PAPER • OPEN ACCESS

Risk Analysis for High Pressure Gas Pipeline Construction Schedule

View the article online for updates and enhancements.

Risk Analysis for High Pressure Gas Pipeline Construction Schedule

Michal Bogucki [1], Mieczyslaw Polonski [2]

[1] ILF Consulting Engineers Polska Sp. z o.o., Osmańska 12, 02-823 Warsaw, Poland
[2] Warsaw University of Life Science - SGGW, Faculty of Civil and Environmental Engineering, Nowoursynowska 159, 02-776Warsaw, Poland

mieczyslaw_polonski@sggw.pl

Abstract. In article authors focus on preparation of construction works schedule for high pressure gas pipeline in urbanized area and implementation of risk analysis in estimation of realistic completion date. In the first step, the pipeline was divided into couple of sections with different construction methods. During evaluation open cut methods, HDD and microtunneling methods were verified and for every approach specific types of risk were identified. Since number of potential risks was significant authors decided to apply the method for ranking the risks and introducing most important potential complications in the construction schedule. After risk identification authors prepared set of impact categories, varying for negligible few days delays to disastrous three months or more delays. Moreover for potential risks a list of probabilities were elaborated to described risk is plausible to happen several times during project execution or is rather likely to occur every couple of similar projects. Combination of sets of possible impacts and sets of probabilities resulted in a project specific risk matrix. Risk matrix was the first tool used for ranking of all risks, especially when regions of intolerable risks and risks requiring mitigation plan were drawn in the matrix. Based on professional literature, and their own experience for every potential risk, authors estimated the risk level. Knowing this in the next step all risks were sorted according to decreasing value of risk level and for risks within intolerable area or within area requiring emergency back-up plan. Authors verified if those plausible risks indeed require a schedule reserve or some other solution may be applied. If schedule reserve was a reasonable solution the relevant additional construction time was estimated, having in mind the schedule impact level of reviewed risk. In the end construction schedule was prepared, which includes the risk analysis for all construction methods.

1. Introduction

Purpose of the following article is to describe and to estimate the potential impact of identified risk on construction schedule of gas pipeline. Furthermore, knowing the influence of listed risks authors plan to modify the construction schedule in such a way, that risk analysis results are implemented.

The science of risk is relatively new, and the terms applied are not always explicit, thus the authors indicate the definitions of the basic concepts that they use in this article.

- risk - the possibility of occurring through our actions, abandonment or forces of nature predictable at a given time, negative consequences of an undesirable random event, the effect and probability of which we are able to estimate,
- adverse event - is a measurable form of one or several risk factors, resulting in failure to achieve fully or not at all the intended purpose, and thus causing some loss,

- risk factor (threat) - a potential source of an adverse event that may or may not occur in the future.

There are couple of risk management methods in construction projects, however always the main goal is to identify the potential risks and to evaluate the probability or risk occurrence and its impact [1,2]. For completing this task, it is required to possess the knowledge of the project and planned execution method.

2. Project description

Project objective is to connect the Client to gas transition network. Key technical parameters of planned investment are: length approx. 10km, nominal diameter 500mm, wall thickness 12,5mm, maximum operating pressure 8,4 MPa, minimal cover 1,20m. The route runs over highly urbanized areas filled with existing third party infrastructure. Pipeline is planned to be constructed in sections, using two basic methods open-cut and trenchless.

Using open-cut method, pending site conditions, most often section execution is used or pipeline pulling through the trench. On the opposite, there are closed methods of construction, like thrust, horizontal directional drilling and microtunneling.

Thrust method is based on pushing or hammering into the ground the puncher or casing pipes and finally installation of product pipe. In favourable soil conditions, it is feasible to thrust using product pipe. Soil gathered within the pipe is being removed by for example compressed air, water, mini-excavator or flight auger. Horizontal direction drilling (HDD) is used commonly for crossing terrain features like rivers, nature protected areas roads, railroads and areas densely filled with third party technical infrastructure. Method can be applied for both straight sections as well as for sections with curves. Microtunneling method uses tunnelling shield for drilling the tunnel to desired diameter. Comparing to HDD it requires to starting and finishing shafts, which may go down to around 12m, depending on crossing requirements and soil conditions.

Construction works execution using any of described methods results in different risks and different impact on construction schedule. In general, it is planned to conduct:

- 6 microtunnels, summarized length 820m, which is approx. 8% of the route
- 2 HDD, summarized length 1480m, which is approx. 15% of the route
- 27 open-cut sections, summarized length 7620m, which is 77% if the route

3. Preliminary schedule

During schedule preparation authors focused on main construction works, its relations and sequence of execution. Number of squads working for each of described methods were chosen taking into account the size of the squad and its effectiveness.

In table 1 list of tasks for open-cut construction were provided.

Table 1. List of tasks for open-cut method for whole route

Task	Working days
Top soil removal	25
Temporary construction road and needed levelling.	25
Distribution of product pipes	5
Trench excavation	75
Welding	30
Pipeline lowering	40
Backfilling	30
Reinstatement works	25

Assumed duration of trench excavation, pipeline lowering and backfilling may seem considerably long, however authors notice, that pipeline route is divided into several sections, according to assumed construction method, this unfortunately implicates bigger waste of time for mobilization and demobilization for each pipeline section, altogether open-cut methods should take 225 working days, assuming parallel execution of some tasks.

In table 2 list of tasks for microtunneling were provided.

Table 2. List of tasks for microtunneling, single section.

Task	Working days
Topsoil removal	1
Access road preparation, drilling site arrangement, site levelling	5
Execution of starting and ending chambers, including dewatering or jet-grouting	10 - 40
Distribution of product pipes	1
Microtunneling	24 - 115
Backfilling and disassembly of chambers	5
Site reinstatement	5

Summarized duration of single crossing done by microtunneling method will vary from 59 days to 188 days. Such wide spread is caused by different length of each crossing and expected soil conditions. Shortest microtunnel will be 50m, while longest one approx. 350m.

During execution of HDD following tasks were considered in construction schedule (table 3).

Table 3. List of tasks for HDD, single section.

Task	Working days
Top soil removal from HDD sites	5
Access road preparation, drilling site arrangement, site levelling	20
Laying of drilling fluid transfer pipeline on surface	3
Execution of HDD	43 - 74
Drilling site demobilization	10
Site reinstatement	5

Difference in duration each of HDD depends from various approaches to each HDD, expected soil conditions and length of each crossing. Summarized duration of single HDD crossing will vary from 86 days to 117 days.

Taking into consideration expected duration of construction works for each technological section of the gas pipeline, number of sections and its length, availability of construction squads, authors prepared preliminary site organization. Schedule included 108 tasks, connected with relevant relations and structured in Work Breakdown Structure. Schedule of construction works simplified to level one view is presented in figure 1. During preparation of the schedule Microsoft Project 2013 was used.

As it may be seen in the figure 1 critical path is built on tasks related to microtunnels 4, 5, 6. First estimations for overall duration of gas pipeline construction works shown 229 working days. Such approximated schedule was part of the contract between Client and Pipeline Contractor.
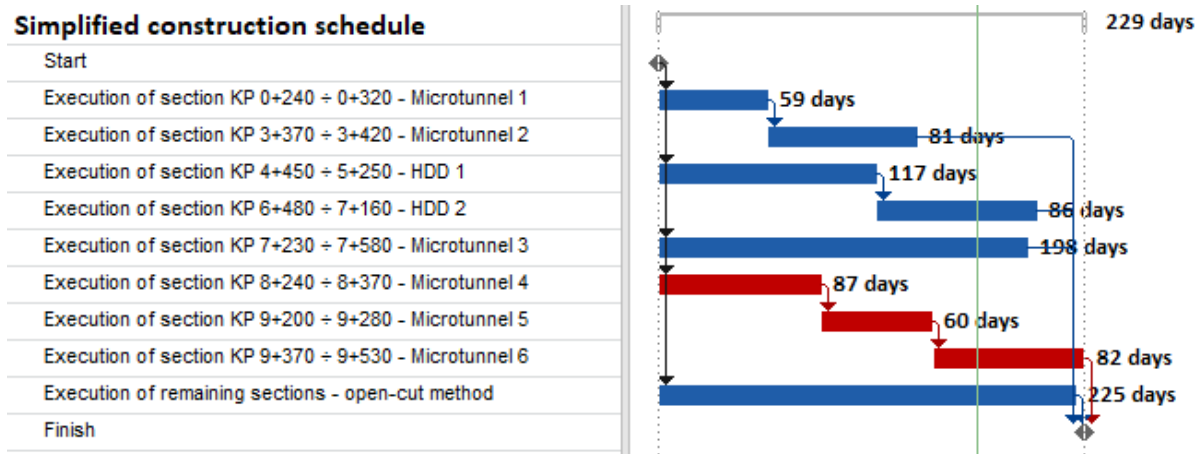
Figure 1. Simplified construction schedule.

4. Identification of time risk for selected construction methods of gas pipeline

Potential project risks were divided into following categories [3]:

1. Environmental-geological, related to geotechnical conditions and environmental setting – symbol A,
2. Technical, related to technical assumptions, used equipment, staff experience and required construction works schedule – symbol B,
3. Legal and formal – symbol C,
4. Budget, related to estimated budget and cost control – symbol D.

Using assumed risk categories for each method of construction of relevant gas pipeline section risk identification was done. List of risk was based on available literature [4-8] and own experience. In table 4 risks related to open-cut method were listed together with estimation for probability, consequence and risk level calculations, which will be described in detail further in the article. Other risks list for HDD and microtunneling were also prepared, however they are not presented in the article.

Table 4. Possible risk during execution of construction works using open-cut method

No	Type of risk	Description of impact	Probability	Consequence	Risk level
01-C	Changes in legal system	Change in important legal act affecting contract terms	2	3	6
02-A	Change in environmental protection requirements	Change in important contract terms	1,5	4	6
03-C	Landowners do not allow construction works starting on their parcel	Delay in start of construction works	3	2,5	7,5
04-C	Social protests	Locals protest against the planned works, delays in construction works	5	3	15
05-B	Pipeline route change	Significant changes in pipeline route, causing the need for additional building permit application	2,5	4	10
06-B	Often equipment failures	Not reaching the deadlines of relevant milestones assumed in the schedule	3	2	6
07-B	Lack of important supplies (pipes, other long-lid items)	Construction works delay	1	4	4
08-B	Damage to existing high pressure gas pipeline	Damage to properties, environment, severe injuries, lethal accidents, construction works suspension	1,5	4,5	6,75
09-B	Damage to existing underground infrastructure	Temporary suspension of construction works	4	3	12
10-B	Big defectiveness of welds	Failure to meet welding requirements and delays in the execution of construction works	2	3,5	7

No	Type of risk	Description of impact	Probability	Consequence	Risk level
11-B	Failure to meet resistance to earth values	Necessity to apply additional cathodic protection elements	3	3	9
12-B	Trench dewatering system failure	Temporary suspension of construction works	3	2	6
13-B	Pipeline coating damage	Damage to coating during i.e. installation of buoyancy control system. Necessity for local coating repairs.	4	1	4
14-B	Stability failure of temporary construction road	Damage repairs, delays in construction works	3	3,5	10,5
15-B	Defects of pipeline identified during pigging	Application of intervention plans or acceptance of a problem	2	3	6
16-B	Discovery of unexpected objects during pipeline construction works (i.e. garbage)	Site clean up	3	3	9
17-A	Contamination of the natural environment	Site clean-up, necessity for remediation measures	1,5	4	6
18-A	Geotechnical conditions differ from expected	Necessity for replacement solution	2	3	6
19-A	High variability of geological conditions	Construction works delay	3	2	6
20-A	Discovery of new archaeological sites	Necessity for additional permit	1	4	4
21-A	Discovery of protected fauna and flora species	Necessity to obtain derogation	1,5	2,5	3,75
22-A	Adverse weather	Temporary suspension of construction works	2	3	6
23-A	Severe winter conditions	Temporary suspension of construction works	2	3	6
24-A	Unexpected bird nesting in vicinity of construction works	Necessity to obtain derogation	2	2,5	5
25-B	Finding of unexplosive ordinance	Temporary suspension of construction works, the need to call sappers.	3,5	3	10,5

5. Calculation of risk levels and its impact on schedule

For risk quality analysis following risk matrix was prepared (table 5). Risk matrix was elaborated based on authors experience and available literature [3-4]. Chances for risk occurrence was estimated from 1 to 5 according to description provided in table 6 [3]. Using risk matrix for each identified risk it was estimated subjectively chances for occurrence and possible consequences for each event (in scale $1 \div 5$).

Table 5. Risk matrix used during calculations

Chances for occurrence / Consequence		Risk occurrence chances				
		Very low <10%	Low 10-20%	Moderate 20-50%	High 50-80%	Very high >80%
		1	2	3	4	5
Schedule impact	Negliable up to 3 days 1	1	2	3	4	5
	Meaning 3-7 days 2	2	4	6	8	10
	Significant 1-4 weeks 3	3	6	9	12	15
	Very serious 1-3 months 4	4	8	12	16	20
	Disastrous longer than 3 months 5	5	10	15	20	25

During analysis authors considered conditions for execution of the project, staff experience, utilized equipment etc. Ratio of those two factors, potential occurrence and possible impact, allowed to calculate the risk level of each risk. Since the number of risk was significant, in the next step authors defined risk level, which required preparation of the plan decreasing the chances for materialization and possible impact. To estimate the risk level Pareto principle was used, which states that 20% of most significant

risk factors causes 80% of damage [3,9]. Knowing that risk list was sorted according to decreasing value of risk level for each of gas pipeline construction method. In the next step 20% of risks were chosen, for which it was strongly recommended to evaluate the chances for minimization of risk and preparation of back-up plans.

As a remedy authors introduces into the schedule time reserve or proposed possible other actions, which should lower the chances for happening. In some cases, only reasonable strategy for risk handling was just to accept it. In the end after applying Pareto principle, limit level for open-cut method was assumed as 10, which caused that for 5 potential risk of such construction method it was obligatory to prepare in advance the remedy plan. In table 7 possible remedy plans are shown for open-cut method.

Table 6. Description of risk occurrence chances

Chances for occurrence	Scale		How often?
Very low	1	10%	The phenomenon is unlikely during a couple of projects
Low	2	10-20%	The phenomenon is unlikely during a given of projects
Moderate	3	20-50%	The phenomenon may occur during the course of a given project
High	4	50-80%	The phenomenon will occur at least once during the given project
Very high	5	>80%	The phenomenon will occur more than once during the given project

Mentioned potential delays may happen at any stage of construction works, so they should be treated separately.

Table 7 a) Example remedy plans for main risks for open-cut construction method.

No	Type of risk	Risk level	Remedy plan
04-C	Landowners do not allow construction works starting on their parcel	15	Conducting an information campaign before construction starts
09-B	Damage to existing underground infrastructure	12	For close-ups to gas pipelines, developing a dedicated plan of work organization. For close-ups to the rest of the infrastructure, work shall be carried out under the supervision of an infrastructure owner representative. Due to the risk of damage to undisclosed underground infrastructure, a reserve of 4 days should be taken
14-B	Stability failure of temporary construction road	10.5	Performing calculations of the stability of the temporary road. Possible application of the reinforcement of the temporary road in the form of e.g. concrete slabs or an aggregate layer in geotextile.
25-B	Finding of unexplosive ordinance	10.5	Implementing 3 days reserve.
05-B	Pipeline route change	10	In order to avoid the need to change the pipeline route, perform any reconstruction of third party infrastructure or change the construction technology to a trenchless method

6. Schedule after risk analysis

The schedule for the construction of the gas pipeline, taking into account the time reserve for particular hazards in all three technologies of its construction, is presented in figure 2. As can be seen in the figure, the total slack for the HDD method was considerably reduced taking into account possible threats. After considering the provision for potential risks, the estimated duration of construction is 250 days.
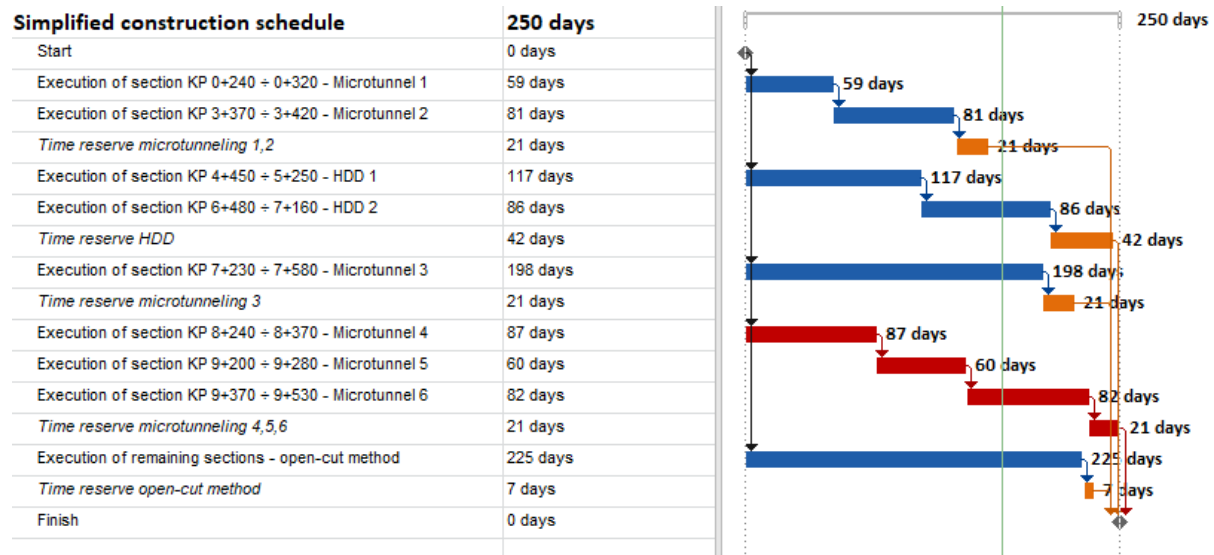

Figure 2. General schedule with time reserve for risks.

Because the contract signed by the contractor obliged him to perform the works in 229 days, the schedule including time reserves related to the occurrence of potential threats and 250 days schedule had to be shortened. This was done by the method proposed by Goldratt [10], thus shortening the initial times of tasks and inserting time buffers. At the beginning, the times of most tasks have been shortened. This was possible because the initial estimates of the times contained a certain reserve of time and were estimated at 90% probability of keeping the time assumed. Such a way of accepting the times of individual tasks meant that the probability of keeping the deadline for the entire project was relatively high. By shortening the original task times, this was done individually for relevant activities, taking into account the existing technological and organizational constraints for individual methods of building subsequent sections of the gas pipeline. After inserting new task times in the schedule, the deadline for completing the entire facility was 207 days. This allowed designing time buffers in the structure of the schedule [11]. One auxiliary buffer and project buffer on the critical path were used as well as three feeding buffers on non-critical sequences. The sizes of individual buffers were calculated using the MP-KP method, taking as a basis the probability of keeping individual sequences of tasks protected by buffers at the level of 0.97 [12,13]. After inserting them into the schedule, the whole works period increased to 250 days and after taking into account the existing restrictions, some of the buffers lying on the critical path were shortened, so that the final date of completion of works does not exceed the required 229 days. It should be noted that after the insertion of shortened buffers, the critical path has not changed its position and involves the execution of three of the same sections by microtunnelling.

The final, simplified construction schedule including the time reserve from the risk analysis, appropriately shortened tasks and time buffers has been presented in figure 3.

7. Results and conclusions

The initial construction schedule, made mainly to determine the estimated time of construction of the gas pipeline, after taking into account the risk analysis and the use of time buffers, was subject to gradual

modifications. Table 8 summarizes the total duration of works at particular stages of the preparation of the schedule.
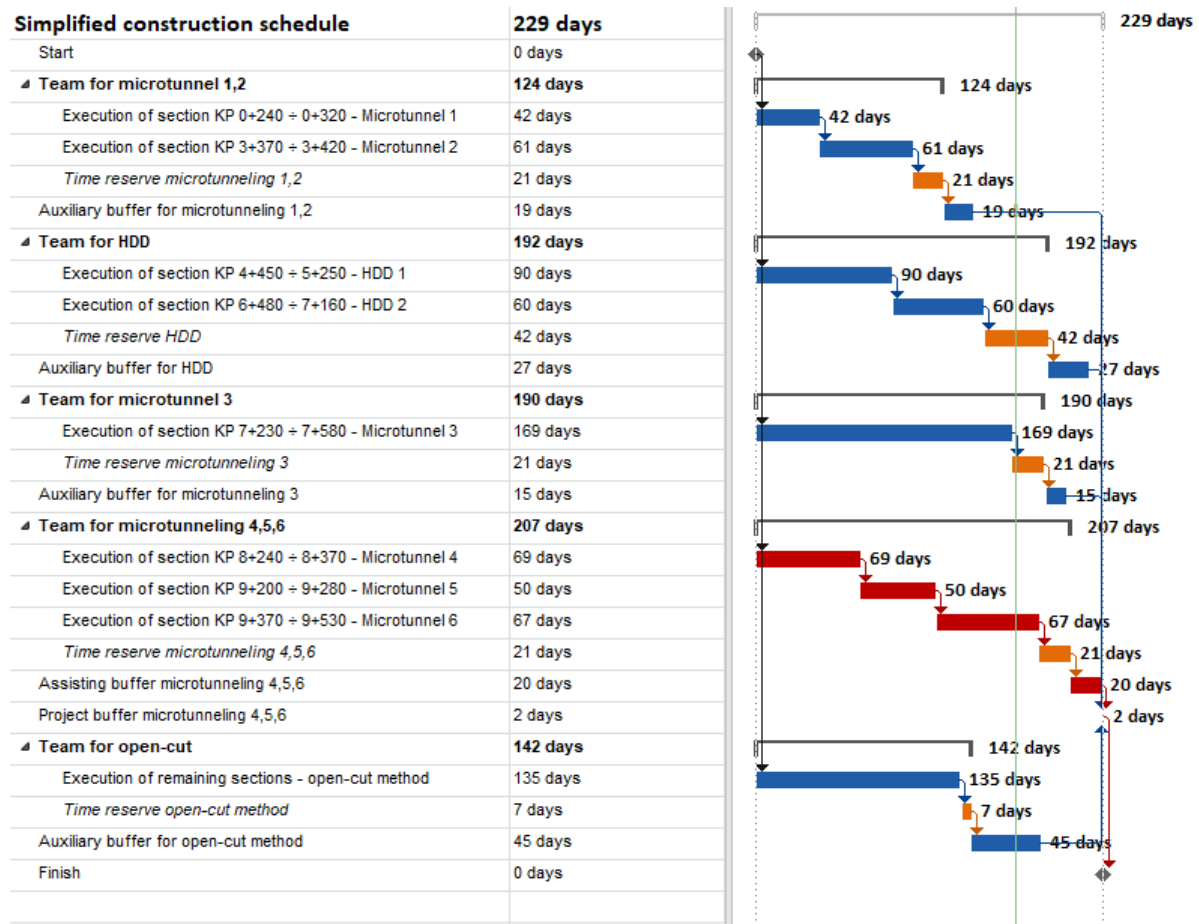

Figure 3. General construction schedule after risk analysis.

Table 8. Total duration of works at particular stages of preparation of the schedule.

Stage	Duration [working days]
Initial schedule (contract)	229
Schedule with time reserve from risks	250
Schedule after shortening the time of tasks	207
Schedule after initial implementation of buffers	250
Final construction schedule	229

At first glance, after carrying out the entire process described in this article, the same total duration of construction was obtained as in the original schedule. In fact, the initial and final schedules are completely different schedules. The first one only provides information on the expected date of execution of works. The final version of the schedule takes into account potential risks that may occur during the execution of works with particular technologies and allows for reliable management of planned robots during their execution [14].

What's more, subsequent versions of schedules and dates obtained are great for selective transfer of to individual participants. The project manager implementing the investment should provide the general contractor with a schedule resulting from the risk analysis and taking into account the shortening of the task duration (207 days). The general contractor should be controlled against these dates. On the other hand, for the internal needs of the investor, the construction progress should be monitored taking into account the time buffers provided (229 days), and during the execution of works, control the consumption of individual time buffers. This applies in particular to buffers located on the critical path, that is the auxiliary and the project buffer. The conducted risk analysis also provides the investor and the contractor with information about potential risks and gives them the opportunity to take earlier actions limiting the probability of their occurrence and to eliminate the negative effects if they occur.

References

[1]   Project Management Institute, "A Guide to the Project Management Body of Knowledge", 5th edition, 2013.
[2]   Project Management Institute, "Practice Standard for Project Risk Management", Pennsylvania, USA, 2009.
[3]   R. Osikowicz, "Risk management in drilling projects Part I: Introduction. Identification and categorization of risks", Inżynieria Bezwykopowa, pp. 74-84, 2017(1), (in Polish).
[4]   R. Osikowicz, "Risk management in drilling projects Part II: Qualitative risk assessment", Inżynieria Bezwykopowa, pp. 98-112, 2017(2), (in Polish).
[5]   R. Osikowicz, „Borehole quality management", Inżynieria Bezwykopowa, pp. 32-43, 2015(1), (in Polish).
[6]   T.J. Lyman, "Technical Report: Design Considerations for Microtunneling Proper Planning Needed to Ensure Successful Construction", North American Microtunneling Industry Review, pp. 14-17, 2011.
[7]   P.C., Schmall, "Geotechnical Aids for Microtunneling: Making the Right Choice", North American Microtunneling Industry Review, pp. 19-21, 2009.
[8]   W. Michałowski and S. Trzop, V edition, Warsaw, Poland, 2006 (in Polish)
[9]   J.M. Juran, "Quality Control Handbook", First Edition, McGraw-Hill Book Company, 1951
[10]   E. Goldratt, „Critical chain", North River Press, 1997.
[11]   M. Połoński, "Application of the work breakdown structure in determining cost buffers in construction schedules", Archives of Civil Engineering. Vol. LXI(1), pp. 147-161, DOI: 10.1515/ace-2015-0010, 2015.
[12]   M. Połoński, K. Pruszyński, „Location of time buffers in the critical chain method in works schedules (part I) - Theoretical basics", Przegląd budowlany, pp. 45-49, 2008(2), (in Polish).
[13]   M. Połoński, K. Pruszyński, „Location of time buffers in the critical chain method in works schedules (part II) - Practical application", Przegląd budowlany, pp. 55-62, 2008(3), (in Polish).
[14]   M. Lendo-Siwicka, M. Połoński and K. Pawluk, "Identification of the interference in the investment process during the realization of a shopping centre – a case study", Archives of Civil Engineering, Vol. LXII(1), pp. 159–172, DOI: 10.1515/ace-2015-0058, 2016.