Changes in Land Plot Morphology Resulting from the Construction of a Bypass on the Example of the Polish City of Olsztyn

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Abstract:

An intensive development of the road network has been noticed in Poland in recent years. Old roads have been renovated and a lot of new roads created. This is particularly easy to see from the number of built highways and city bypasses. The adaquate amount and quality of roads is essential to ensure the economic development of regions and entire countries. However, such line investments are an expansive element and have a significant impact on the environment, landscape, spatial planning and land management. Thanks to the use of GIS tools, we can, by performing appropriate spatial analyzes, limit the negative impact of the communication network on the environment, on the spatial structure of neighboring areas or influence the reduction of social conflicts arising in connection with the construction of a new road.

The article presents an assessment of changes in the spatial structure of plots due to the construction of the city bypass. The preliminary stage of the research was the acquisition and segregation of information about the existing state and their analysis. In the next step, the surface effects of the construction of the bypass were analyzed and evaluated. The obtained results were the basis for determining the degree of change in the morphological structure of the plots. The results of the research are presented on maps, charts and tables. The conducted research is important considering the rapid development of the road network in Central and Eastern Europe.

The use of GIS tools makes it possible to shorten the time needed in the road planning and design process and to standardize the procedures of conduct, at the same time contributing to the protection of limited goods such as space, through the ability to review and evaluate different road options.

Keywords: bypass; morphological structure; land plots.

1. Introduction

The influence of bypass construction on the spatial structure of the adjacent areas was analyzed based on a review of the relevant literature regarding motorways. According to the authors, bypass roads and motorways exert a comparable influence on the surrounding areas due to similarities in their construction and operation.

Poland is an important transportation hub in Europe. Owing to its central location, Poland is a major logistics center for the flow of goods between Eastern and Western Europe. In the past, Poland differed considerably from the Western European countries in the number and quality of motorways and express roads. However, significant changes have taken place in recent years when major progress was made in road planning, design and construction and the development of cohesive transportation concepts. The latest transportation concepts no longer focus solely on the construction of new routes connecting Eastern and Western Europe, but also recognize the need for linking the southern and northern parts of the European continent.

The existing road transport system has to be modified to:

- achieve the required environmental protection standards,
- provide reliable transport to domestic and foreign destinations,
- integrate public transport systems in metropolitan areas,
- improve the profitability of passenger and cargo transport (Zych, 1993).

A dense and suitably equipped road network promotes fast and convenient transport and is essential for the economic growth of every country. It also creates opportunities for eliminating economic exclusion zones in the poorest regions (Kowalczyk et al., 2014).

The combined length of Polish motorways increased from 358 km in 2000 to 552 km in 2005 and 765 km in 2008 (Rocznik Statystyki Międzynarodowej, 2012). The greatest increase of 210 km and 300 km was noted in 2012 and 2013, respectively. In 2017, Poland had 1641 km of motorways and 1611 km of express roads. Around 20 km of motorways will be commissioned for use in 2018 and another 40 km – in 2019. According to statistical data, motorways are the safest type of roads. In the European Union, accident rates were several times lower on motorways than on urban and local roads (Lenart ,1998). In Poland, there were 50 fatal motorway accidents in 2016 (3.2 fatalities/100 km) (Wypadki drogowe w Polsce w 2016 r., 2017).

Road planning requires extensive information campaigns to minimize the risk of social conflict which substantially hinders and delays decision-making and construction. The relevant information has to be communicated not only to the owners of property directly covered by the roadway or in the direct vicinity of a planned motorway, but to all members of the local community. Social protests can have dire consequences, and they can never be fully predicted, avoided or managed in a way that does not hinder the construction process. Motorway planning requires substantial foresight and social campaigns to solicit the support or at least the tacit consent of the local community (Ney, Kozubek, 2007). Local communities are mostly perturbed by the motorways' adverse impact on the local landscape and environment during construction and operation. Educational campaigns are needed to provide all stakeholders with reliable information about the extent and the environmental impacts of motorway projects as well as the planned preventive and repair measures.

The direct impact of city bypass roads is usually analyzed within a radius of up to several hundred meters. However, linear referencing and the type of the construction project determine the extent of changes in the natural and cultural environment and the local landscape, in particular (Cymerman, Karwowski, 1997):

- river drainage basins,
- forest and field ecosystems,
- scenic and cultural heritage sites,
- agricultural farms,
- human settlements,
- infrastructure,
- protected areas.

According to Cymerman, the adverse consequences of motorway construction, such as spatial fragmentation (property rights and land use), unfavorable cropland distribution and longer access roads, are experienced within a 2 km radius from the planned roadway.

Bypass roads occupy extensive stretches of farmland, which decreases the area of land under crops. Bacior argued that the relevant risks should be evaluated based on analyses of changes in land use, soil quality class and the distribution of access roads to land plots situated along the axis of the planned motorway. Such analyses precede motorway construction projects, but their results are largely universal and can also be applied to city bypass roads. The value of land appraised based on its suitability for agricultural production is an important criterion in evaluations of the multi-directional influence of motorways on farmland. This parameter is an important metric for assessing the suitability of land for agricultural production (Bacior, 2012). Bacior developed a simplified method for analyzing a motorway’s impact on the surrounding areas during the planning process. This preliminary analysis relies on the following types of data:

- changes in soil quality in the areas occupied by the motorway,
- distribution of access roads and motorway overpasses,
- area of farmland which is accessed by roads that intersect the planned motorway,
- parameters of cropland intersected by the motorway,
- distribution of green belts.

The above data are analyzed to identify changes in land parameters which influence agricultural productivity, and the results are used to evaluate a motorway's impact on cropland. The discussed method supports a comprehensive assessment of a motorway's influence on farmland (Wilkowski, 1995, Harasimowicz, 1998), including the loss of land reserved for motorway construction, decrease in the productivity of farmland situated in the vicinity of the motorway, and fragmentation of cropland intersected by the motorway (Bacior, 2012).

Bacior and Harasimowicz have also identified other factors which exert a negative influence on the spatial structure of agricultural land, such as cutting off fields from the farmstead, and unfavorable size and distribution of plots. These risks contribute to the underutilization of agricultural machines and fixed assets, longer access roads to cultivated fields, lower farm productivity, decrease in animal stocks, and barn vacancies (Bacior, Harasimowicz, 2005).

The environmental impacts of motorway construction have been studied by Badora, and his findings can be extrapolated to bypass roads. Badora proposed a methodology for a multi-criteria evaluation of a motorway's influence on the natural environment. The developed method combines indicators of environmental valuation with indicators of environmental transformation. Projects that induce extensive changes in farmland imply higher spending on the restoration of agricultural ecosystems. Badora rightly noted that due to the considerable degradation of agricultural ecosystems in the vicinity of the planned motorways, construction projects carried out in these areas make the greatest contribution to environmental protection.

According to the above author, motorway construction could have a more detrimental impact on local businesses (Badora, 2004).

Kozłowski observed that the extent to which human activities influence the environment is largely determined by the natural value and the degradation of local ecosystems. The most serious conflicts can be expected in areas characterized by high natural value and significant degradation (Kozłowski, 1994).

Areas in the vicinity of motorways and changes in their spatial structure were also analyzed by Wilkowski. The author developed a multi-criteria cause-and-effect matrix containing 23 parameters that describe motorways' impact on farmland (Wilkowski, 1995). Wilkowski also identified the main environmental impacts resulting from the construction, maintenance and operation of motorways as well as factors that are indirectly associated with motorways.

Wilkowski divided the environmental impacts of motorway construction into five categories:

I. Loss of farmland,

II. Adverse changes in the spatial structure of farms,

III. Decrease in crop yields in areas directly adjacent to the motorway,

IV. Limited use of land occupied by vegetable gardens, berry farms, meadows and pastures.

V. Disorganization of the existing technical infrastructure.

The described method can be used to evaluate motorway routes which intersect farmland, to assess their influence on the surrounding areas, and to select the optimal farm management strategies in rural areas affected by motorway construction.

According to Hopfer and Marcinkowska (1997), motorway construction:

- decreases farm area,
- increases the number of agricultural land plots,
- increases the distance between the farmstead and fields.

A simplified approach to evaluating the severity of functional changes in farmland has been proposed by Chmielowiec and Kaszycki. The authors have divided farms into groups based on the percentage of farm area affected by functional changes (Chmielowiec, Kaszycki, 1997):

- up to 50% of affected farm area,
- 50-90% of affected farm area,
- more than 90% of affected farm area.

The influence of motorways on agricultural land was also investigated by Marcinkowska. The author developed a novel method for evaluating the extent of farmland degradation caused by motorway construction. Marcinkowska proposed a set of rural degradation indicators which were divided into 7 groups and 4 types. The identified groups of indicators denote the consequences of motorway construction, whereas the types of indicators make a reference to spatial elements (Marcinkowska, 1999). The author also outlined the principles for selecting remedy measures that best address local needs and proposed a list of recovery treatments. The described method can be used to select the optimal farmland restoration measures, identify the most pressing needs and determine the sequence of the required treatments in rural areas that are negatively influenced by motorway construction (Kowalczyk et al., 2014).

Motorway construction also necessitates changes in local zoning plans. The designation of areas zoned for various purposes could change, and completely new functions could also be introduced in a given area (Hopfer, Marcinkowska, 1997). Gwiaździńska-Goraj and Kurowska (2011) in their research analyzed the course of two variants of the Olsztyn bypass. The analysis took into account environmental and social conditions. In their opinion, social expectations expose valuable natural areas to degradation.

1. Results of analysis

1.1. Input data

The study was performed on the Olsztyn bypass with an estimated length of 28 km (including the bypass road of Wójtowo). The analyzed bypass intersects the municipalities of Gietrzwałd, Stawiguda, Purda and Barczewo as well as Olsztyn, the capital city of the Region (Voivodeship) of Warmia and Mazury which has county status. The bypass road stretches from the village of Kudypy west of Olsztyn to the village of Wójtowo east of Olsztyn, and it is connected to the national road No. 16 at both ends. It consists of two roadways with two lanes in each direction. The Olsztyn bypass will ultimately have six road junctions, 36 engineering structures and 32 culverts (Kil, Siemiński, 2015).

The bypass is connected to the national road No. 16 at both ends. It intersects mainly agricultural areas situated far from dense development and village centers. Short sections intersect forests, clusters of field trees and scattered settlements. In three locations, the bypass crosses railway lines connecting Olsztyn with the neighboring towns. It also intersects the Łyna River and the Szczęsne Canal. The bypass road will also intersect nature conservation areas and the surrounding territories, including:

- Protected Landscape Area of the Pasłęka Valley,
- Protected Landscape Area of the Middle Łyna Valley
- Protected Landscape Area of the Napiwodzko-Ramucka Primeval Forest (Studium Uwarunkowań…, 2012),
- Special Bird Protection Area of the Napiwodzko-Ramucka Primeval Forest which is part of the Natura 2000 network.

The analysis was performed on cadastral land plots in the vicinity of the Olsztyn bypass. The municipalities intersected by the bypass are presented in Table 1. They have a similar population which ranges from 9565 in the municipality of Gietrzwałd to 19,446 in the municipality of Barczewo (including 7349 urban residents and 9734 rural residents).

The number of land plots is similar in the rural areas of the analyzed municipalities. Barczewo is characterized by the largest average plot area of 1.6 ha. The shape of a land plot is determined by its surface area and perimeter. The examined plots have the shape of narrow rectangles. The plots in the municipalities of Gietrzwałd and Purda are characterized by the least desirable shape (aspect ratio of 1:13), and the plots in the municipality of Stawiguda – by the most desirable shape (1:11). A dense road network in the analyzed area is probably responsible for the elongated shape of the examined plots.

Table 1. Characteristic features of the municipalities intersected by the Olsztyn bypass

Municipality	Total area [km2]	Population [persons]	Number of plots	Average plot area [m2]	Average plot perimeter [m]
Stawiguda	222.9	8449	10886	20454	447
Barczewo	319.85	17662	19446	16442	463
Purda	318.1	8612	12544	25326	557
Gietrzwałd	172.3	6536	9565	17993	470

Source: http://www.polskawliczbach.pl

1.2. Plot shape analysis

The morphological features of the areas directly adjacent to the Olsztyn bypass were analyzed. Morphological analyses are a popular research method in many fields of science (Bitner et al., 2009, Bitner, 2011, Pigol et al., 1993). In this study, the analysis focused solely on changes in morphological features resulting from the division or consolidation of land. In mathematics and physics, the term “morphology” denotes the geometric properties of a structure (Bitner, 2011).

The cadastral land plot is the smallest unit of geodetic division in Poland, and it was adopted as the basic unit of analysis in this study. Cadastral plots can be divided or consolidated, which leads to changes in their spatial structure.

Thousands of cadastral plots have to be divided in the process of planning and designing a bypass road. The physical boundaries of a roadway denote the extent to which land plots are occupied and split by the motorway. Linear referencing in physical space induces significant changes in the natural environment and creates new spatial structures in agricultural areas. The route of a bypass road significantly alters local morphological features. The land plot mosaic is analyzed before and after bypass construction to evaluate the project's impact on the existing spatial structure. In this study, only the morphological features of the evaluated land plots were analyzed.

Variations in the land plot mosaic were evaluated on the assumption that the perimeter and the area of land plots have normal distribution over an area larger than the examined territory. The bypass road will change the above parameters, and the extent of these changes will be determined by a land plot's distance from the bypass.

The route of the Olsztyn bypass against the land plot mosaic is presented in Figure 1. Parallel lines were mapped at a distance of 400 m and 800 m from the bypass axis. The above distances were selected to evaluate the land plots adjacent to the bypass on the assumption that the contribution of the intersected land plots to the calculations of the neighboring line will not exceed 5% (ratio of the number of land plots repeated on the neighboring line to the number of plots intersected by a given line). The influence of the intersection on the primary structure (morphology) decreases with an increase in distance from the bypass (Kowalczyk et al., 2014).

The shape factor was adopted as the basic indicator of an area's morphology. Analyses of two-dimensional objects are often used in settlement geography. The shape factor was determined based on the object's basic parameters: surface area and perimeter. Indicator k proposed by Kostrubiec is the only shape indicator that relies on a land plot's area (P_{dz}) and perimeter (O_{dz}) (Kostrubiec, 1972). This indicator is calculated with the use of the following formula:

$$k = \frac{{O_{dz}}^{2}}{P_{dz}} - 4 * \pi$$

Shape factor k is a measure of an object's "cohesion". It adopts a minimum value equal to zero for a circle, and it increases as the object becomes more elongated. Shape factor k takes on an infinite value for an infinitely narrow rectangle (Bitner et al., 2009). The shape factor equals 5.44 for a rectangle with an aspect ratio of 1:2, and 3.44 for a square.

Key: Distance from the roadway boundary
- 400 m
- 800 m
- bypass roadway
- land plots adjacent to the bypass
- land plots intersected by the line mapped 400 m from the bypass
- land plots intersected by the line mapped 800 m from the bypass

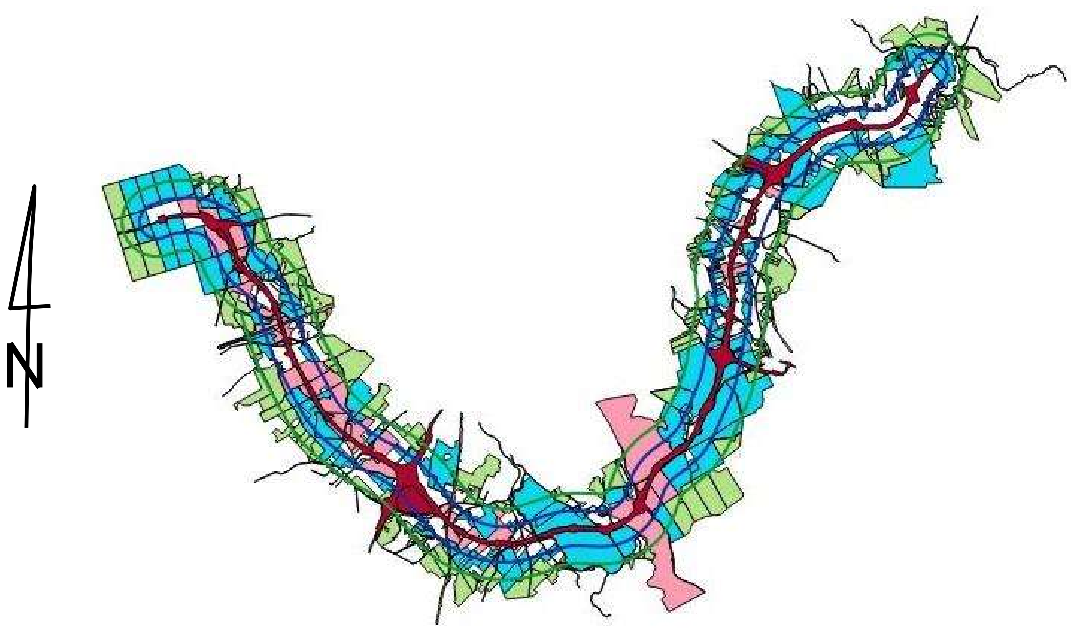

Figure 1. The route of the Olsztyn bypass with an indication of the analyzed land plots.

1.3 Map analysis

The study was performed along a 28 km section of the Olsztyn bypass, including cadastral plots directly adjacent to the bypass road on both sides. GIS software (http://www.quantum-gis.pl) was used to map two lines parallel to the road axis: line a2 at a distance of 400 m from the road axis, and line a3 at a distance of 800 m from the road axis. The road axis is marked by line a1 (Fig. 1). The spatial correlations between the above lines were analyzed. Datasets describing every land plot, including land plot number, perimeter, area and orientation (N – north and S – south), intersected by each line were exported. Numeric maps were analyzed to calculate the shape factor of every land plot and the mean values of shape factors. The results are presented in Table 2.

Table 2. Descriptive statistics of land plots intersected by lines at various distances from the bypass.

Line	Orientation	Number	Shape factor				
			Mean (kśr)	Median	Minimum	Maximum	SD
a1	N	86	208.55	30.29	3.92	1217.72	305.06
	S	96	175.28	40.6	3.92	1217.72	274.25
a2	N	307	78.73	78.73	2.66	2438.34	212.99
	S	209	86.3	12.1	2.99	1276.95	191.48
a3	N	238	63.92	9.59	2.47	954.97	148.99
	S	294	92.53	10.79	2.55	4121.37	292.97

The presented results indicate that land plots directly adjacent to the bypass roadway have higher shape factors on average, which implies that they are more elongated (Fig. 2 and Fig. 3). Land plots on the northern side of the bypass are more elongated than those situated on the southern site, and their aspect ratios were determined at 1:35 (N) and 1:45 (S), respectively. Land plots directly adjacent to line a1 (road axis) are not highly suitable for agricultural production. Land plots intersected by lines a2 and a3 are characterized by more desirable proportions. Plots situated 400 m away from the roadway have an average shape factor of 78.73 (northern side) and 86.3 (southern side), with an aspect ratio of 1:21 (northern side) and 1:23 (southern side), respectively. Similar observations were made in land plots situated at a distance of 800 m from the roadway and intersected by line a3. These plots have an average shape factor of 63.93 (northern side) and 92.53 (southern side), with an aspect ratio of 1:17 (northern side) and 1:24 (southern side), respectively.

Land plots directly adjacent to the bypass are characterized by less desirable proportions than those situated further away from the roadway. The above can probably be attributed to the suburban character of the evaluated area and a large number of roads that were divided by the bypass. The plots occupied by roads are long and narrow, which explains the average values of their shape factors and aspect ratios.

The shape factors were presented separately on both sides of the bypass in a scatter plot (Fig. 2 and Fig. 3) to illustrate the changes in the morphological properties of the analyzed area.

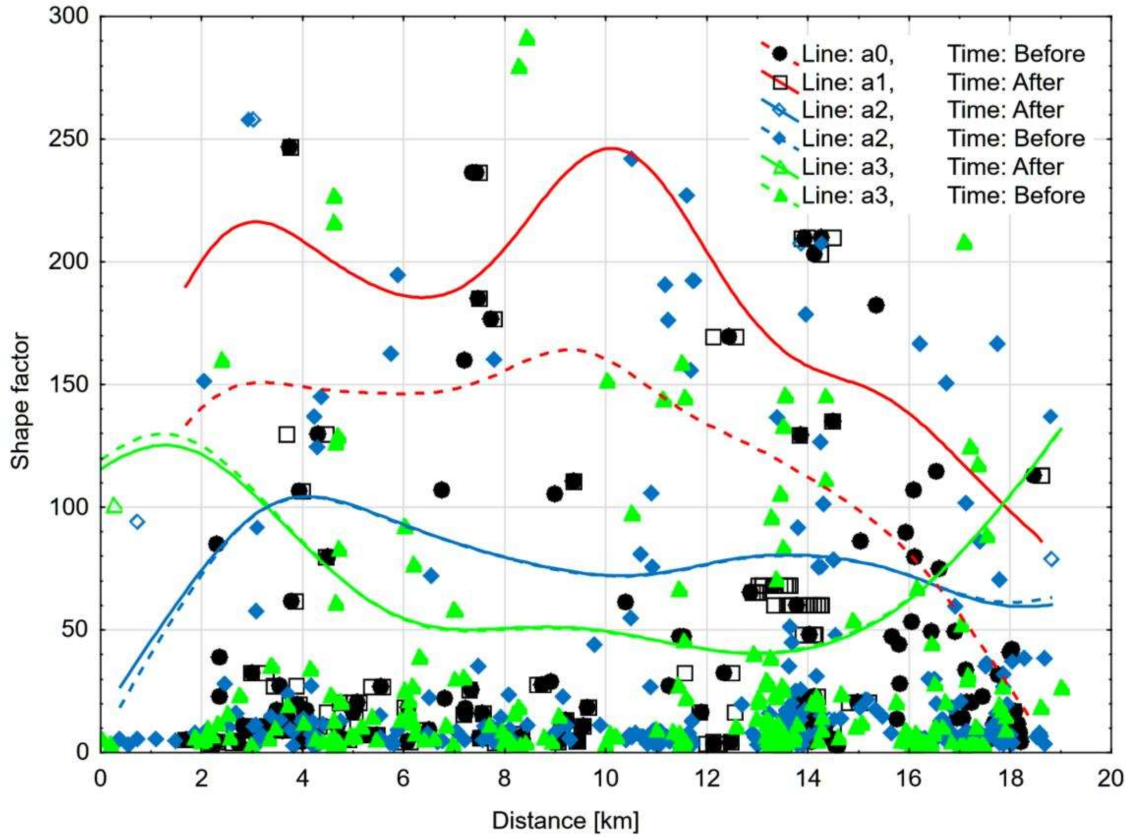

Figure 2. Scatter plot of shape factor values for land plots on the northern side of the bypass (the lines were smoothed with the distance-weighted least squares procedure).

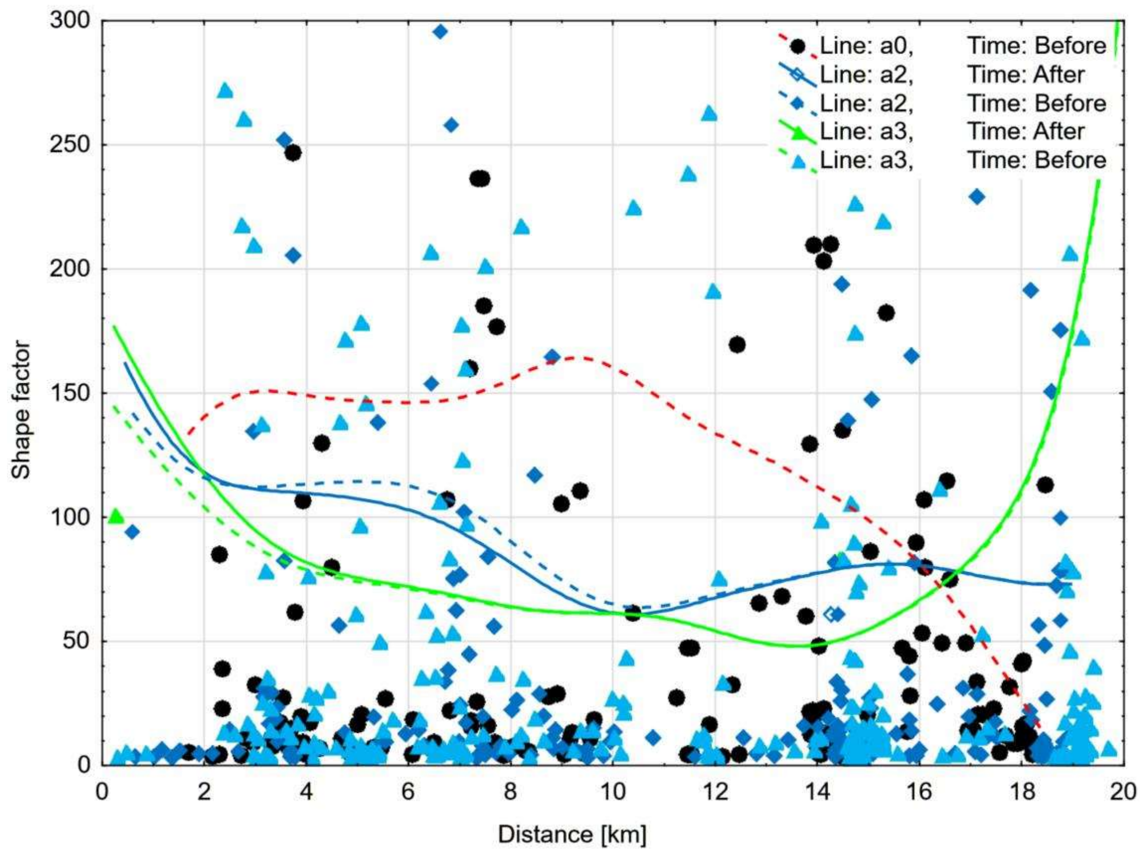

Figure 3. Scatter plot of shape factor values for land plots on the southern side of the bypass (the lines were smoothed with the distance-weighted least squares procedure).

Table 3. Descriptive statistics of land plots intersected by lines at various distances from the bypass

Line	Orientation	Number	Plot area [m^2]				
			Mean (Pśr)	Median	Minimum	Maximum	SD
a1	N	86	125867.48	46986.62	353.84	1763222.20	263624.61
	S	96	144172.84	66361.43	324.00	1763222.20	255480.65
a2	N	307	38422.92	4090.36	153.16	963945.02	105522.81
	S	209	61858.48	8263.47	202.21	1095084.56	144933.35
a3	N	238	29130.72	3197.07	105.3	405716.90	68058.58
	S	294	32706.19	4773.69	145.94	426111.94	73217.24

The area of land plots situated at various distances from the bypass is presented in Table 3. The average area of plots intersected by line a1 is 12.5 ha on the northern side and 14.4 ha on the southern side. The average area of plots intersected by line a3 is 2.9 ha on the northern side and 3.3 ha on the southern side. The distribution of land plots intersected by the above lines is presented in scatter plots in Figure 4 and Figure 5. The x-axis represents the distance from the start point, and the y-axis represents plot area in m^2. The lines smoothed by the distance-weighted least squares method procedure were fitted into the model. The results indicate that smaller plots are situated further from the bypass. As previously noted, the Olsztyn bypass intersects agricultural land in the suburban zone. It bypasses clusters of residential development, and line a3 (800 m from the bypass) intersects land plots zoned for the construction of single-family homes whose area is relatively small in comparison with the agricultural plots adjacent to the bypass.

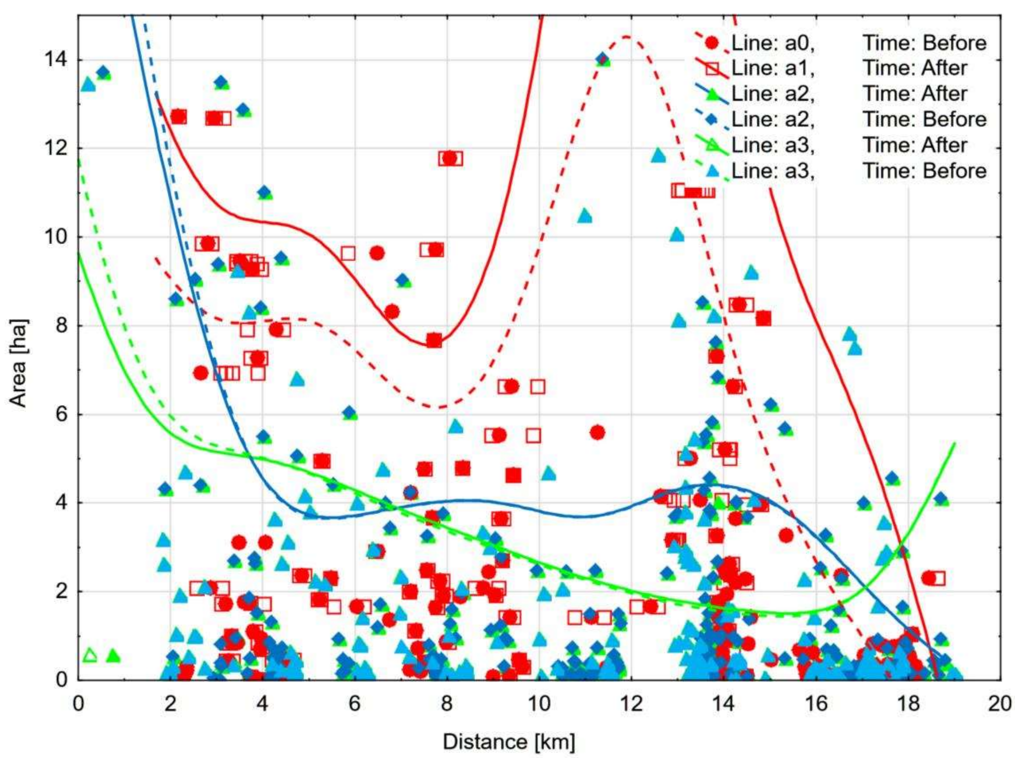

Figure 4. Scatter plot of plot areas on the northern side of the bypass (the lines were smoothed with the distance-weighted least squares procedure).

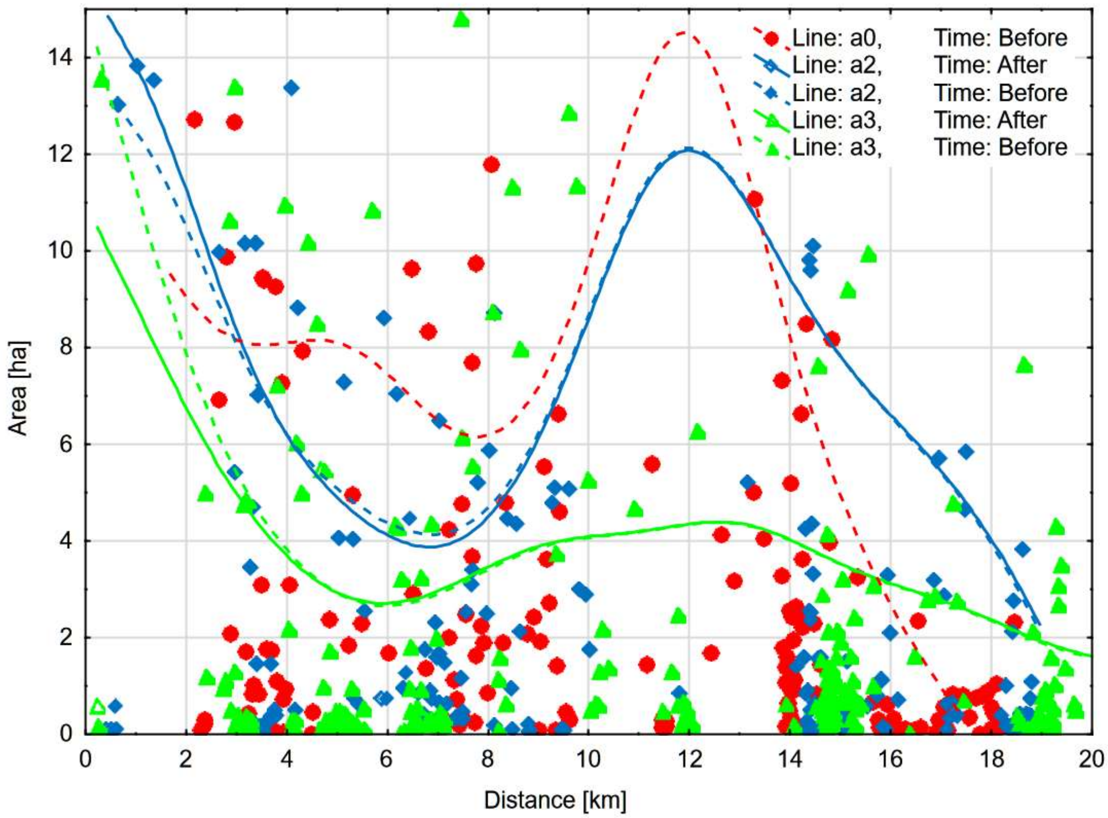

Figure 5. Scatter plot of plot areas on the southern side of the bypass (the lines were smoothed with the distance-weighted least squares procedure).

The construction of the bypass road altered the shape factors of the analyzed land plots. To determine the extent of changes in shape factor values presented in Table 4, the variations in shape γ were calculated based on the difference in the mean shape factor of plots intersected by line a3 and line a2 relative to the shape factor of plots intersected by line a3.

$$\gamma = \frac{\left(k_{śr\_an} - k_{śr\_a(n-1)}\right)}{k_{śr\_an}}$$

The results are presented in Table 4. Land plots situated closer to the bypass road have a higher shape factor (the mean shape factors of land plots intersected by extreme lines differ by up to 220%).

Table 4. Changes in the shape factor of land plots intersected by the mapped lines.

Change between lines	Orientation	Change in shape γ
a3 – a1	N	-226%
	S	-89%
a2 – a1	N	-23%
	S	7%
a3 – a2	N	-165%
	S	-103%

The changes in plot area δ were also calculated based on the difference between the average area of land plots intersected by line a3 and line a2 relative to the area of plots intersected by line a3.

$$\delta = \frac{\left(P_{śr\_an} - P_{śr\_a(n-1)}\right)}{P_{śr\_an}}$$

The greatest differences in average plot area were determined in the plots that are intersected by line a1 and are directly adjacent to the bypass on both the northern and southern side. The results are presented in Table 5.

Table 5. Changes in the average area of land plots intersected by the mapped lines

Change between lines	Orientation	Change in plot area δ
a3 – a1	N	-332%
	S	-341%
a2 – a1	N	-32%
	S	-89%
a3 – a2	N	-228%
	S	-133%

2. Conclusions

The morphology of the spatial structures modified by the construction of the Olsztyn bypass was analyzed to determine:

- the correlations between changes in plot area and the location of the Olsztyn bypass;
- plot shape characteristic of the analyzed area.

The examined suburban area is difficult to analyze because it constitutes a transitional zone between the urban area of Olsztyn and the rural areas of the surrounding municipalities. It is characterized by overlapping areas of clustered and dispersed single-family homes and farmland. The analyzed area also features extensive fragments of two forest complexes and a road network.

A similar study was previously conducted by the authors to evaluate the influence of motorway construction on a rural area. The results revealed a decrease in the average area of land plots directly adjacent to the motorway. The present study produced contrary results, and land plots with the smallest average area were situated furthest from the Olsztyn bypass (800 m). The above indicates that land plots that are not directly adjacent to the roadway (line a3) are more attractive due to easy access to the city. For this reason, larger plots are divided into smaller plots for residential construction, in particular in the vicinity of villages. Land plots directly adjacent to the bypass are less attractive for urban development. In the rural municipalities surrounding the urban core, suburbanization begins with residential construction, and areas directly adjacent to expressways are not attractive for this purpose.

Land plots situated further from the bypass have a more desirable shape factor which was determined at 63.93 (northern side) and 92.53 (southern side) for the plots intersected by line a3 (800 m) which have an aspect ratio of 1:17 (northern side) and 1:24 (southern side). Land plots intersected by line a1 and adjacent to the bypass have an aspect ratio of 1:53 (northern side) and 1:45 (southern side). The average aspect ratio of land plots intersected by line a1 can be attributed to the fact that most of them are long and narrow and are utilized as roads. Bypass construction disrupted the spatial structure of the analyzed plots and produced irregularly-shaped remnants of larger parcels, which also influenced the observed results.

This study analyzed a relatively short fragment of the Olsztyn bypass; therefore, it does not support the formulation of general conclusions regarding changes in spatial morphology, in particular in transitional suburban zones (at the contact point of urban and rural areas). Further research is required to validate the results of this study in other areas where bypass roads are planned.

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