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DIFFERENTIATED ROAD CONSTRUCTION COSTS

Summary. In the context of the variability of road construction costs in Europe, the prices of 24 contracts for sections of motorways in Poland, concluded in 2016 by the General Directorate for National Roads and Motorways, were analysed. According to the proposed method of calculation, taking into account the fact that road prices in tunnels were several times higher than in other sections, the unit cost of the road in a tunnel (between Naprawa and Skomielna Biała) was assessed, compared to the road in a tunnel in Slovenia. Based on the study of the values of standard deviations and coefficients of variation, it can be stated that there is a small price differentiation in S-class roads on flat and corrugated areas, and very large price differentials on the roads that bypass cities and in mountainous terrain.

Keywords: road costs; motorways; express roads; tunnels

1. INTRODUCTION

High construction costs, which total as much as several million euros per km of state-of-the-art road, pose a major obstacle to the rapid development of the road network [2, 7, 11]. Such costs highly depend on road location. Capital expenditure (capex) within cities is much higher than outside them. The lower the number of urban obstacles and the easier the access to areas outside the city offer the simpler, less burdensome and quicker execution of works,

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which translates into lower construction costs. In turn, in mountain areas, where there is a need for strengthening embankment and excavation slopes with retaining walls and anchors, as well as a need for building many bridges and even tunnels, costs are much higher than when constructing roads in undulated and flat areas.

Local conditions often require the transfer of entire habitats of flora and fauna, together with building special passes, changing watercourses, creating roadside greens or constructing acoustic screens. The costs are also affected by fluctuating prices in the construction industry.

The article presents the costs of motorway construction across Europe, as well as an analysis of capex per road sections with various tunnel lengths. The analysis also considers varying contract prices involving the construction of 24 S-class road sections, concluded in 2016 in Poland.

2. AREAS GENERATING MOTORWAY CONSTRUCTION COSTS

Apart from consuming several dozen metres of the width of a belt of land directly intended for the road, motorways contribute to pollution levels with exhaust gases and significant noise spreading for several kilometres. Furthermore, the area is artificially divided into separate parts. There is a need for transferring habitats and constructing passes for animals, as well as other pro-environmental solutions. As a result, according to [2], the value of environmental elements totals about 18%, while sometimes even reaching 35%, of motorway capex (Fig. 1). Costs relating to land purchase and the relocation of residents total about 15%, while, in urban areas, they can even reach up to 30% of the total investment value (such as during the construction of the M74 motorway in Glasgow in 2009). Currently, engineering costs amount to between 3% and 5%, expertise and consulting typically total around 7%, while sometimes reaching up to 15% of the investment value. Construction itself usually costs about 25% of the motorway value, whereas administrative expenses of such projects total about 30%.

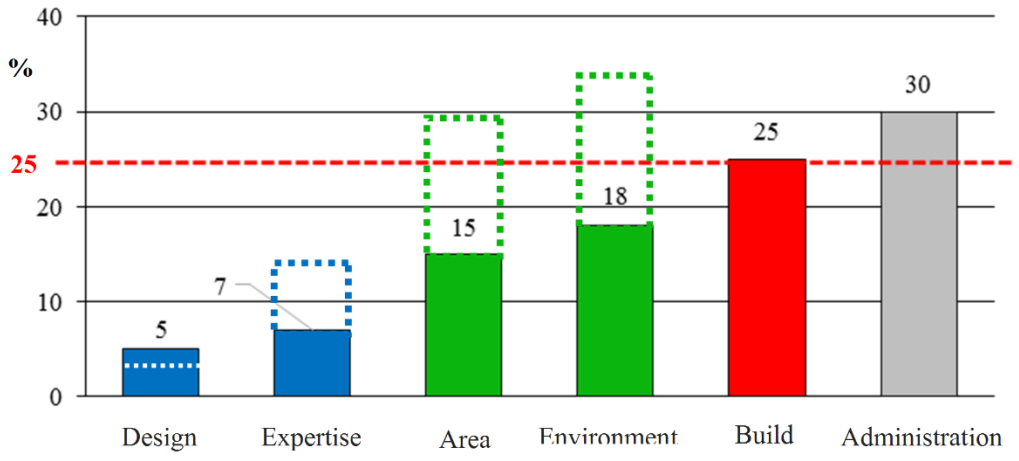

Fig. 1. Motorway construction cost component generation areas
(own study, pursuant to [2])

3. ROAD CONSTRUCTION COST VARIABILITY ACROSS EUROPE

When analysing road construction costs across Europe, according to [9], in 1998, the lowest capex/km of a motorway (on average in the entire road section analysed) totalled between EUR 1.9 million in Spain, in flat and undulated area, to EUR 12.5 million in Switzerland, in a difficult mountain area (Fig. 2). For example, in France, the cheapest 1 km of motorway was built for EUR 5.2 million, while the price was about 23% higher in Germany, totalling EUR 6.4 million. With average costs across all lands of EUR 10.6 million/km, the value of the cheapest roads in Germany was 2.1 times lower than the value of the most expensive sections. In Italy, the value of the most expensive road sections was four times higher than that of the cheapest ones, while, in Switzerland, the proportion totalled 6.4 times.

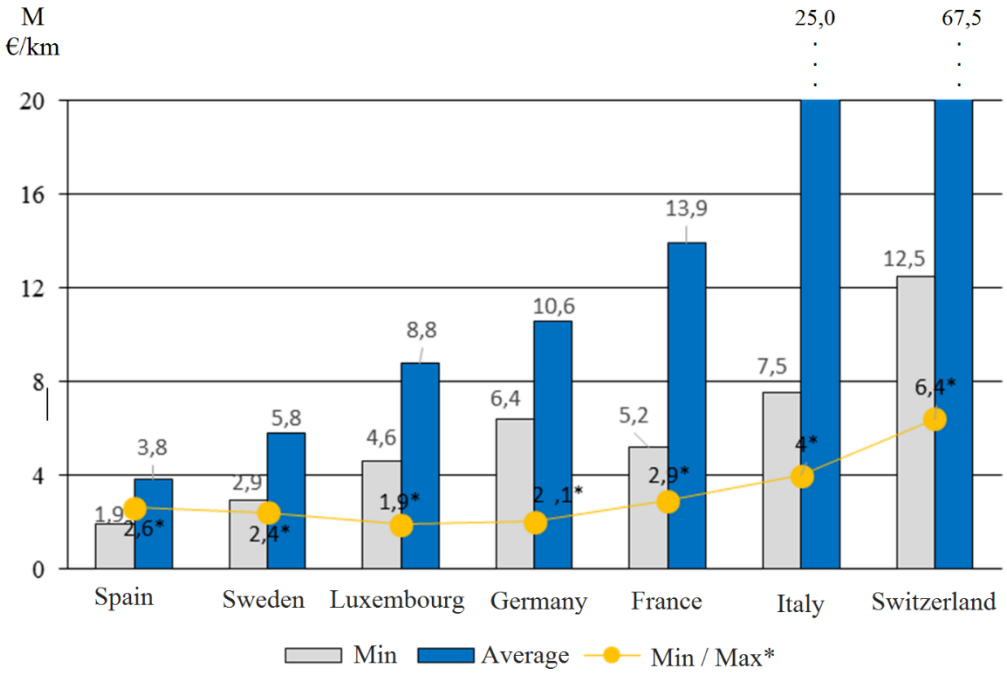

Fig. 2. Motorway construction cost variability in selected European countries, 1998 (own study, pursuant to [9])

In 2012, the average cost of construction of 1 km of motorway in Germany totalled EUR 8.2 million/km (Fig. 3). This was 23% lower than in 1998 and 13% lower than the average construction costs of such roads across Europe, which totalled EUR 9.4/km. In Poland, despite the fact that the costs of motorway construction, according to [10], decreased by 36%, compared with the costs from 2008, the average cost totalled EUR 9.6 million/km in 2012, which was still 2% higher than the average value in Europe. However, after a reduction of 39% in the costs of S-type express roads in Poland, compared to 2008, their average value totalled EUR 8.7 million/km, which was just by 7.5% lower than the average cost of motorway construction in Europe.

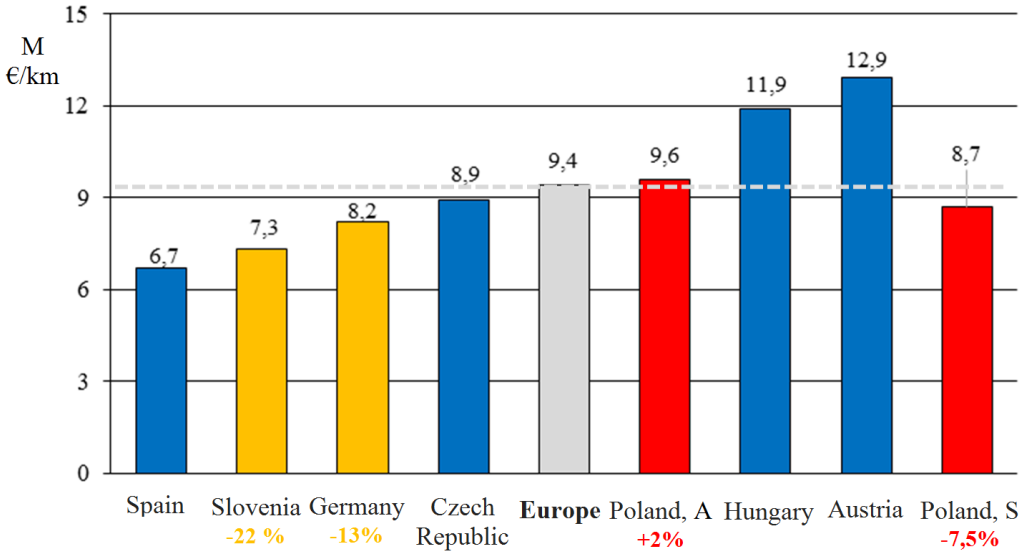

Fig. 3. Average costs of motorway construction in 2012
(own elaboration based on [10])

4. COMPARISON OF ROAD CONSTRUCTION COSTS WITH VARIOUS TUNNEL LENGTHS

In order to confront the issue of road construction costs with various proportions of tunnel length p, as compared to total road section length, the calculation can be performed according to the following equation:

$$k_p = k_t\, p + k_d\,(1\text{-}p) \tag{1}$$

where k_p is the average cost of construction of 1 km of road for the adopted p; p is the value of the proportion of tunnel length l_t km, as compared to the length of the analysed road section l_d km; $p = l_t / l_d$; and k_t, k_d are the construction costs of 1 km of tunnel and the remaining road section outside the tunnel, respectively, in PLN millions.

In Slovenia, where the average cost of motorway construction was, as stated above, 22% lower than the European average, the construction of a road, whose length ld = 4.5 km, with a tunnel whose length lt = 1.5 km, totalled as much as EUR 59 million/km, meaning it was 6.3 times higher than the European average, and also eight times higher than the average cost of motorways in that country (cf. Fig. 3).

A section of the S7 road from Naprawa to Skomielna Biała (a dual carriageway with a two-chamber tunnel [1, 7]), with a length of 3.05 km and a tunnel stretching 2.057 km, will cost, according to the tender results, EUR 79.4 million/km on average (which is 34.6% more expensive than an average section of road with a tunnel in Slovenia [2]). When considering, however, the same proportion of p = 0.333, as in the case of Slovenian road, and with average S7 costs of k_t = EUR 104.5 million/km for the tunnel, and k_d = EUR 27.5 million/km for the remaining road section, according to Equation (1), the average cost of 1 km of S7 road would total k_p = EUR 53.1 million/km, that is, 9.9% less than in the case of Slovenian motorway (Fig. 4).

In the case of a 4.7 km section of S69 from Szare to Laliki (single lane, with a single-chamber tunnel [5, 8]), the construction cost on average totalled EUR 20.9 million/km. When calculating, according to the same proportion of tunnel length to the remaining road section, for p = 1/3, as in Slovenia, the average cost should total EUR 27.5 million/km.

Given that road construction in tunnels is several times more expensive than other sections of road, a comparison of the unit costs of construction of such roads should involve the same proportion p of tunnel length, as compared to the remaining section of the road being analysed.

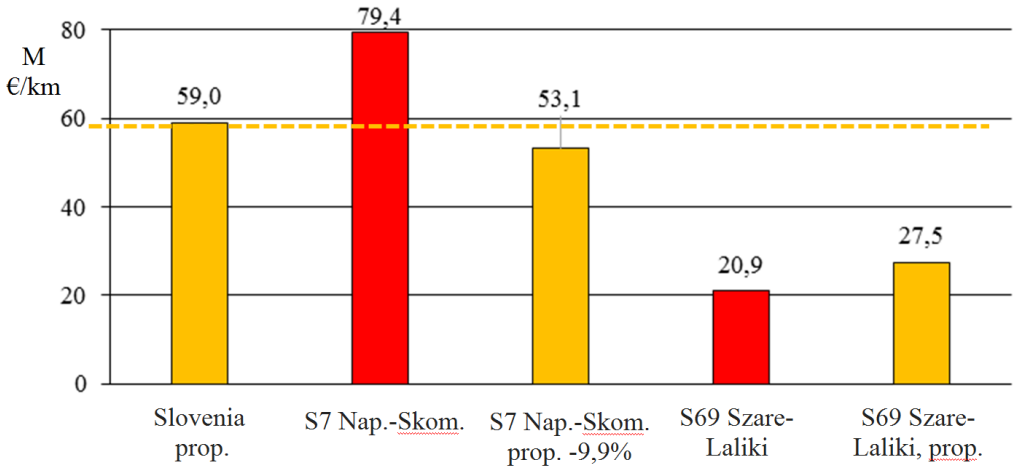

Fig. 4. Average costs per 1 km of the roads analysed and when observing the proportion p = 1:3 of tunnel length as compared to the total road section length (own study)

5. CONTRACTUAL PRICES FOR ROAD CONSTRUCTION IN POLAND

When analysing 24 contracts [4] concluded by the General Director for National Roads and Motorways in 2016 [11], for the construction of S-class express roads (with two separate double-lane carriageways, with a bearing strength of 115 kN/axle, emergency lanes, bridges and pedestrian passes, passenger service areas, underpasses and animal passes), there is a high difference in the average unit prices, ranging from PLN 9.4 million to PLN 322.9 million/km (Fig. 5).

For assessing price differentiation, V variability factor values were analysed according to the following equation:

$$V = s / \bar{x}, \ \bar{x} \neq 0, \tag{2}$$

where:
s – standard deviation in a sample
$\bar{x}$ – arithmetic mean in a sample

According to Wawrzynek [6], if the value of V variability factor remains within the interval <0%, 20%>, the differentiation within the population is low. On V values falling in the next interval (20%, 40%>, one can point to an average differentiation within

the population, whereas a high differentiation is observed in the case of values falling in the range (40%, 60%>, and a very high differentiation is found at V > 60%.

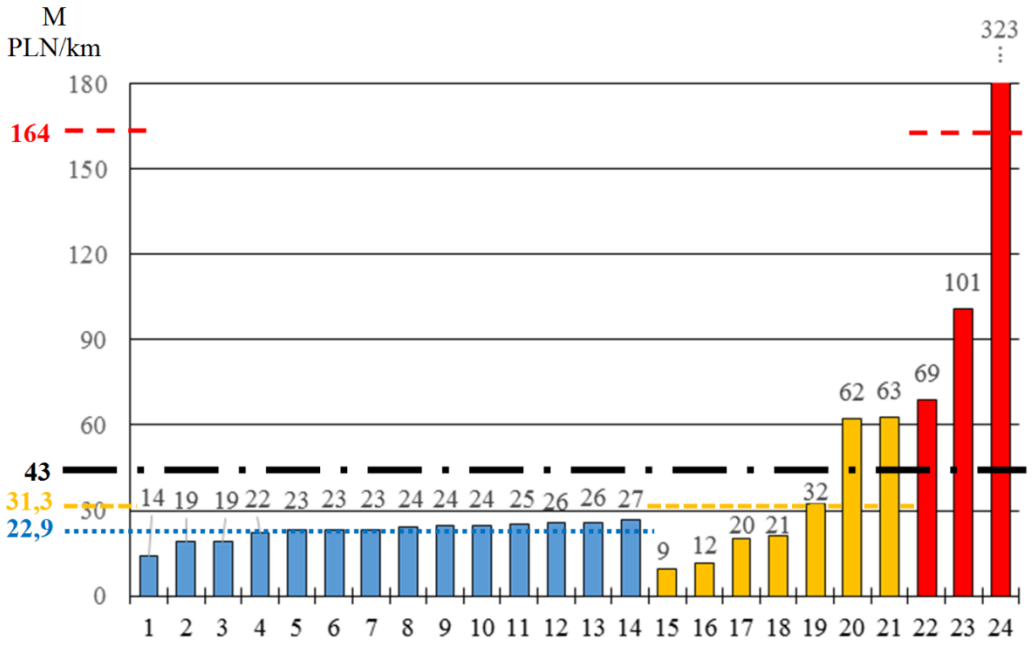

Fig. 5. S7 road construction contract prices in Poland, as concluded in 2016

Average price for all contracts under analysis totalled $\bar{x}_{24}$ = PLN 43 million/km, with standard deviation s_{24} = 63.3. The value of variability factor V_{24} = 147.2%, which is much higher than 60%, indicating a very high differentiation in prices.

5.1. Roads constructed in flat and undulated areas

When analysing 14 contracts for S-class road construction in the area of Poland north of Wrocław and Lublin, comprising flat and undulated areas, the average costs of such roads totalled $\bar{x}_{14}$ = PLN 22.9 million/km, with standard deviation s_{14} = 3.4. As the value of variability factor V_{14} = 14.8%, which is lower than 20%, according to Wawrzynek [6], one can assume that the price differentiation was low.

5.2. Bypass construction

A different price distribution was observed for contracts involving the construction of seven city bypasses. Rings around large cities were several times more expensive (e.g., for Olsztyn: PLN 62.1 million/km) than in the case of smaller cities and towns (e.g., Bolków: PLN 9.4 million/km). The average price of bypasses totalled $\bar{x}_7$ = PLN 31.3 million/km, with standard deviation s_7 = 22.5. The value of variability factor V_7 = 71.9% is higher than 60%, which means a very high differentiation in prices.

5.3. S7 express road sections

In the Małopolska region, between Krakow and Zakopane, in a difficult mountain area, involving the necessary strengthening of embankment and excavation slopes with retaining walls and anchors, and the need for constructing many bridges, as well as a double-chamber tunnel, construction is much more expensive than construction in flat areas. For example, the 7.6 km section between Lubień and Naprawa, comprising 10 engineering facilities and six small bridges, as well as two passenger service areas, will be built at an average cost of PLN 68.6 million/km, while the 6.1 km section between Skomielna and Rabka Zdrój, with two road nodes and 17 bridges with a total length of about 2.3 km, the longest of which being 992 m, will be built at an average cost of PLN 100.8 million/km. The most difficult section, that is the 3 km stretch between Naprawa and Skomielna Biała, with a double-chamber tunnel of 2.06 km, will be constructed at a cost of PLN 322.9 million/km. The average price of these S7 road sections total $\bar{x}_3$ = PLN 164.1 million/km, with standard deviation s_3 = 138.5 and variability factor V_3 = 84.4%, which is much higher than 60%, indicating a very high price differentiation.

6. CONCLUSION

Road infrastructure significantly interferes with the natural environment (by occupying a large area and dividing it into separate parts, prompting the need to transfer habitats of flora and fauna, construct passes and screens, and change watercourses, as well as causing pollution with exhaust gases and noise). As a result, the value of environmental elements totals about 18% (sometimes even 35%) of motorway capex. The costs of land purchase and transfers total about 15% (up to 30% in cities), whereas construction itself usually constitutes 25%, while administrative expenses total about 30% of the motorway value.

In 2012, the average construction cost of motorways in Europe totalled about EUR 9.4 million/km. Low costs were observed in Spain (EUR 6.7 million/km), while high costs were noted in Austria (EUR 12.9 million/km). In Germany, motorway construction was about 7% cheaper than in 1998, current costs are lower by 13% compared to the European average. In Poland, motorway construction costs total about EUR 9.6 million/km, which is 2% higher than average costs in Europe.

The most expensive sections are the ones with tunnels. For example, compared to average motorway construction costs in Slovenia, which total EUR 7.3 million/km (i.e., 22% lower than the European average), a 4.5 km road section with a tunnel that is 1.5 km long costs EUR 59 million/km, which is eight times more expensive. Similarly, a 3.05 km section of the S7 road from Naprawa to Skomielna Biała, with a tunnel stretching 2.057 km, will cost, according to the tender results, an average of EUR 79.4 million/km (i.e., 35% more expensive than in Slovenia). At the same time, with the same proportion of tunnel length to the length of road analysed, as in Slovenia, p = 0.33, after calculating the cost of the road section from Naprawa to Skomielna Biała, which is 9.9% lower than in Slovenia. Therefore, any comparison of unit costs of the construction of such roads (where roads in tunnels are several times more expensive than at other sections) should involve the same proportion p of tunnel length as the remaining section of the road analysed.

The average price in the 24 contracts for S-class road construction, concluded in 2016 by the General Director for National Roads and Motorways, totalled $\bar{x}_{24}$ = PLN 43 million/km. Certain contracts were characterized by a very high differentiation in prices, with standard

deviation s_{24} = 63.3 and variability factor V_{24} = 147.2%. Similarly, a very high price differentiation was observed for three sections of the S7 road in the mountain area ($\bar{x}_3$ = PLN 164.1 million/km, s_3 = 138.5, V_3 = 84.4%), as well as in the case of seven city rings ($\bar{x}_7$ = PLN 31.3 million/km, s_7 = 22.5, V_7 = 71.9%). In flat and undulated areas, however, the prices for the 14 S-class road sections in the area of Poland north of Wrocław and Lublin were characterized by low price differentiation ($\bar{x}_{14}$ = PLN 22.9 million/km, s_{14} = 3.4, V_{14} = 14.8%).

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