Basenowa Street	0.409	171	6	37	10	0	**226**

Source: own calculation and elaboration.

5. The AADT forecasting in the reference period for the project

Annual Average Daily Traffic (AADT) on last mile road sections presented in Table 2 was a basis for the prediction of AADTs in the reference period 2022–2042. Forecasts of AADT were stated in the reference period for each road segment separately and were prepared for the following variants: investment variant without tram line on the Kłodny Brigde (WI), investment variant with tram line on the Kłodny Brigde (WIt) and non-investment variant (W0) (Bernacki, Lis, 2016).

The following equation was used in AADT predicting:

$$AADT_{t+1}^{k} = AADT_{t}^{k} \times \left(\frac{GDP_{t+1} - GDP_{t}}{GDP_{t}} \times E^{k}\left(GDP\right) + 1 \right),$$

where:

$AADT_t^k$ – Annual Average Daily Traffic for *k* category of vehicle in year *t*,

GDP_t, GDP_{t+1} – Gross Domestic Product in year *t* and *t* + 1 in constant prices from baseperiod, wherein $(GDP_{t+1} – GDP_t)/GDP$ means a relative increase of GDP in year *t* + 1 compared to the year *t* (dynamics indicator),

$E^k(GDP)$ – elasticity coefficient for k^{th} vehicle category.

Elasticity coefficients and GDP forecasts were adopted from *Blue Book. Road Infrastructure* (*Blue Book. Road…*, 2015, p. 147). In case of forecasts of AADT for buses demographic conditions were in addition taken into account according to the methodology described in *Blue Book. Public Transport Sector in cities, agglomerations and regions* (*Blue Book. Public…*, 2015). Population forecasts in Zachodniopomorskie voivodship in 2014–2050 published by Central Statistical Office (CSO) were used in the research. Statistical chain indices were determined for forecasts of demographic changes and GDP,

and then the geometric mean was calculated as the second root of the product of two indices. Finally, the geometric mean was used as a growth rate of AADTs for buses.

Elasticity coefficients of GDP by vehicle category are presented in Table 3.

Table 3. Elasticity coefficients of GDP by vehicle category

Vehicle category	Elasticity coefficient
Passenger cars	0.80
Commercial vehicles	0.33
Trucks without trailers	0.35
Trucks with trailers	1.00

Source: *Blue Book. Road…* (2015), p. 147.

In the case of the investment variant WI, in order to determine AADTs forecasts for new (non-existing yet) road sections it was necessary to assume what will be the scale of so called "shift effect" from existing stretches of roads to the newly built ones. In determining these assumptions the observation of the distribution of existing traffic on some road sections was carried out, e.g. the splitting of traffic from Gdańska Street to Energetyków Street and Trasa Zamkowa road or the splitting of traffic on the connectors of Trasa Zamkowa road in relations with Jana z Kolna Street and Wieleckie wharf. The detailed assumptions were stated in *Feasibility Study for Modernization of the access roads to the port of Szczecin: reconstruction of the transport system in the area of Międzyodrze* (Bernacki, Lis, 2016).

In order to present differences between current traffic in road sections that are covered by the project and forecasted traffic in 2041 two schemes were selected respectively for 2016 and 2041. In addition, AADTs projections are presented in Table 4.

Table 4. Annual Average Daily Traffic (AADT) on road sections covered by the project in 2041 (*forecasts*)

No.	Street/Road section	The length of road section [km]	AADT					
			passenger cars (SO)	commer-cial vehicles (SD)	trucks without trailers (SC)	trucks with trailers (SCp)	buses (A)	total
			vehicles per day					
1	2	3	4					
DK 10								
1	Gdańska Street (from Gate 3 to Estakada Pomorska)	0.700	88,710	5,714	2,481	5,549	1,397	103,851
2	Estakada Pomorska	0.730	80,726	4,159	1,641	3,345	1,397	91,268

1	2	3	4					
3	Gdańska Street (among Estakada Pomorska)	0.730	3,470	1,555	840	2,208	0	8,072
4	Gdańska Street (from Estakada Pomorska to Trasa Zamkowa)	0.860	101 167	6,508	2,113	2,711	1,194	113,693
5	Gdańska Street (from Trasa Zamkowa)–Portowy Brigde–Energetyków Street (to Władysława IV Street)	0.645	40,482	4,121	1,044	1,563	1,137	48,348
6	Energetyków Street (to Długi Brigde)	0.625	20,996	2,612	1,351	1,732	616	27,307
Roads leading to the port								
7	Celna Street (from Energetyków Street to Gdański Boulevard)	0.195	7,275	1,051	356	54	132	8,867
8	Gdański Boulevard	0.317	4,248	577	101	105	153	5,183
9	St. Florian Street (from Energetyków Street to Gdański Boulevard)	0.199	5,088	480	80	282	0	5,930
10	St. Florian Street (from Energetyków Street to Władysława IV Street)	0.095	8,889	532	258	577	0	10,255
11	Gdański Boulevard/Śląski Boulevard	0.514	9,157	518	158	368	117	10,317
12	Władysława IV Street/Zbożowa Street	0.660	5,302	205	80	0	0	5,587
13	Wendy Street	0.650	1,640	73	23	0	0	1,736
14	Wieleckie Quey – Długi Brigde	0.444	24,275	1,494	486	522	162	26,939
15	Jana z Kolna Street	0.357	44,706	3,046	1,066	1,020	84	49,922
16	Władysława IV Street	0.330	1,018	197	134	101	0	1,449
17	Władysława IV Street (from St. Florian Street to Bytomska Street)	0.321	9,073	494	175	526	61	10,329
18	Bytomska Street (from Main Gate to Śląski Boulevard)	0.161	9,071	575	199	599	95	10,540
19	Bytomska Street (from Śląski Boulevard to Rybnicka Street)	0.242	3,360	284	162	495	104	4,405
20	Rybnicka Street	0.366	3,206	366	315	427	104	4,418
21	Kujota Street	1.130	572	79	12	9	0	673
22	Hryniewieckiego Street	0.620	5,016	656	331	1,077	119	7,199
23	Logistyczna Street	0.355	820	128	92	568	20	1,629
24	Górnośląska Street	1.150	684	165	60	77	0	985
25	Basenowa Street	0.409	294	8	47	7	0	356
New roads or road sections (since 2022)								
26	Kłodny Brigde	0.180	16,482	653	0	0	616	17,751
27	Trasa Zamkowa (new section)	0.440	25,886	1,365	310	308	480	28,350
28	Władysława IV (the brigde connection)	0.220	17,271	653	0	0	616	18,540
29	Spichrzowa	0.166	2,651	102	40	0	0	2,794
30	Zbożowa (new section)	0.105	8,889	532	258	577	0	10,255

Source: own calculation and elaboration.

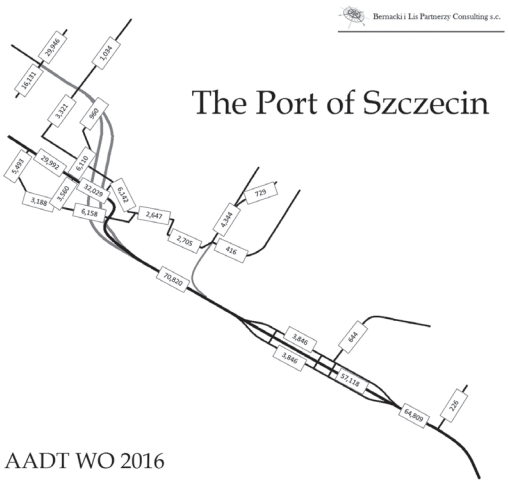

Figure 3. Observed Annual Average Daily Traffic (AADT) in 2016 on DK 10 and last mile road sections leading to the Port of Szczecin

Source: own elaboration based on Bernacki and Lis (2016).

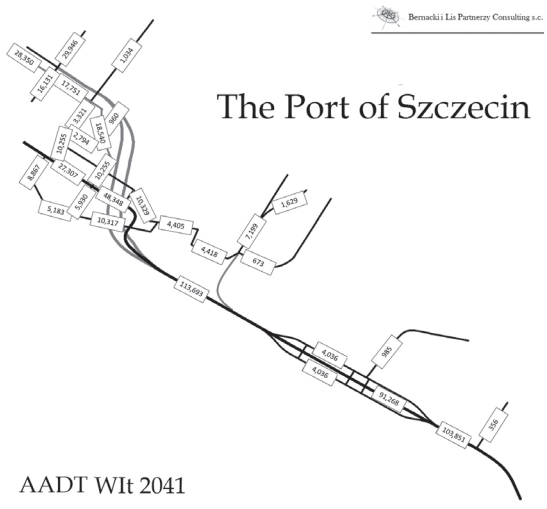

Figure 4. Predicted Annual Average Daily Traffic (AADT) in 2041 on DK 10 and last mile road sections leading to the Port of Szczecin

Source: own elaboration based on Bernacki and Lis (2016).

Conclusion

Two components, namely real traffic observations and cargo turnover forecasts, have been used to determine Annual Average Daily Traffic (AADT) forecasts for last mile roads that lead to the port of Szczecin.

The busiest section of the road leading to the Port of Szczecin according to Annual Average Daily Traffic of vehicles was Gdańska Street (from Estakada Pomorska to Trasa Zamkowa). The AADT amounted in 2016 to 70.8 thous. vehicles per day in total.

It is predicted that by 2041 the AADT on Gdańska Street will be able to amount to 113.7 thous. vehicles per day, which means that the AADT will be growing by 1.9% annually.

The number of trucks on the road sections covered by the project will amount to 297.8 thous. units in 2016 and will by growing to 667.8 thous. units per year, which means that annual growth rate will be 3.3%.

Connections of access roads to the port with national road No. 10 and the Długi Brigde are relevant bottlenecks in the transport system of Międzyodrze (port surroundings). The AADT on the Długi Brigde amounted in 2016 about 30,000 vehicles per day on average. Needless to say, the Długi Bridge has only two lanes in one direction. It is predicted that over the next 25 years AADT on the Długi Brigde will increase up to 50,000 vehicles per day. It is obvious that it will cause severe problems with congestion (traffic jam) and extend the travel time to and from the port. The construction of a new bridge and modernization of the transport system can solve this problem to a large extent.

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ESTYMACJA STATYSTYCZNA I PREDYKCJA ŚREDNIEGO DOBOWEGO RUCHU ROCZNEGO (SDRR) NA ODCINKACH DRÓG PIERWSZEJ/OSTATNIEJ MILI W PORCIE SZCZECIN

Słowa kluczowe: średni dobowy ruch roczny (SDRR), rozwój infrastrukturalny, porty morskie

Streszczenie: Pogłębienie toru wodnego Świnoujście–Szczecin do głębokości 12,5 m poprawi dostęp do portu w Szczecinie od strony morza. Stworzy to możliwości do zawijania większych statków do portu w Szczecinie i tym samym wpłynie na zmianę dotychczasowych tendencji w zakresie przeładunków portowych. Aby stało się to możliwe, konieczne są również inwestycje w poprawę dostępu do portu od strony lądu. W artykule autorzy przedstawiają szacunki i prognozy średniego dobowego ruchu rocznego pojazdów (SDRR) na drodze krajowej nr 10 i drogach dojazdowych do portu, tzw. odcinkach „ostatniej mili", które wykonali na podstawie autorskich badań ruchu przeprowadzonych na tych drogach w okresie wrzesień–październik 2016 roku dla potrzeb Studium Wykonalności dla projektu „Modernizacja dostępu drogowego do portu w Szczecinie: przebudowa układu komunikacyjnego w rejonie Międzyodrza" realizowanego przez Miasto Szczecin.

Cytowanie

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