Case Study - Benefits from Constructing a Grade-Separated Interchange

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Abstract. The paper presents the results of analyzes regarding the benefits of the planned road network development, reconstruction of a road intersection of the national road No. 25 and provincial road No. 254. Actual and forecasted traffic volumes and saturation factors on the road network were calculated based on the regional simulation transport demand model. The value of transport work performed by all vehicles traveling on this network, the value of travel time of drivers and passengers traveling during the weekday as well as the costs of impact of traffic into the environment were also determined. On this basis, a preliminary economic analysis was made as the base for a feasibility study, to prove economic benefits of such investment. Traffic analyzes, the results of which were presented in this paper, were made using the actual and prognostic four-stage regional simulation transport demand models. The authors adopted a typical trumpet-type of grade separated interchange for economic analyzes. It is a collision-free interchange, and therefore very safe in its very nature. The experience of current road practice indicates that significant improvement of road traffic safety will be the undoubted benefit resulting from the construction of such interchange. Additionally, such construction will also reduce time lost by road users in traffic. It should be noted that at present a railway at-grade crossing located in a short distance from the abovementioned intersections is the most serious source of time lost in traffic by road users. The railway line with heavy passenger and freight traffic causes each closing of the turnpikes effectively blocks traffic on main turns of above mentioned intersection. The construction of the grade separated interchange will enable collision-free intersection of the road with the railway, and thus will reduce the loss of time - a significant improvement in the functioning of the analyzed area.

1. Introduction

In 2013-2014, the ‘Transport Study of the Kujawsko-Pomorskie Province for the Sustainability of the Public Transport’ [1] was elaborated by researchers of the Department of Road Engineering and Transport. After that, in 2015-2016, the same authors prepared the ‘Sustainability Study of Transport Systems in Bydgoski and Toruński Poviats, Focusing on the Cities of Bydgoszcz and Toruń’ [2]. The presentation of the concept of road network improvement and development in the area of the province was the major part in both documents. The recommendations for optimum development of road network were determined for three possible scenarios of the economic situation of Poland and the Province, namely: optimistic (the high dynamics of the social and economic growth), balanced (mostly the preservation of the present trends in economy and the slower pace of implementing investment projects than in the previous scenario) and passive (the possibility of an economic crisis and the slowest development of road investment projects compared to the previous two scenarios).
The detailed scope of necessary transport investments for the study area in the three scenarios of its social and economic development as well as the forecast period of 2020-2035 have been presented in the studies. They concern the general premises within the development of road transport infrastructure prepared in order to meet future transport demands, both for passenger and freight traffic. Further work is certainly required, in order to detail the technical and operational solutions of the planned transport investment projects, including such issues as assumptions for road junctions and grade separated intersections design parameters, the scope of road facilities, etc.

2. Assumptions in the analysis
The application of relevant computing techniques, which enabled to carry out a number of complex mathematical analyses was required to create the concepts of transport system development. The analyses were aimed at determining the recommended and also realistic investment activity within transport infrastructure, including the development of the basic road network in the study area. The application of a numerical method recorded in simulation transport demand models has been adopted as suitable for the analyses of this type. The vast complexity of transport processes, including their dependence on numerous demographic and economic factors, make it impossible to develop reliable analyses without tools of that type, based on advanced computing technologies. Such tools enable to reflect transport processes that take place in the study area, both for the current and forecast situation. Hence, it becomes possible to forecast traffic volume and its structure by vehicle classification and direction for different social-demographic development scenarios as well as changes related both to investments in the transport infrastructure (roads, railways, etc.) and social-economic projects (e.g. establishing economic zones).

Simulation transport demand models applied in the analyses, which recreate transport processes, both for the existing state and forecast periods (in the 15-years’ perspective), were developed in the Department of Road Engineering and Transport, University of Science and Technology in Bydgoszcz, Poland [1,2]. The environment of a German software [3, 4]. PTV VISUM, was applied in the analyses. The above-mentioned models were defined in the coordinates system applicable in the study area, defined and the 2000 projection, zone 6, with the attributed system definition as ETRS_1989 Poland_CS2000_Zone_6/GCS_ETRS_1989. The definition provides the correct and complete compatibility with available free map resources, which greatly facilitated both their construction, verification, and implementation.

It needs to be emphasized that it is necessary to collect and next enter vast quantities of data into especially designed databases to build transport demand models in total, several hundred thousand data were stored in the databases, detailing the whole study area, including but not limited to any traffic-generating objects and transport networks. Moreover, numerous transport fields tests were carried out, both within transportation behaviour and preferences of transport system users and the operation of its individual elements. Moreover, in the course of constructing the above-mentioned transport demand models, numerous archival results were used from fields tests that had examined road traffic characteristic, the operation of public transport service, and transportation behaviour of inhabitants of the province.

Due to the large scope of the study, the whole work was divided into stages. The implementation of the first stage required the in-depth analysis, recognition, and analyses of the following elements for the study area:

- strategic acts on the national, provincial, regional, and local levels [5],
- present and forecast external and internal conditionings resulting from social and economic processes,
- characteristics of the internal and external transport infrastructure,
- present and future conditionings of private, public and fright transport operation in the internal and external system,
- assessment of the environment in terms of transport operation,
- suitable transport studies including the analysis of their results, encompassing:
o surveys carried out among the residents of the study area covered as well as the managers of economic zones, personnel of large production-service-commercial facilities and members of transport associations,

o analyses of road traffic qualities and characteristics (e.g. sectional counts of road traffic volume and its structure by vehicle classification as well as counts of occupation in public transport vehicles).

At the next stage, it was necessary to adopt premises for the study area focusing on:

- the land use and transport development in the internal and external system resulting from strategic acts,
- the concept of developing individual transport sub-systems resulting from planning acts and legislations,
- forecast changes in land use, and
- sensitivity of the above-mentioned concepts and changes in the economic development scenario function.

In addition, it is noteworthy that the developed scenarios of the transport network development will be subject also to social consultation. Some certain changes in these scenarios, that result from social conditionings, are foreseen to be introduced as a result of this social consultation.

The conformity analyses to the strategic documents and guidelines of the European Union were a very important aspect of this work. Therefore, environmental aspects were so much focused on. It means the demand the search for sustainability in every transport sub-system, in order to provide their environmentally-friendly development and to minimize the negative impact of the transport on the environment. And that is why, the objective was to comply with the guidelines and recommendations included in the ecological policy of the European Union as well as the domestic, regional, and local policies. Hence, a very important part of each work was the so-called ‘Strategic Environmental Impact Assessment’ for the development of transport, taking into account specific economic development scenarios. It was approved both by the regional and national environmental protection authorities.

3. Scope of analyses

The analyses concern the planned reconstruction of the area of a junction of a major national road that will feature a two-roadway section (two roadways, each with two lanes in each direction) with a provincial single-roadway way. Two scenarios of possible changes in this area were subject to traffic and economic analyses in the presented case study:

- a zero scenario, with no investments (S0), where nothing is done, i.e. the road solution is left as it is at present; and
- an investment scenario (S1), presented in figure 1, which involves undertaking an investment project consisting of geometric changes and the reorganization of traffic in the study area.

At present, i.e. without investments, the basic problem due to traffic are major losses of time for travelers. They result from the close proximity of the junction to the at-grade intersection of a provincial road with a twin-track railway line, whose route goes parallel to the national road. Due to the crossing of the road with the railway, it is necessary to close the road for the periods when trains pass by (both passenger and cargo ones). Therefore, a new transport solution was proposed, which involves the construction of a tunnel under the railway line and a grade-separated intersection (trumpet interchange) of the above-mentioned roads located in a new place, outside the study area, about 0.5 m south of the present intersection of roads. This solution will significantly eliminate the loss of time caused by the crossing of the railway line with road traffic and will also facilitate the connection of two roads. The access to the interchange from the provincial road would be possible by a new bypass road of the village. Owing to this solution, the through traffic of cars and trucks would not pass the center of the village, but rather along its outskirts. Hence, the living standard of the local community would improve, as a
consequence of limiting air pollution and noise emissions from traffic. Importantly, from the perspective of both present and forecast traffic volume, the construction of the at-grade separated interchange in the study area is justified as well. Moreover, the construction of the interchange without flow collisions should contribute to the greater safety of road traffic in the study area, as indicated by numerous road safety statistics [6]. Unfortunately, the introduction of the bypass road makes the trips longer, thus increasing the number of vehicle-kilometers.

Figure 1. Site map of the existing and planned road network in the study area [7]

4. Results of traffic analyses
In order to determine the economic effectiveness of the proposed transport solution, which will also make it possible to confirm if it is economically reasonable, the authors carried out the simulation of traffic for each of the two scenarios, S0 and S1, and for prognostic periods of 2020-2035. The analysis was to determine if due to the traffic the proposed solution is economically justified. At the same time, the analysis did not cover other aspects, such as safety and efficiency of railway traffic or social aspects of the proposed changes. The basis for the assessment of the transport demand model test results were the following measures of road traffic conditions:

- traffic volume per average working day,
- traffic saturation index of road network elements,
- carriage work in vehicle*kilometre, performed during an average working day by all vehicles, and
- time spent by drivers and passengers of vehicles during an average working day expressed in person*hour.

Based on the above-mentioned measurements and the guidelines presented in the study [8], the costs of traffic per day and year were determined, including the operating costs of vehicles, time spent by road users, and costs of the environmental impact of traffic.
The simulation calculations of traffic were carried out for the zero investment scenario (S0) and the investment scenario (S1 – the construction of the road interchange and a ring road) for the forecast period of 2020-2035.

Examples of maps of the forecast daily traffic volume determined with the simulation transport demand models for the zero and investment scenarios until 2035 are presented in figures 2 and 3 respectively.

![Map of forecast traffic volume – the zero investment scenario – 2035](image)

In addition, figure 4 presents the map of road traffic saturation indexes, which are calculated as traffic volume in each link of the road network divided by its model daily capacity multiplied by 100%. Traffic conditions on network elements where its value does not exceed 100% can be generally recognized as acceptable.

According to the data presented in the figures and the calculation results for other forecast periods, traffic conditions in the analyzed section of the road network during the whole forecast period are to be deemed as satisfactory.

The next stage of analyses was aimed at determining economic effects, i.e. savings of costs of road traffic as the result of investment activity, i.e. the construction of a road interchange and a ring of a nearby village. The following costs were taken into account: time spent in trips by drivers and passengers, the operation of vehicles, and the environmental impact. The analysis results have been presented in the following tables as the differences in costs of:

- time spent in trips – table 1,
- costs of vehicle*kilometres – table 2, and
- costs of environmental impact – table 3,

for the analyzed scenarios taking into account the years of forecast and the structure of vehicles by types.
Figure 3. Map of forecast traffic volume – the investment scenario – 2035

Figure 4. Map of forecast traffic saturation indexes – the investment scenario – 2035
Table 1. Differences in costs of time spent in trips between the analysed scenarios (S0-S1) taking into account the years of the forecast and the structure of vehicles [€]

| Specification   | 2020 | 2025 | 2030 | 2035 |
|-----------------|------|------|------|------|
| Trucks          | 230  | 249  | 335  | 263  |
| Vans            | 70   | 127  | 183  | 161  |
| Private cars    | 6,253| 7,967| 10,023|43,732|
| Total – day     | 6,553| 8,344|10,540|10,933|
| Total – year    | 1,966,133| 2,503,207| 3,162,067| 3,433,862|

Table 2. Differences in costs of vehicle-kilometres between the analysed scenarios (S0-S1) taking into account the years of the forecast and the structure of vehicles [€]

| Specification   | 2020 | 2025 | 2030 | 2035 |
|-----------------|------|------|------|------|
| Trucks          | 888  | 2,283| -1,058| -1,331|
| Vans            | -490 | -977 | -644 | -961 |
| Private cars    | -4,958| -4,457| -4,864| -5,480|
| Total – day     | -4,560| -3,150| -6,566| -7,771|
| Total – year    | -1,367,996| -945,049| -1,969,662| -2,331,272|

Table 3. Differences in the environmental impact between the analysed scenario (S0-S1) taking into account the years of the forecast and the structure of vehicles [€]

| Specification   | 2020 | 2025 | 2030 | 2035 |
|-----------------|------|------|------|------|
| Trucks          | 141  | 321  | -131 | -146 |
| Vans            | -5   | -9   | -5   | -7   |
| Private cars    | -87  | -69  | -67  | -67  |
| Total – day     | 49   | 243  | -203 | -219 |
| Total – year    | 14,653| 72,731| -60,974| -65,755|

The presented results of the analyses show that the implementation of the investment will contribute to reducing the total costs of trip time by road users in all periods of the forecast traffic. Moreover, the investment will increase the number of vehicle-kilometres, thus increasing the operating costs of vehicles, as a result of extending the route along the bypass to the road interchange. Table 4 shows total differences in the costs of traffic and environmental impact between the analyzed scenarios considering the years of the forecast.

Table 4. Total differences in the costs of traffic and environmental impact between the analysed scenarios for the individual years of the forecast [EURm]

| Year of forecast | Differences in costs (S0-S1) |
|------------------|-------------------------------|
| 2020             | 0.62                          |
| 2025             | 1.63                          |
| 2030             | 1.13                          |
| 2035             | 1.04                          |

The results of calculations presented in table 4 indicate that the project involving the reconstruction of the road network in the analyzed area according to calculated traffic effects is economically
reasonable. It is forecast that during 15 years of its operation, savings due to traffic costs and travel time would amount to ~17.5 EURm, with the forecast cost of the project at 13.1 EURm.

5. Conclusions
The analysis of the economic justification of transport investment projects is one of the indispensable elements of the process of preparing investments. Its basic objective is to determine economic effects of investment measures, including costs of saving the time of travellers, the costs of vehicle operation, the environmental impact, as well as the broadly understood social costs. At present, it is necessary in such analyses to apply advanced simulation techniques, which enable to determine transport effects not only in the area of the investment but in the whole impact area of a project as well. It is obvious that efficient transport solutions affect the mode of travel chosen by users of transport systems. Hence, it is necessary to apply simulation techniques that cover the whole area of investment impact, rather than only a fragment covered by an investment project. Such solutions have been presented in this study.

The analyses presented within the case study to justify the investment project were limited only to road transport. Due to the limited scope of this article, the analysis that results from the improvement of railway traffic conditions and safety as well as the costs of operating the analyzed transport solutions was omitted. It is noteworthy that closing the present railway crossing will contribute also to the major reduction of time lost in railway transport, thus increasing its economic effectiveness. This outcome will result from the fact that high speed trains will not be forced to reduce their speed, either in sections in front of or behind the crossing.

The results of the analyses have shown that the project of reconstructing the road system, taking into account the costs of travellers’ time, operating of vehicles, and the environmental impact, is reasonable. As indicated by the results of traffic forecasts, in the period of 15 years after completing the investment work, the balance of savings and costs will be positive at 4.4 EURm.

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