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RZECZOZNAWCA

Analysis of selected parameters affecting the duration of infrastructure investments

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Abstract: The purpose of this analysis is to present factors that contribute to delays in completing road investments and to identify a set of properties that could be used as the basis for predicting as accurately as possible the actual time required to construct a motorway or an express road. All contract parameters subject to analysis are known before signing. These include location conditions and the building permit design. A database was populated with 69 road contracts for which tender proceedings were initiated between 2009 and 2014. The contracts in question entailed construction works in Poland and the infrastructure was commissioned by the end of 2020.

Keywords: delays, scheduled duration, express roads, motorways, correlation

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1. Introduction

"Time is money", and even more so when it comes to long-term construction investments. In other words, one might say that delays are costs borne by the client or contractor resulting from extending the duration of construction. These extra costs mean that the subject of timely delivery is particularly important, both for the investor and for the contractor. Especially today, in a time when road infrastructure in Poland is developing rapidly. Since Poland's accession to the European Union, many new A-class roads and S-class roads have been built in Poland. These serve as important intercity links, European corridors, or bypasses for large cities.

Not all motorways or express roads have been completed according to schedule in terms of handing the road into use on time. Some took much longer to complete than it was anticipated at the tender stage. And this happened even though the ordering party for all those cases was the same public institution, i.e., the General Directorate for National Roads and Motorways [GDDKiA]. The question therefore arises as to whether GDDKiA uses any methods or calculations based on which it sets a completion date for the contractor? If so, then what data are used to determine the scheduled investment duration? The General Directorate does not provide information about this on its website. It is difficult to find papers in the currently available literature that analyse methods for determining scheduled duration of road investments. Most of the available literature focuses on researching delays.

2. Delays in infrastructure investments

Construction investment projects, and in particular long-term infrastructure (linear) projects, are highly susceptible to a number of external factors causing delays to the performance of works. The literature mentions three primary groups of factors. These include macroeconomic factors (unemployment rate and inflation), which are driven by global market conditions. The next group are factors associated with unique investment parameters, which, in addition to the design, include weather conditions and the relationship between the parties during the construction or design phase. Factors related to the contractor engaged in a given undertaking constitute the last group. The size, profile and experience of the contractor care significant here [1]. Errors in the submitted technical documents, which cause misunderstandings and disputes between the parties, are considered to be the main cause of delays. This often goes hand in hand with poor cooperation between the ordering party and the contractor, further exacerbating problems, for example when clarifying ambiguities in the documentation. A large number of subcontractors does not bode well for timely execution either. Perhaps proper cooperation is also missing. Furthermore, weather factors and failure to deliver construction materials on time also have a negative impact. [2]

However, merely identifying causes of delays is not sufficient to prevent them. Furthermore, the aforementioned disruptive circumstances become apparent only after a contract between the parties has been signed, so that it is not possible to use them to change the scheduled investment duration. Therefore, research has been ongoing for many years into the possibility of predicting the actual duration, even before construction begins. Such knowledge would allow one to organise and manage an investment in a more informed manner, thus avoiding many insufficiently thought-out decisions (made under time pressure) which do not always represent the best (cheapest) possible solution.

3. Data for analysis

A database of 69 road contracts for which tender proceedings were initiated between 2009 and 2014 was analysed. Contracts for investments published during that period were signed between 2009 and 2017. The contracts in question entailed construction works in Poland and the infrastructure was commissioned by the end of 2020. See below a table presenting a breakdown of the analysed contracts according to year and province. Investments spanning two provinces are shown in separate columns.

Table 1. Analysed contracts: location and year (author's own work)

Contract signing year	Dolnośląskie	Dolnośląskie / Wielkopolskie	Kujawsko-Pomorskie	Lubelskie	Lubuskie	Łódzkie	Małopolskie	Mazowieckie	Podkarpackie	Podlaskie	Pomorskie / Warmińsko-Mazurskie	Śląskie	Świętokrzyskie	Warmińsko-Mazurskie	Wielkopolskie	Wielkopolskie / Dolnośląs-kie	Wielkopolskie / Łódzkie	Zachodniopomorskie	**Total**
2009						1	1	2	2						2				**8**
2010						3	2		2			2		1		1			**11**
2011		1		1		1											1		**4**
2012						3				1									**4**
2013															1				**1**
2014	3			1	1		1	1	1				1		2				**11**
2015	3		2	2				1		1	1	3	1	4				5	**23**
2016							1	2				1			2				**6**
2017													1						**1**
Total	**6**	**1**	**2**	**4**	**1**	**8**	**5**	**6**	**5**	**2**	**1**	**6**	**3**	**5**	**7**	**1**	**1**	**5**	**69**

Twenty-five different contractors were engaged in the performance of the contracts presented in Table 1. Fourteen contractors were awarded only one contract each, whilst the others were used by GDDKiA several times. Only one of the contractors was responsible for more than 10 investments.

4. Analysis of selected parameters

Six parameters that can affect the duration of a construction investment were analysed. Table 2 shows the parameters in question and Pearson correlation coefficients for the parameters and scheduled duration.

Table 2. Correlation between given parameters and scheduled duration (author's own work)

No.	Parameter	Correlation coefficient
1	Number of junctions	0.19
2	Length [km]	0.09
3	Total number of engineering structures	0.04
4	Ground frost line	-0.09
5	Number of service stations [MOP]	-0.16
6	Mean altitude above sea level	-0.20

The table above shows that none of the analysed properties show a strong correlation with the scheduled duration. This probably means that none of these factors are taken into account by GDDKiA when setting investment completion dates. Diagrams (No.1, No. 3, No. 5, No. 7, No. 9, and No. 11) for each of the aforementioned properties and scheduled durations were drawn up to confirm the above assumptions.

Furthermore, the results obtained were confronted with diagrams (No. 2, No. 4, No. 6, No. 8, No. 10, and No. 12) on the given characteristics and contract delays. Delay with respect to the scheduled duration was taken into account. A delay in itself does not provide a clear answer as to how much a contract was delayed by. Therefore, a calculated delay was compared with the scheduled duration in order to obtain a percentage value that makes it possible to compare delays between contracts. However, it should be noted that delay is calculated on the basis of the date on which a section under construction is commissioned. The actual completion date for contracted works is usually different, as some finishing works are carried out when it is already possible for cars to drive along the section in question.

Graphs depicting the relationship between the parameter in question and the scheduled duration and relative delay are shown in sections 3.1 to 3.6.

4.1. Number of junctions

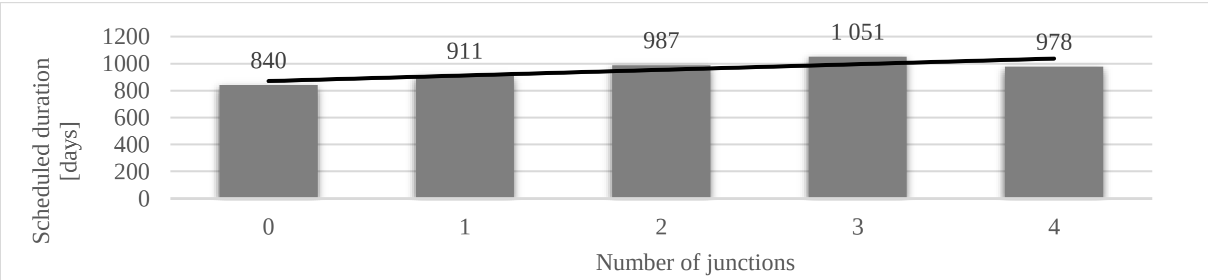

Fig. 1. Relationship between the number of junctions and scheduled duration (author's own work)

The graph of the number of junctions (Figure 1) shows that it impacts the planned duration of the investment, even though the Pearson correlation coefficient is only 0.19. The deviation for number 4 may be due to insufficient data based on which the average scheduled duration was calculated. Figure 2 below shows that for the maximum number of junctions the average delay is almost three times higher than if there are less junctions. This result may be related to the scale and complexity of an investment, as the larger the investment (more junctions), the less frequently it is delivered within the contractual deadline. It is therefore right to make the planned duration dependent on the number of junctions designed along a given section.

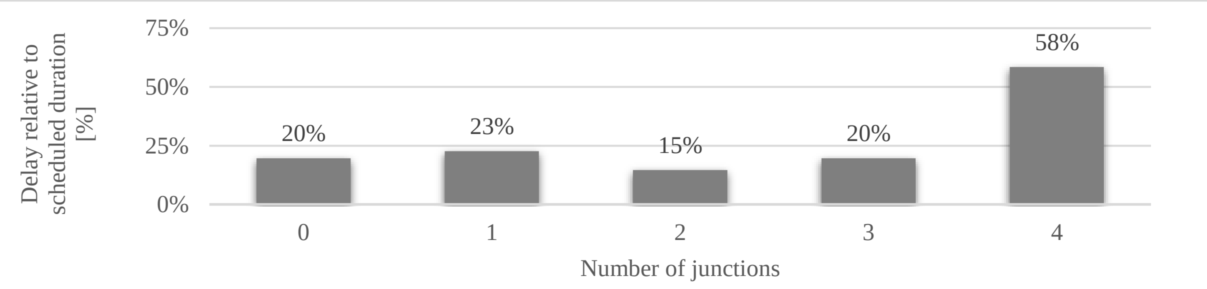

Fig. 2. Relationship between the number of junctions and average delay (author's own work)

4.2. Section length

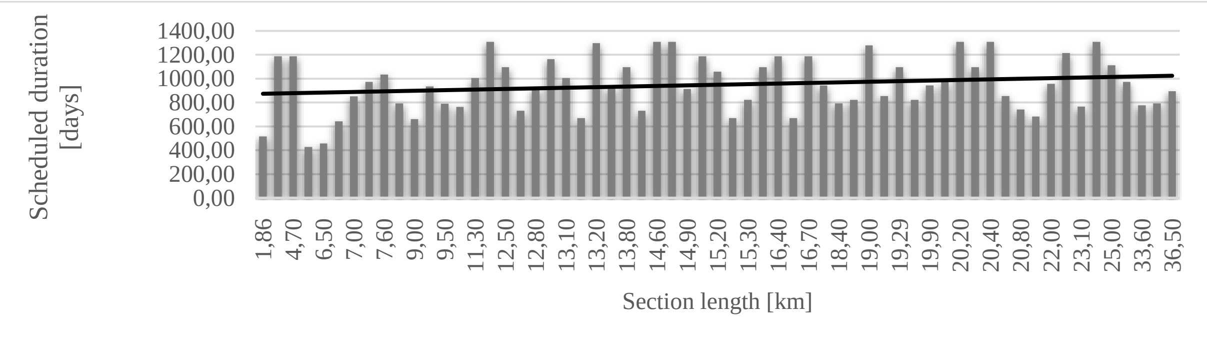

Fig. 3. Relationship between section length and scheduled duration (author's own work)

The graph above shows that section length is not clearly relevant in determining investment duration. Admittedly, the trend indicates a slight increase in duration as length increases, but looking at individual contracts one gets the impression that duration was determined independently of this parameter. Figure 4 shows that delays of up to 50% of the scheduled duration occur for short sections. Many more contracts were delayed by more than 50% for lengths of 15 km and above. One may therefore conclude that contract delays may depend on section length and this parameter should therefore be taken into account when determining scheduled duration.

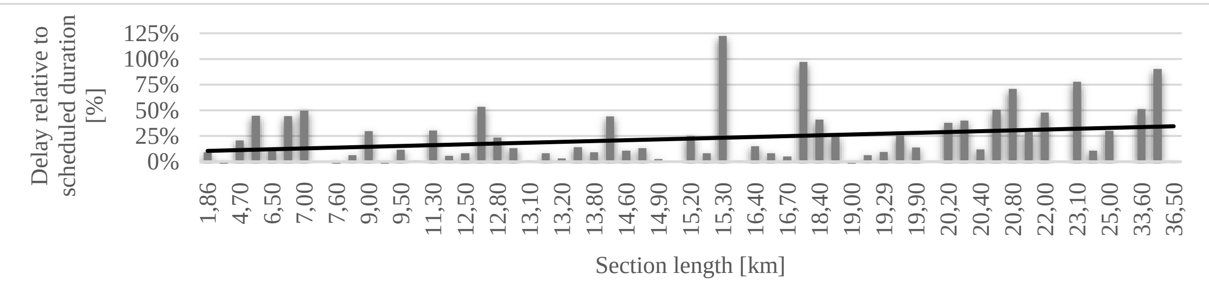

Fig. 4. Relationship between section length and average delay (author's own work)

4.3 Number of engineering structures

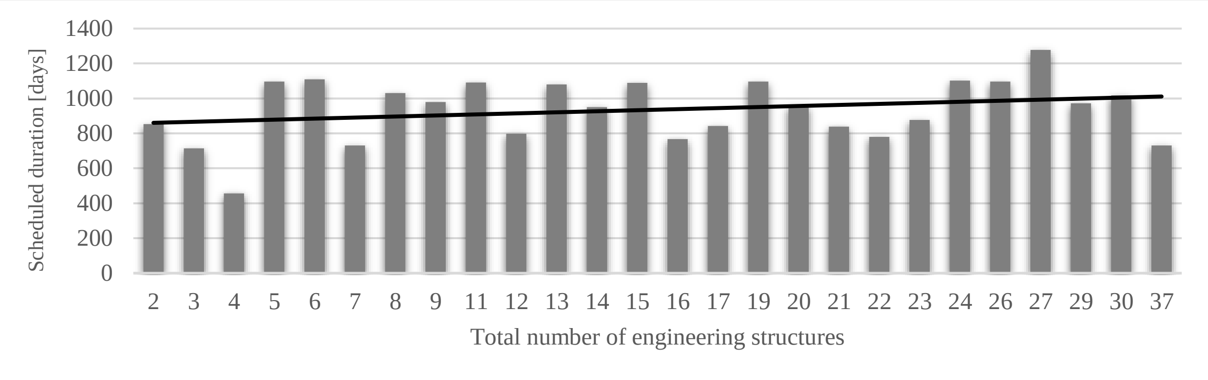

Fig. 5. Relationship between the total number of engineering structures and scheduled duration (author's own work)

Similar to section length (Figure 3), the graph above (Figure 5) shows that the number of engineering structures is not clearly significant in determining investment duration. However, Figure 6 does show that the number of planned engineering structures has a strong impact on the actual date the road is commissioned. The reason for this may be that road engineering structures have a strong impact on the ability to carry out works along the entire section. In addition, bridges and flyovers are often built over areas with valuable natural qualities and require particular care during construction works. Therefore, this parameter should undoubtedly be taken into account when determining the duration of works.

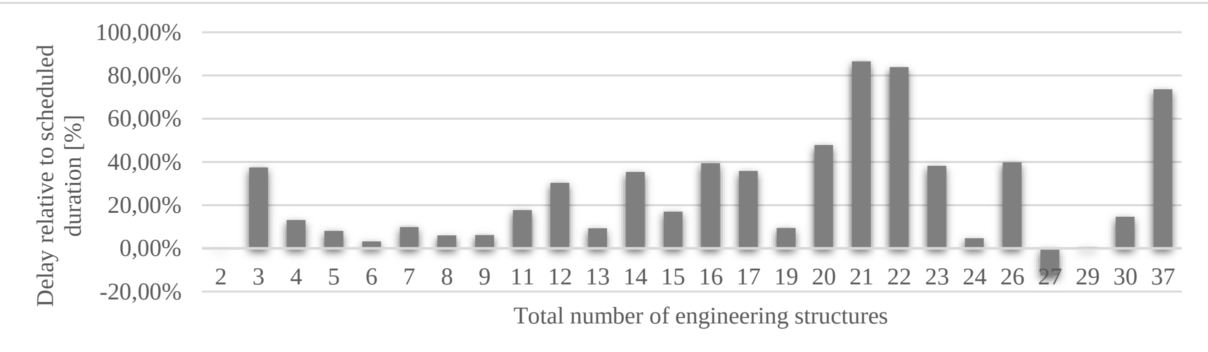

Fig. 6. Relationship between the total number of engineering structures and average delay (author's own work)

4.4. Ground frost zone

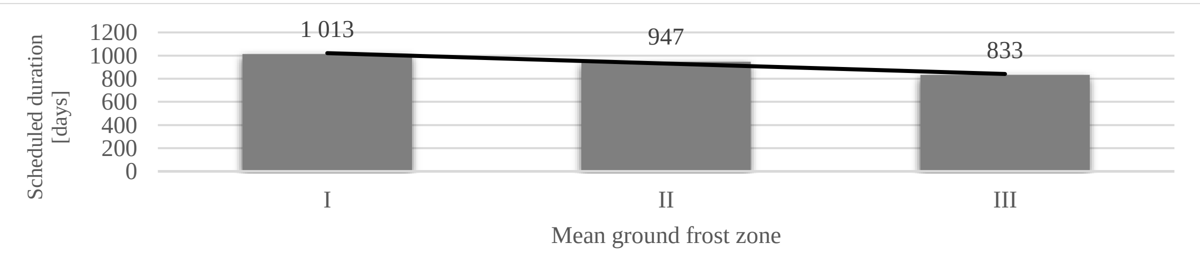

Fig. 7. Relationship between ground frost zone and scheduled duration (author's own work)

To some extent the ground frost zone reflects the nature of the atmospheric conditions prevailing in a given area. It is obvious that unfavourable weather can delay even the best organised road projects. However, Figure 7 shows that scheduled duration tends to be shorter in areas with more difficult weather conditions. Figure 8 shows that when it comes to delays the trend is reversed: the larger (deeper) the ground frost zone, the greater the average delay. One may therefore presume that if GDDKiA had taken the ground frost zone into account when determining contract duration, relative delays in Zone III would decrease.

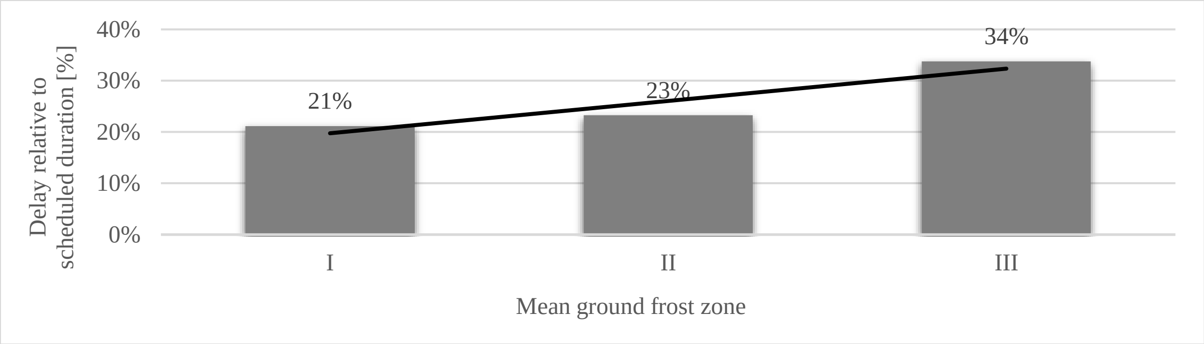

Fig. 8. Relationship between ground frost zone and average delay (author's own work)

4.5. Number of Service Stations

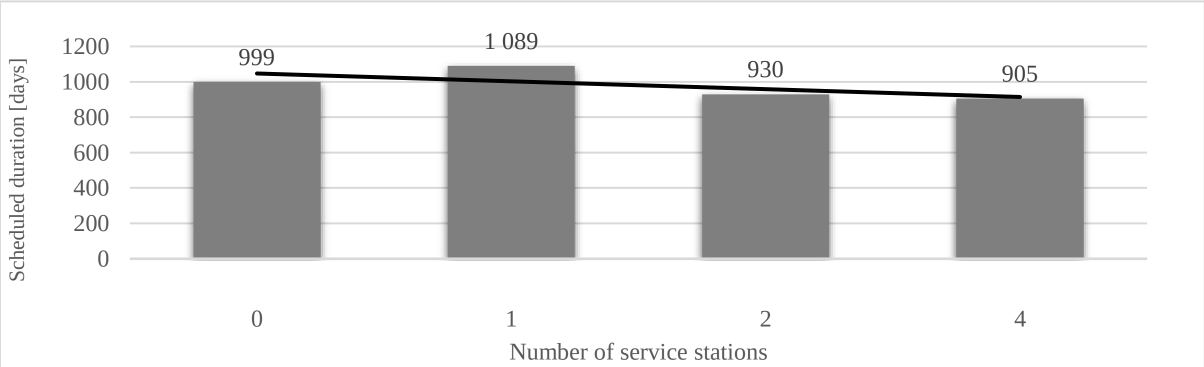

Fig. 9. Relationship between the number of service stations and scheduled duration (author's own work)

Figure 9 shows that as the planned number of service stations increases, the scheduled duration decreases. Such action seems to be devoid of logic. However, the differences in average durations are so small that one may conclude that this parameter was probably not taken into account when determining investments duration. On the other hand, similar to ground frost zone, an analysis of the number of service stations in Figure 10 shows that as the number of planned Service Stations increases, the time the works actually take to complete in relation to the scheduled period increases. One may therefore presume that if GDDKiA had taken the number of service stations into account when determining contract duration, relative delays for investments with larger numbers of service stations would decrease.

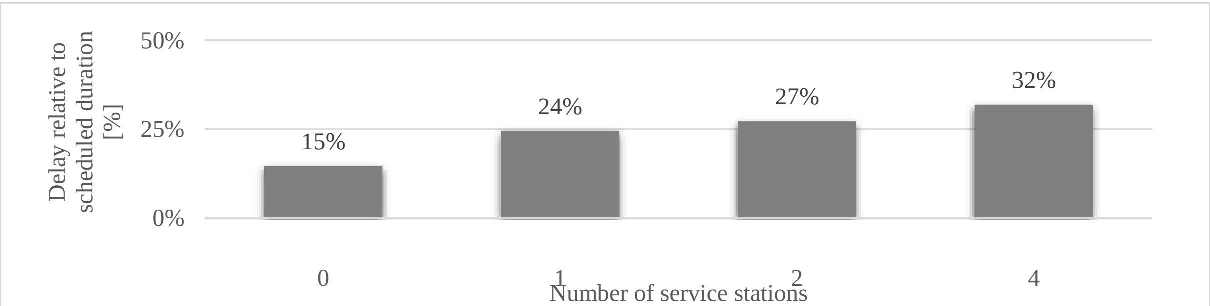

Fig. 10. Relationship between the number of service stations and average delay (author's own work)

4.6. Mean altitude above sea level

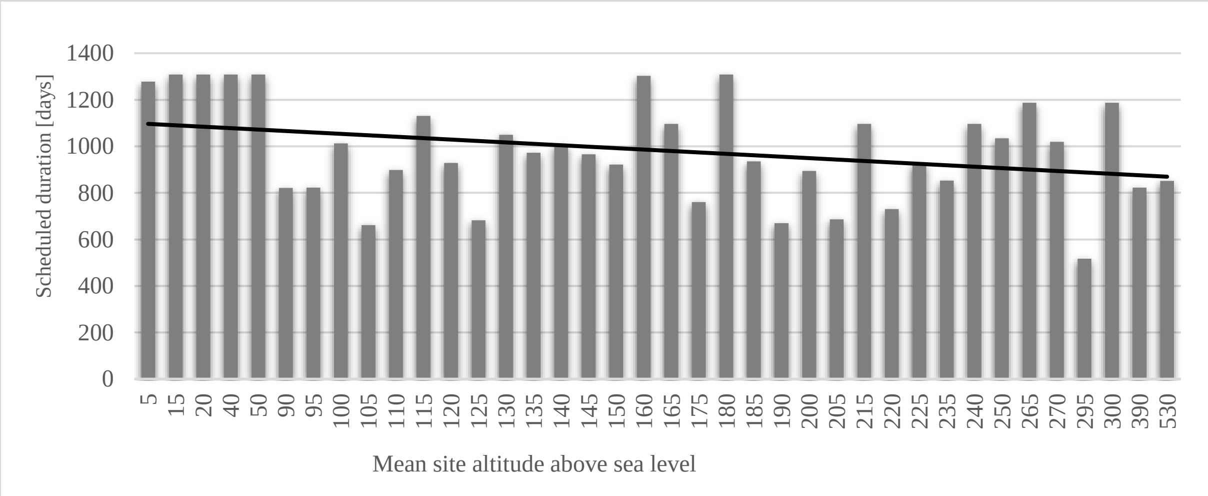

Fig. 11. Relationship between the mean altitude above sea level and scheduled duration (author's own work)

Figure 11 shows that the scheduled duration tends to decrease as the mean height above sea level for the construction site increases. Results for delays are reversed. Figure 12 clearly shows a correlation between the following variables: the higher the construction site, the more delays the contract generates. There are also exceptions to this rule, but the overall trend is quite clearly increasing. This may be caused by the types of substrates at given altitudes. The higher the construction site, the likelier it is that the ground conditions that can cause problems in completing the investment on time will be more difficult and less predictable.

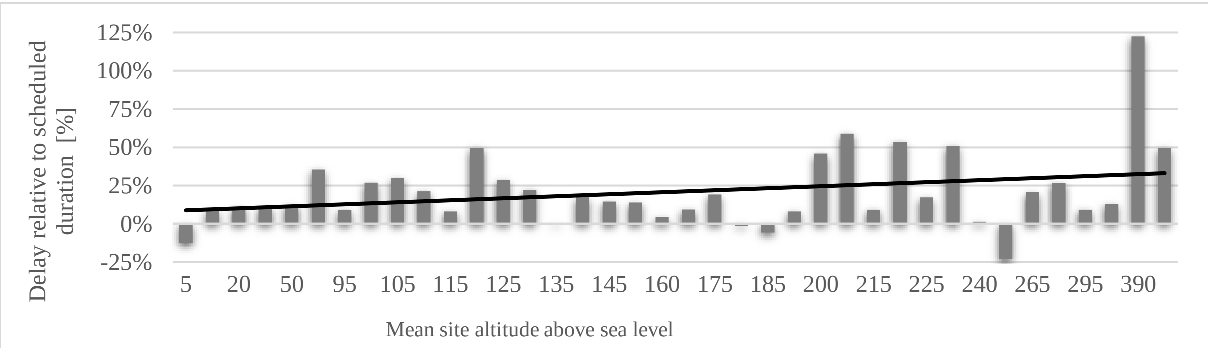

Fig. 12. Relationship between the mean altitude above sea level and average delay (author's own work)

5. Conclusions

The graphs in Section 3 show that all the selected contract parameters have an impact on timely completion of an undertaking. However, not all of them are related to scheduled duration. Only the number of junctions and the number of engineering structures showed a correlation with the designated completion date. Interestingly, the length of a road section does not appear to be related to the designated completion date, although the trend is positive.

Figures 8 and 12 show that simple parameters defining the location, such as, for example, the ground frost zone or the mean altitude above sea level, can indicate the scale of the delay. However, they are closely linked to technical features and a design tailored to the site of the planned investment. A single parameter depends on a second property and thus changes together with it. In such a situation, it is not possible to determine which of them has a real impact on the completion date and which parameter is merely a by-product. However, even knowing the relationship between the parameter, which is a by-product, and the actual duration, one can identify investments for which the scheduled duration should be longer.

However, it should be borne in mind that the above analysis is based on average delays in a group of contracts, which goes some way in showing the impact of these properties, but it lacks precision. An average can be calculated on the basis of contracts with 0% and 100% delays, yielding a value of 50%.

The research presented here indicates that it is possible to show that there are contract parameters which, even before the start of an investment, can determine whether a road will be commissioned on time. At this point, it should be pointed out that research on a larger body of data is necessary before actual principals can be identified. The database used in this analysis, populated with 69 contracts, is only a fraction of the experience from hundreds of already completed construction projects. A larger number of records would facilitate predictions that better generalise the obtained small-scale relations and will allow for an implementation of rules that minimise the risk of delay by appropriately forecasting the scheduled duration for future investments. Such action will make it possible to introduce a better work system that can improve in both the time and the costs required for completing undertakings.

Special thanks

The data for this research was obtained from the General Directorate for National Roads and Motorways' website and from websites of relevant Contractors and Designers. Some of the data were obtained courtesy of GDDKiA, who released the data as a result of email correspondence or within the scope of providing public information. The parameters selected for this analysis have been taken from a master's thesis entitled "Evaluation of the influence of selected parameters on construction delays using machine learning" written at the Warsaw University of Technology under the supervision of dr inż. Hubert Anysz.

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