

RELATIONSHIP BETWEEN THE COORDINATION OF RAILWAY ENGINEERING WORKS AND THE SIZE OF DISRUPTIONS IN TRAIN TRAFFIC¹

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Carrying out renewal or modernization works on a railway line require temporary closures of track sections. An important issue is to plan the works to minimize the traffic disruptions associated with the track closures, but simultaneously limiting the total duration of engineering works. In this paper the influence of works coordination on different track sections on the size of traffic disruptions was examined. The analysis was performed for three different schedules of renewal project on a 30-kilometer section of double-track railway line No. 353 Inowrocław – Nieszawka. The results of the study indicates that grouping works on many tracks and sections may be beneficial for low traffic intensity, while for high traffic intensity (lines with a high level of traffic capacity utilization) it results in significantly longer travel times and the need to cancel trains).

Key words: railway construction works, works coordination, traffic disruptions, track possessions.

1. INTRODUCTION

Maintenance of primary operational parameters for railway lines within their whole life cycle requires performing systematic renewal works while growing expectations of railways users induce implementation of modernization projects. Engineering works, however, require introduction of the so-called “track closures” [14] which cause temporary disruptions of rail traffic. A crucial organizational challenge is to plan works in such a way as to finish them as soon as possible while restricting rail traffic disruptions [5]. This article focuses on the influence of grouping (coordination) of works on various railway sections on the size of traffic disruptions resulting from track closures.

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2. LITERATURE REVIEW AND SCOPE OF THE ARTICLE

The issue of optimization of planning maintenance and modernization works, discussed in the literature, can be divided according to [2] into two groups:

- planning of the proper scope of works at the proper time span and establishment of necessary schedule of track closures, based on the prognosed wear of rails, sleepers, ballast and subgrade,
- assigning the top-down defined scope of works, in particular locations, adequate time spans and track closures resulting from this assignment, or preparing a train timetable for the top-down defined track closures.

The first group rarely covers an analysis of the influence of conducting engineering works on the rail traffic quality, and the optimization focuses mainly on the costs directly connected with maintenance of the railway line. The main task is planning repairs or replacement of permanent way elements at the proper state of their degradation and also cost-efficient performance of works, including labor and machine costs (e.g. [6, 9]).

In the second group optimization may refer to:

- the schedule of works implementation and of track closures on the analyzed section of the rail network, at the defined and unchanged train timetable [5] or excluding the train timetable analysis [3] or [10],
- the train timetable at track closures, which are defined and unchanged [15], whereas in some models it is acceptable to introduce small changes of the track closure starting time within a pre-defined period [4],
- simultaneously the train timetable and the works implementation schedule as well as the track closures schedule related to them [8].

This article, discussing the influence of various variants of works implementation on the size of rail traffic disruptions, can be placed in the second of the afore-mentioned groups. Attention should be paid that most publications refer to several-hour closures whereas the discussion presented in the article deals with renewal and modernization projects requiring twenty-four-hour closures.

The article presents an analysis of the traffic disruptions carried out for:

- three variants of works phasing and corresponding three variants of track closures,
- three variants of efficiency of track closures for the performance of works described by various works schedules,
- three variants of traffic intensity, described by the line capacity usage.

The scope of the article defined above covers only chosen aspects of the discussed issue. There have been assumed the following limits for the presented analysis scope:

- For the analysis the train timetable optimization model at preset track closures has been used (not changed during the optimization process). Its most

- important assumptions have been presented here, however, the formal mathematical model formula has not been repeated, as it has been presented in [7];
- The technology, phasing and coordination of engineering works on railway lines influences not only the size of traffic disruptions but also the project implementation costs or the risk of the works implementation delay [8]. A full evaluation of alternative phasing variants of works and their schedules requires conducting a complex cost-benefit analysis. An extension of the analysis shall be the subject of further study.

The results presented in this article refer exclusively to traffic disruptions included in the train timetable (extension of the scheduled travel time and the number of cancelled trains). Another group of disruptions includes train delays, the probability of which increases together with the increase of the capacity usage [1], i.e. in the event of necessary track closures. A comparative analysis of the delay volumes, using simulation methods, shall be further examined.

3. ASSUMPTIONS

Every railway renewal or modernization project is divided into phases, at which the train travel time, on the railway section under analysis, may be different due to:

- speed limits due to safety of the workers and works technology, increased dwell times caused by crossing or overtaking of two trains (negative effect),
- increased running speed limits as a result of completed works, finished at previous phases (positive effect).

It should be stressed that the result of the works completed in previous phases will be noticeable only if the changed railway line operational parameters are taken into account in the train timetable, thus if the annual train timetable or a temporary timetable are updated. It has been assumed, for the sake of the analysis, that completion of each works phase is related to changing the train timetable (every 6-8 weeks). Application of so frequent changes to the train timetable, especially regarding passenger trains, seems questionable, however, it is consistent with the current policy of the Polish Railway Infrastructure Manager – PKP PLK S.A. For example, in the annual train timetable for 2015/16 there were assumed five periods of temporary train timetables, and the shortest period covered six weeks (04.09.16-15.10.16) [12]. Simultaneously, according to the internal instructions of PKP PLK S.A. [11], for each temporary train timetable an update in the data base was possible in order to take into consideration improved parameters of the railway line in the train timetable.

Moreover, an additional comment should be given to the assumption that together with the completion of a particular works phase the target speed of trains shall be introduced. It is in compliance with requirements set forth for contractors of works by the PKP PLK S.A. – according to the internal instructions [13]

any engineering works should be performed applying such technologies to achieve the target speed at the stage of the operational commissioning. Among others, it requires applying a dynamic stabilization or stressing CWR track [13].

The proportions between the negative and positive effect of works are changing during the investment period and the course of this fluctuation depends on the assumed phasing and works schedule. In order to evaluate alternative variants of works implementation a parameter has been suggested which takes into account both extension as well as shortening of the timetable travel time, but also the number of cancelled trains. Definition of this parameter is presented in the following section of the article.

4. RESEARCH METHOD

We shall mark the set of all works phases as P , the set of all trains within the period of a phase $p_i \in P$ as T^{p_i} , and from this set we shall define a subset of cancelled trains or trains directed to an alternative route due to limitations of capacity during the closure period: $T_c^{p_i} \subset T^{p_i}$. For each train $t \in T^{p_i} \setminus T_c^{p_i}$ there shall be allocated timetable travel time over the whole analyzed track section before commencement of works ($JT_t^{p_0}$) and in a particular works phase ($JT_t^{p_i}$). In the case of cancelled trains ($t \in T_c^{p_i}$) there shall be determined an equivalent of the travel time over the studied track section (also marked as $JT_t^{p_i}$), which may be assumed as:

- train travel time via an alternative route,
- awaiting time for the nearest train of the same destination and the travel time on this train.

Weights w_t shall be assigned to travel times of particular trains. Under the cost-benefit analysis, the weights may express the costs of passengers' time or the costs of transport of goods. Moreover, an assumption has been made that at the commencement of works the train timetable is already defined and during the implementation of the works the arrival time of a train at the first station of the studied track section and the departure time from the final station of the studied track section may vary from the original timetable only in certain preset limits.

With the assumptions stated above the value of traffic disruptions at each works phase $p_i \in P$ may be expressed with the following formula:

$$TD^{p_i} = \sum_{t \in T^{p_i}} (JT_t^{p_i} - JT_t^{p_0}) \cdot w_t, \quad p_i \in P \quad (4.1)$$

Negative value of TD^{p_i} means that in the particular phase positive effects of completed works exceed current traffic disruptions.

Determining the value of the travel time $JT_t^{p_i}$ requires preparing a train timetable for each phase. For this purpose we have used the train timetable optimization model, at pre-defined track closures, described in detail in [7], in which the objective function is the following:

$$\min \sum_{t \in T^{p_i}} JT_t^{p_i} \cdot w_t, \quad p_i \in P \quad (4.2)$$

Using the optimization model guarantees that a train timetable for each phase of works should be drawn, characterized by the smallest possible rail traffic disruptions, taking into account the pre-defined track closures.

The longer the works implementation time the longer traffic disruptions appear, and the later profits are achieved from raising operational railway line parameters. This relation is determined by the function defining the sum of delays, calculated from the commencement of works:

$$f(t) = \sum_{p_i \in P} TD^{p_i} \cdot t^p \quad (4.3)$$

In the formula above the t^p parameter achieves values dependent on the commencement (t_{start}^p) and completion of a given phase (t_{end}^p), according to the following formula:

$$t^p = \begin{cases} 0, & \text{for } t \leq t_{start}^p \\ \frac{t - t_{start}^p}{t_{end}^p - t_{start}^p}, & \text{for } t_{start}^p < t < t_{end}^p \\ 1, & \text{for } t_{end}^p \leq t \end{cases} \quad (4.4)$$

A typical shape of the graph of the function $f(t)$ over time for investment projects, as a result of which the operational parameters of the railway line are improved, is shown in Figure 1.

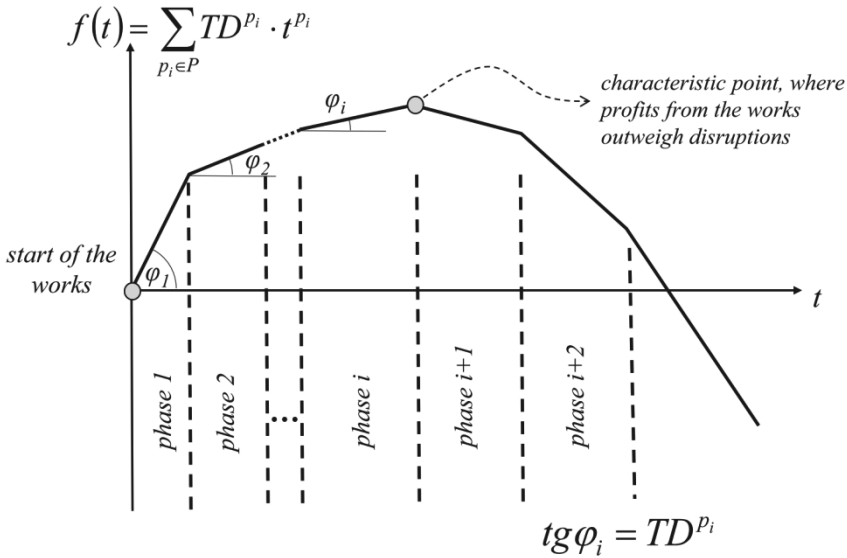


Fig. 1. A typical shape of the graph of the function $f(t)$ for the implementation of renewal and modernization projects (source: based on the author's research for several investment projects on the PKP PLK SA railway network in 2014-2017)

5. CASE STUDY

The issue of the impact of the coordination of works on the size of traffic disruptions was analyzed on the example of a renewal project for a 30-kilometer section of railway line No. 353 Inowrocław–Nieszawka, which was implemented in 2014. Original timetable, actual effects of the works (reduction of travel time) and actually used speed limits, when performing engineering works, were used as the basis for the analysis. For the sake of better legibility of the presented case, however, the track layout of the section was simplified, where only the main tracks were mapped. It was also assumed that at each side of the station it is possible to pass between the tracks No. 1 and 2, and the passenger platforms are located at stations (Fig. 2). The above assumption made it possible to make the results independent of the choice of the order of performing works on particular railway routes (which was not the object of analyses).

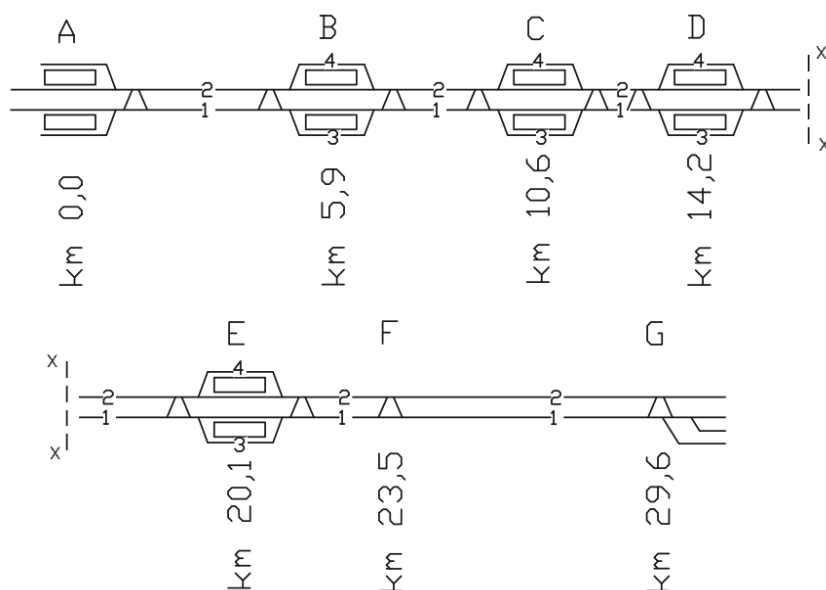


Fig. 2. The analyzed track layout

The following variants of track closures for the needs of engineering work execution were considered:

- reference variant (Fig. 3) – 12 phases of track closures (the variant actually implemented in 2014 on the railway line 353),
- variant 2 (Fig. 4) – 6 phases of track closures,
- variant 3 (Fig. 5) – 4 phases of track closures.

In the reference variant, the works lasted 40 weeks; in the remaining variants, various durations of works were analyzed, depending on the assumed efficiency of using the time of track closures:

- variant 2 – 20, 25 and 30 weeks,
- variant 3 – 16, 20 and 24 weeks.

In addition, various variants of the traffic intensity, expressed by the utilization of railway line capacity, were analyzed:

- variant A – 35% of railway line capacity utilization during the day and 40% during the peak hour (variant according to the actual timetable),
- variant B – 45% of railway line capacity utilization during the day and 60% during the peak hour,
- variant C – 60% of railway line capacity utilization during the day and 80% during the peak hour.

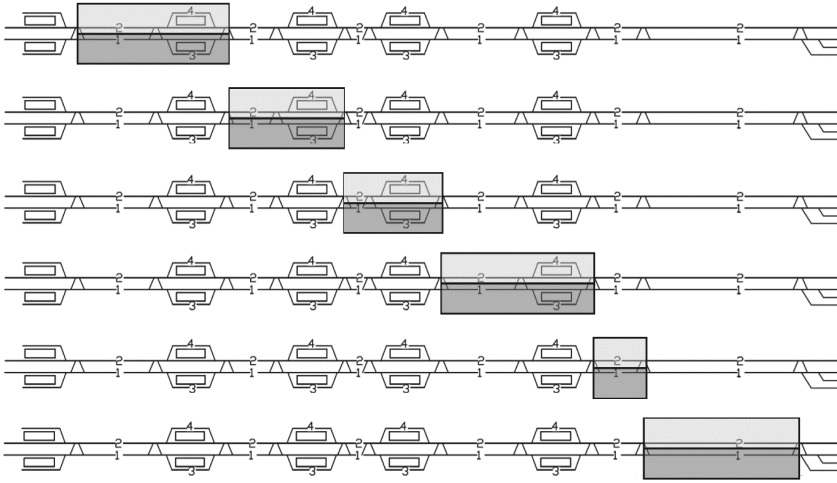


Fig. 3. The phasing of track closures in the reference variant

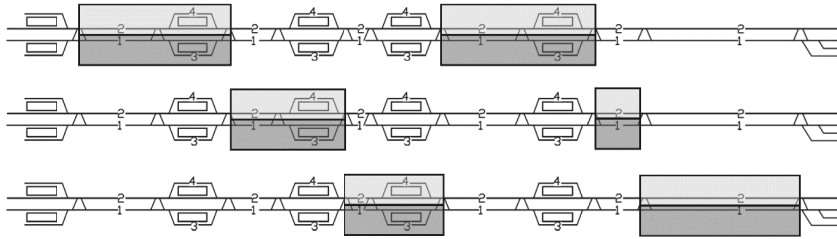


Fig. 4. The phasing of track closures in the variant 2

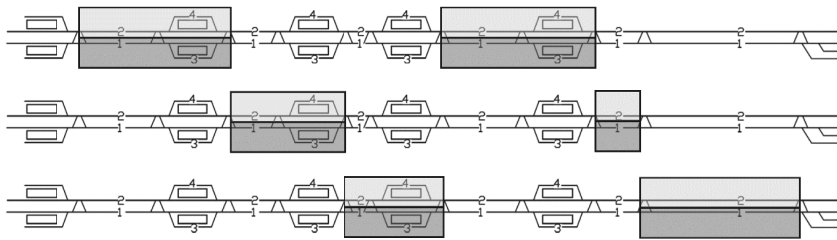


Fig. 5. The phasing of track closures in the variant 3

It was assumed that the weights w_i would be equal for all trains. The values $JT_i^{P_i}$ adopted for cancelled trains, based on the train timetable 2013/2014 for alternative route, are presented in the table 1. Thanks to the above assumptions, the values of the function $f(t)$ are expressed in minutes.

Tab 1. The values of the travel time for cancelled trains (based on the train timetable 2013/2014)

Train category	Alternative route	$JT_i^{p_i}$ [min]
Passenger: long-distance trains	Toruń Główny – Bydgoszcz Główna – Inowrocław via railway lines No. 18, 131	71
Passenger: regional trains		84
Freight trains		120

The values $JT_i^{p_i}$ for each phase and each variant are presented in the table 2. The values TD^{p_i} for each phase, calculated using optimization model, described in detail in [7], are presented in the table 3.

Tab 2. Number of trains per day for variants A, B, C

	Number of trains per day		
	variant A	variant B	variant C
Passenger: long-distance trains	44	66	88
Passenger: regional trains	8	12	16
Freight trains	28	42	56

Tab 3. The value of traffic disruptions TD^{p_i} (calculations in detail presented in [7])

Works phase p_i	The value of traffic disruptions TD^{p_i} [min]								
	Variant of track closures								
	reference			2			3		
	Variant of the traffic intensity								
	A	B	C	A	B	C	A	B	C
1	430	1773	3341	912	2587	8178	1779	4763	14687
2	434	1779	3341	912	2597	8180	1785	4765	14689
3	-99	191	546	143	745	1582	-401	-257	7010
4	-93	193	548	145	743	1586	-415	-259	7006
5	-582	228	1381	-42	3080	16770	-	-	-
6	-570	228	1383	-54	3076	16772	-	-	-
7	-1533	-2108	-40	-	-	-	-	-	-
8	-1539	-2116	-48	-	-	-	-	-	-
9	-772	-1025	1731	-	-	-	-	-	-
10	-762	-1039	1725	-	-	-	-	-	-
11	-2541	-3452	1327	-	-	-	-	-	-
12	-2547	-3460	1323	-	-	-	-	-	-

6. ANALYSIS RESULTS

The results of the analysis, in the form of graphs of the function $f(t)$ for individual variants of work phasing, assumed times of work realization and assumed train traffic intensity are presented in the following Figures 6-8.

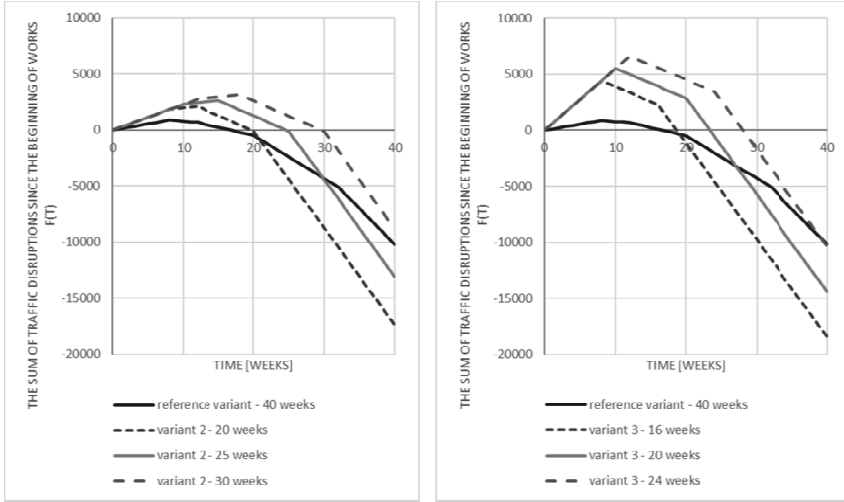


Fig. 6. Graph of function $f(t)$ - variant A of the traffic intensity, variant 2 of track closure phasing (left figure) and variant 3 of track closure phasing (right figure)

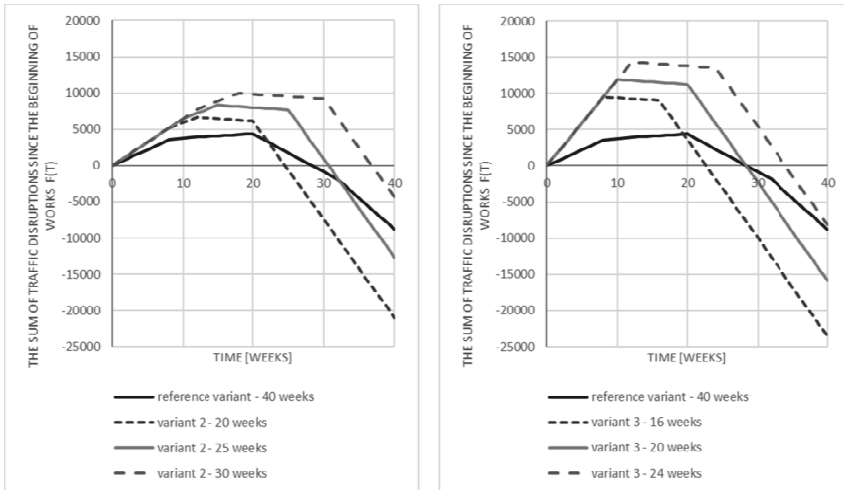


Fig. 7. Graph of function $f(t)$ - variant B of the traffic intensity, variant 2 of track closure phasing (left figure) and variant 3 of track closure phasing (right figure)

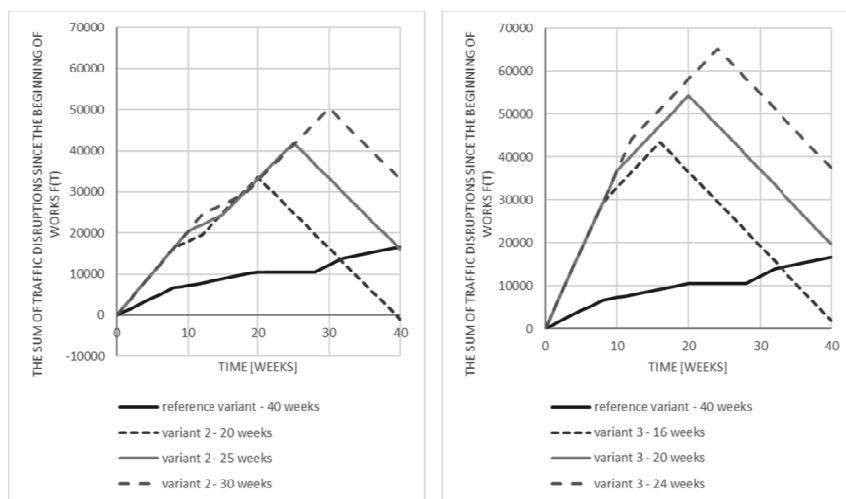


Fig. 8. Graph of function $f(t)$ - variant C of the traffic intensity, variant 2 of track closure phasing (left figure) and variant 3 of track closure phasing (right figure)

When analyzing the obtained graphs of the function $f(t)$, the following conclusions can be formulated:

- in the variants 2 and 3 of track closure phasing, in the early stages of execution of works, several times greater disruptions to train traffic in relation to the reference variant are noted (greater values of the function $f(t)$),
- simultaneous carrying out works on several sections makes it possible to achieve lower total disruptions to train traffic at the end of the reference period, but only under the condition of high track closure utilization efficiency - e.g. in variant 3 of track closure phasing for the works lasting 24 weeks, greater values of function $f(t)$ in all variants of traffic intensity (A, B, C) were obtained than in the reference variant,
- the greater utilization of the railway line capacity, the less noticeable benefits from simultaneous execution of works on several sections - e.g. in the variant C of traffic intensity, it is only possible to achieve advantages in relation to the reference variant, when the works are shortened to 16 or 20 weeks (smaller values of the function $f(t)$ at the end of the analyzed period of 40 weeks),
- in the variant 3 of track closure phasing, significantly greater in relation to the variant 2 disruptions to train traffic in the early stages of execution of works do not translate themselves into tangible benefits at the end of the reference period of 40 weeks.

7. CONCLUSIONS

The conducted analysis indicates that grouping works on many tracks and sections may be beneficial for low traffic railway lines, while on heavily traffic

loaded railway lines (with a high degree of traffic capacity utilization) it results in significantly longer travel times and the need to cancel trains. The results of the research also indicate that a foreordained assumption of conducting works only at one station and one adjacent track of the railway line may be too cautious from the point of view of traffic disruptions. Since the coordination of works can be of great importance to traffic disruptions, it is worth analyzing this aspect individually for each project. At the same time, it should be noted that a simultaneous closure of too many route tracks and station tracks could result in even twice greater disruptions to train traffic in the initial phases of work realization, without any noticeable benefits during the implementation of the entire project.

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ZALEŻNOŚĆ POMIĘDZY KOORDYNACJĄ KOLEJOWYCH ROBÓT BUDOWLANYCH A WIELKOŚCIĄ UTRUDNIEŃ W RUCHU POCIĄGÓW

Streszczenie

Wykonywanie robót rewitalizacyjnych i modernizacyjnych na liniach kolejowych wymaga wprowadzenia czasowych zamknięć torowych. Istotnym zagadnieniem jest takie zaplanowanie robót, aby zminimalizować utrudnienia ruchowe związane z zamknięciami torowymi, ale jednocześnie ograniczyć całkowity czas wykonywania robót. W niniejszym artykule przeanalizowano wpływ koordynacji robót na różnych torach stacyjnych i szlakowych na wielkość utrudnień ruchowych. Analiza została przeprowadzona dla trzech różnych harmonogramów projektu rewitalizacyjnego na 30 kilometrowym odcinku dwutorowej linii kolejowej nr 353 Inowrocław – Nieszawska. Wyniki badań wskazują, że grupowanie robót na kilku torach i odcinkach może być korzystne dla linii o niskim natężeniu ruchu, podczas gdy dla linii o dużym natężeniu ruchu (dla linii o wysokim poziomie wykorzystania zdolności przepustowej) skutkuje to istotnym wydłużeniem czasów jazdy i koniecznością odwołania pociągów.

Słowa kluczowe: kolejowe roboty budowlane, koordynacja robót, utrudnienia ruchowe, zamknięcia torowe

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