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**Tomáš SEIDLER<sup>1</sup>, Denisa CIHLÁŘOVÁ<sup>2</sup>, Marek MIHOLA<sup>3</sup>, Marián KRAJČOVIČ<sup>4</sup>****PREDICTION OF ROADS DISTURBANCES ON UNDERMINED AREA****PREDIKCE PORUCH POZEMNÍCH KOMUNIKACÍ NA PODDOLOVANÉM ÚZEMÍ****Abstract**

The paper discusses how to predict road disturbances due to mining activities and statistically evaluates the available data of disturbances on roads in relation to the prediction maps of subsidence. It outlines two possible prediction models of disturbances caused by mining incidences and assesses their credibility.

**Keywords**

Undermined area, map of subsidence, pavement management system.

**Abstrakt**

Příspěvek pojednává o možnostech predikovat vznik poruch pozemních komunikací vlivem důlní činnosti. Statisticky hodnotí dostupná archivní data o poruchách ve vztahu k predikčním poklesovým mapám. Nastihuje dva možné modely predikce budoucích poruch od důlních škod a hodnotí jejich věrohodnost.

**Klíčová slova**

Poddolované území, poklesová mapa, systém hospodaření s vozovkou.

**1 INTRODUCTION**

On the present period, characterized by large cuts in the budgets and by an investments shortage in all sectors, becomes important, more than ever, to consider carefully each investment. In the domain of transport and road construction it is necessary to pay an attention to the quality of maintenance. New investments are evaluated, therefore the existing road network must be preserved in the highest quality. The ideal tool to resolve this issue would be systematic and consistent use of the pavement management system (PMS hereafter). Its implementation in Czech Republic environment is still inadequate and systems, as well as management differ in each region. Unfortunately the PMS launching, in times when the funds designated to transport infrastructure were

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available, rather failed and its launching will be not quite this simple today. The initial investments for PMS implementation are relatively important however, properly functioning PMS can then save a large amount of funds every year.

For instance, the study of the PMS benefit in the state of Arizona, USA [1], published in 2000, shows that each dollar spent on PMS operation, development, management represents 30 dollars of savings on pavement repair costs.

If there would be also included the expenses of the road infrastructure users, the yearly savings, for each dollar spent on PMS, would be more or less of 250 dollars. These numbers result from sixteen years long PMS experience.

Generally, the benefits of PMS operation are beyond dispute, but many obstacles must be overcome while launching a PMS project. In the case of Moravian-Silesian region (MSR hereafter), one of these obstacles is the region's specific positioning on the area of long mining activity. We are dealing with two districts here, the district of Karviná where the mining activity is still in progress and the district of Ostrava where the impact of mining activity is exhausted or fading. Furthermore, the article deals closely with Karviná district where the influences from undermining are still active, thus eligible to obtain additional data for further analysis.

## 2 CLASSIFICATION OF REGIONS AND DISTURBANCES

According to the Czech regulation, the mining activity impacts prescribes the standard ČSN 73 0039 "Designing of objects in undermined area" [2]. The selection of construction apprehension against the undermining effects is, accordingly to [2], always based on several factors:

- type and size of continuous or discontinuous surface deformations,
- time period the object is exposed to the influences of undermining,
- importance and life cycle of the construction,
- object design,
- functional and technological equipment requirements.

The expected effect of undermining is sorted accordingly to the terrain parameters (horizontal strain „ $\varepsilon$ “, radius of curvature „ $R$ “ and tilt „ $i$ “) into so-called construction site groups.

Table 1. Classification of undermined areas into construction sites (source: [2], [3])

Construction site	ČR	Poland	Russian federation
I	$\varepsilon > 7 \cdot 10^{-3}$ $R < 3 \text{ km}$ $i > 10 \cdot 10^{-3} \text{ rad}$	$\eta > 120 \cdot 10^{-6} / \text{m}$	$T < 10 \text{ mm/m}$ $\varepsilon < 7,5 \text{ mm/m}$ $\rho > 3 \text{ km}$
II	$7 \cdot 10^{-3} \geq \varepsilon > 5 \cdot 10^{-3}$ $3 \geq R > 7 \text{ km}$ $10 \cdot 10^{-3} \geq i > 8 \cdot 10^{-3} \text{ rad}$	$T < 15 \text{ mm / m}$ $\eta < 120 \cdot 10^{-6} / \text{m}$ $\varepsilon > 9 \text{ mm/m}$	$T < 8 \text{ mm/m}$ $\varepsilon < 6 \text{ mm/m}$ $\rho > 5,5 \text{ km}$
III	$5 \cdot 10^{-3} \geq \varepsilon > 3 \cdot 10^{-3}$ $7 \geq R > 12 \text{ km}$ $8 \cdot 10^{-3} \geq i > 5 \cdot 10^{-3} \text{ rad}$	$T < 10 \text{ mm / m}$ $\eta < 90 \cdot 10^{-6} / \text{m}$ $\varepsilon > 6 \text{ mm/m}$	$T < 5 \text{ mm/m}$ $\varepsilon < 3,5 \text{ mm/m}$ $\rho < 12 \text{ km}$
IV	$3 \cdot 10^{-3} \geq \varepsilon > 1 \cdot 10^{-3}$ $12 \geq R > 20 \text{ km}$ $5 \cdot 10^{-3} \geq i > 2 \cdot 10^{-3} \text{ rad}$	$T < 5 \text{ mm / m}$ $\eta < 50 \cdot 10^{-6} / \text{m}$ $\varepsilon > 3 \text{ mm/m}$	$T < 4,5 \text{ mm/m}$ $\varepsilon < 2,5 \text{ mm/m}$ $\rho < 18 \text{ km}$
V	$\varepsilon = 1 \cdot 10^{-3} \text{ and less}$ $R = 20 \text{ and more km}$ $i = 2 \cdot 10^{-3} \text{ and less rad}$	$T < 2,5 \text{ mm / m}$ $\eta < 20 \cdot 10^{-6} / \text{m}$ $\varepsilon > 1,5 \text{ mm/m}$	$T < 4 \text{ mm/m}$ $\varepsilon < 2 \text{ mm/m}$ $\rho > 20 \text{ km}$
$R$ – radius of curvature, $\varepsilon$ – horizontal strain, $i$ – tilt, $T$ – change in slope, $\eta$ – curvature of terrain, $\rho = 1/h$			

There are five of these groups, whereas the site “V” does not require special precautions, the sites “IV” and “III” can be provided within economically acceptable measures only. The sites “II” and “I” are not suitable for construction and can be used if justified clause only. An equivalent to this classification, in term of Czech conditions, is in usage in other countries (see Table 1).

The basic disturbance classification comes from the type of terrain deformation and is divided into continuous and discontinuous. These disturbances can have a versatile effect on the road. The disturbances incurred on the road network in the district of Karviná are classified by an administrator into so-called large mining damages (VDŠ hereafter) and small mining damages (MDŠ hereafter).

Among MDŠ are included, in particular, small surfaces shaping (piecing), cracks filling, drainage modifications, levering of sewerage manhole covers, as well as repairs or installations of the equipment, such as new barriers, vegetation, vertical and horizontal signs. Generally, MDŠ are merged into the category of disturbances with the repair costs up to 100 000 CZK roughly. Among VDŠ belong all repairs of large scale, i.e. the repairs of costs higher than 100 000 CZK. Most often these include disturbances such as surface deformation, transverse cracks, humps, horizontal and vertical deformation and overall surface denivelation.

### 3 DISTURBANCES ANALYSIS AND CREATION OF FORECASTING MODEL

Disturbances recorded on the road network in the district of Karviná during the last nine years were evaluated and statistically analyzed. The disturbance classification into the categories VDŠ and MDŠ stayed unchanged. The basic objective of the analysis is the question - when the road network disturbance occurs in relation to its location on the map of subsidence. The analysis is based on data from yearly presumptive subsidence maps, thus forecast maps, thereafter processed by the software program ArcGIS. The curvatures (raster models) were generated on the base of subsidence maps of isocatabases (isolines of subsidences) and afterwards categorized into each construction site group. Disturbances, obtained from the road administration of Moravian-Silesian region (SSMKŠ hereafter) and superposed on road network, were then localized in function of elaborated subsidence and curvature maps in order to identify, so-called, the most significant year of the undermining impact on the road, itself already classified into a known site group.

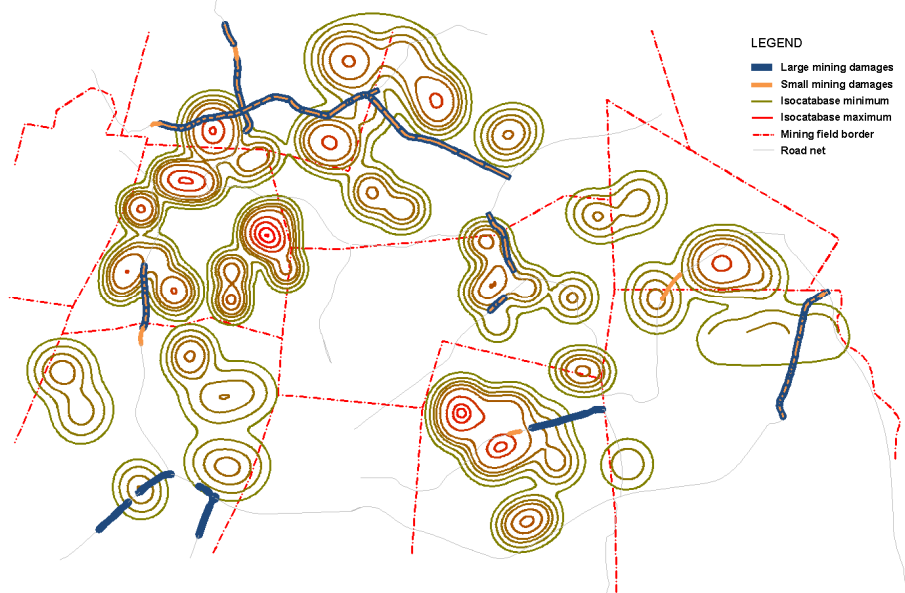


Figure 1: Forecasting subsidence map with recorded disturbances for year 2003

### 3.1 The isolation of the most significant year

The starting point for the most significant year isolation was an assumption that the biggest rate of disturbances would occur precisely in the year of predicted subsidence. Another variant assumes

The most significant year would be one-year respectively two-years postponed with regard to a subsidence forecast. We have used the site groups I and II as a criterion of the most significant year isolation because, on the one hand, they are namely the least favourable groups, and on the other hand, the disturbances appearance and evolution may proceed more slowly in the case of other groups.

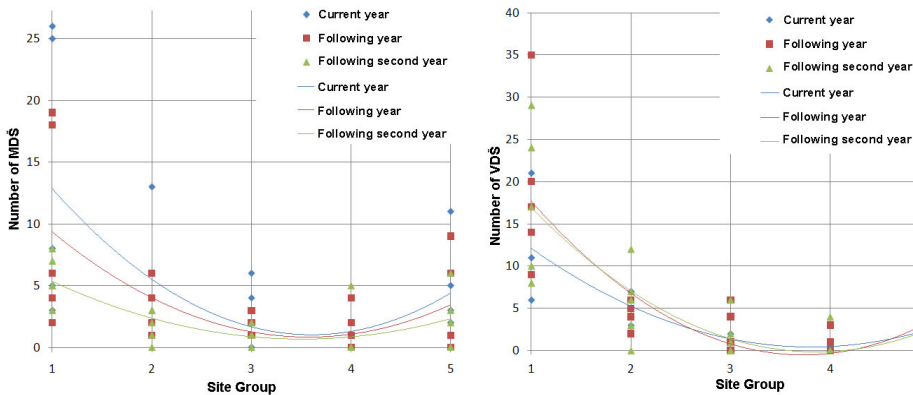


Figure 2: Relation between VDS and MDS appearance and site group in function of time

The graphs on Figure 2, where VDS and MDS occurrence is drawn in logarithmic scale, imply the following:

- Disturbances appearing on the road network within current year fall mostly into MDS
- VDS significantly affect the road net within a period of following and following second year

The VDS appearance delay may have several reasons. For example, the data are tabled in function of the date of reparation therefore, the date of their formation can be shifted into an earlier period. This effect would not necessarily affect MDS because, coming from their definition, their repair costs are of lesser importance. The VDS are, on contrary, of bigger scope thus requiring more financial and organisational resources. That is why the disturbance repair may be time-shifted.

Interesting is also the fact that disturbances appearance of VDS and MDS as well, is raising again in the case of the less menaced fifth group. This will be the subject of further research.

### 3.2 Prediction models of the genesis of disturbance

Next step is to provide the prediction of occurrence rate of the mining damages, appearing on affected roads, in function of the site group classification and of the date of appearance; within current year “ $x$ ”, within following year “ $x + 1$ ”, within following second year “ $x + 2$ ”. The forecast equations were dressed by the mean of multi-linear regression. These equations are based on the whole data-set, ArcGIS program output. The constant procedure lies on the comparison of the subsidence map from year “ $x$ ” with the occurrence rate for year “ $x$ ”, “ $x + 1$ ”, “ $x + 2$ ” similarly, as it was used for the most important year isolation.

Two methods were applied in order to draw up the prediction equations, whose task was to obtain the disturbance rate of year “ $x+1$ ”, respectively “ $x+2$ ” from the data of the year “ $x$ ”.

## First method

From the information of the year “ $x$ ”, containing the construction site group classification and the rate of mining damages ( $PD\check{S}$  hereafter) as well, the rate of disturbances for the year “ $x + 1$ ” was predicted first, its value being used for the prediction of the year “ $x + 2$ ”. Mathematically these relations can be expressed by formulas (1) and (2).

$$PD\check{S}_{x+1} = 5,2 + 0,8 \cdot D\check{S}_x - 1,2 \cdot T\check{R}, \quad (1)$$

$$PD\check{S}_{x+2} = 1,3 + 0,8 \cdot PD\check{S}_{x+1} - 0,3 \cdot T\check{R}, \quad (2)$$

where:

- $PD\check{S}_{x+1}$  – predicted rate of mining damages within a period of following year,
- $PD\check{S}_{x+2}$  – predicted rate of mining damages within a period of second following year,
- $D\check{S}_x$  – predicted rate of mining damages within a period of current year,
- $T\check{R}$  – construction site group.

The model's credibility is stated graphically on Figures 3 and 4. The red line represents 100% accordance ( $R=1$ ), that means, the predicted data entirely correspond to the recorded data.

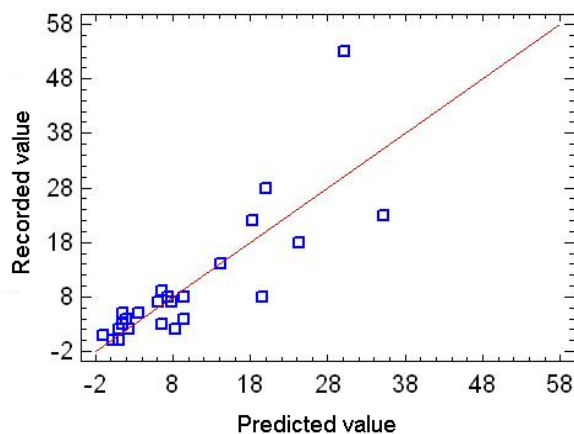


Figure 3: Relation between recorded and predicted rate of mining damages for year “ $x + 1$ ”

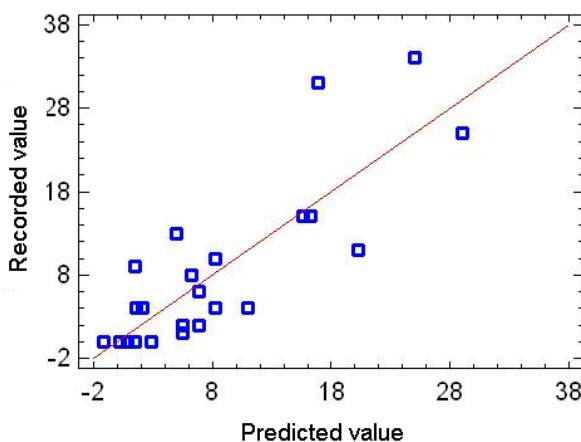


Figure 4: Relation between recorded and predicted rate of mining damages for year “ $x + 2$ ”

## Second method

Based on the construction site group and on the rate of mining damages within the year “ $x$ ” we proceed directly to the forecast of year “ $x + 2$ ”, mathematically expressed by formula (3).

$$PD\check{S}_{x+2} = 5,4 + 0,7 \cdot D\check{S}_x - 1,3 \cdot TR\check{R}, \quad (3)$$

The graph on Figure 5 demonstrates the degree of confidence of this model. Again, the red line represents 100% accordance ( $R=1$ ) thus, a perfect correlation of predicted and recorded data.

The P-value is less than 0.01 for all aforesaid forecast formulas, implying a strong statistical relation, with an overall variation range of 93-95 %, on the confidence level. The coefficient of correlation, in range of 0.83 – 0.84, emphasises the strong relationship between recorded and predicted data of the disturbance rate. If we compare the results of each method, we may observe a very narrow result's closeness (coefficient of correlation 0.99). However, the first method (“ $x + 2$ ” calculus based on “ $x + 1$ ” output) is more accurate. On the other side, it is more exigent on the execution time also, its accuracy may be affected by a calculus error hidden in an already computed value of  $PD\check{S}$ .

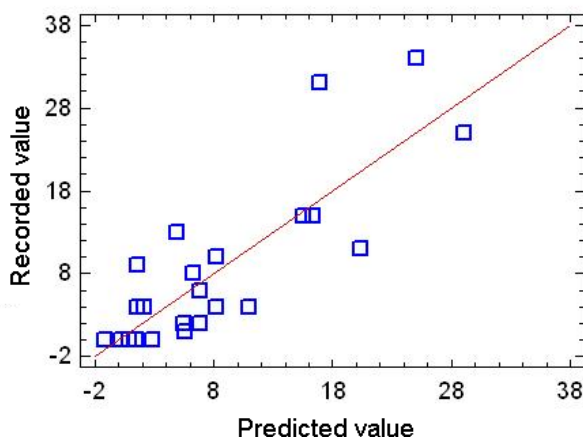


Figure 5: Relation between recorded and predicted rate of mining damages for year “ $x + 2$ ” (direct calculus)

## 4 CONCLUSION

If the prediction, based on year “ $x$ ”, is accurate enough for years “ $x + 1$ ”, “ $x + 2$ ” (as it was shown), one can generalise on year “ $x + n$ ”. Of course, there would be some loss of accuracy related to the subsidence maps availability and to the information of construction site group classification. Nevertheless, such a forecast would be of great use in the scope of PMS. The mining disturbances are and will be random events however, we can try to predict them by the use of similar methods, even in the limited frame. The knowledge of predicted values would permit to reserve future funds in the budget of DŠ eventually, in the general reserve. The financing of DŠ is a complex problem. By operation of law, all damage costs are on full charge of the mine operator nevertheless, in reality, more and more judgements emphasise the ratio of damages caused by mining activity and damages caused by road traffic. Consequently, information such as traffic density and expenses shall be included in the next step.

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