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Creating probabilistic construction schedules in Microsoft Project

The *PERT* method allows generating and analyzing probabilistic construction schedules. In project management software this method takes the form of an information toolkit. However, to use this method to its full extent, it requires information on pessimistic durations of work. A number of methodological approaches based on theoretical provisions of mathematical statistics and expert evaluation methods could potentially be tapped to obtain this information. Under these approaches, a matter of principle is that the conclusions made are based on knowledge and data obtained in the past. However, the data required for *PERT* analysis may either not exist altogether, or not be representative, or fail to reflect the specifics of a project planned. Therefore, to get out of such situations, we have developed a methodology for discounting work time/durations, which allows the formation of pessimistic work schedules. The practical utility of the proposed method lies in the fact that the calculation of pessimistic durations of works is made dependent on the discount rate, which by its basic purpose is used to assess the economic efficiency of investment projects, and therefore is always a relevant parameter for any construction project under development.
Keywords: *project management, probabilistic scheduling of construction works, assessment of project's economic efficiency, flow construction methods, PERT analysis of construction projects*

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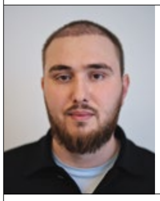

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INTRODUCTION

The *PERT* method is widely used in project management as it allows generating and analyzing probabilistic construction schedules. The schedules generated using this method are classified by groups that include optimistic, most probable, and pessimistic schedules. All these schedules of works are based on the respective probability durations, which are defined as optimistic — t_1, most probable — t_2 and pessimistic — t_3. It is assumed that all three characteristics, defined as parameters of random durations of works, are set by the user. In order to reduce all three schedules to a single work schedule, the beta distribution is used, according to which the mathematical expectation t is calculated using the following formula:

$$t = \frac{w_1 t_1 + w_2 t_2 + w_3 t_3}{6}, \; w_1 + w_2 + w_3 = 6, \qquad (1)$$

where w_1, w_2 and w_3 are weighting factors, the sum of which in Microsoft Project (MP) [1] is considered to be 6, and by default, the numerical values of these weights are set as follows: $w_1 = 1$, $w_2 = 4$ and $w_3 = 1$.

When using the given method of probabilistic scheduling, it should be noted that the interpretation of the given durations of works should take into account the specific circumstances of the project delivery. For example, an optimistic duration can be interpreted as a planned time, which can also be inherently represented as a deterministic duration. In this case, both network and flow-based methods of work scheduling can be used to form optimistic schedules [2, 3].

The most probable duration is generally interpreted as the maximum value of the probability density distribution for a unimodal random variable. However, if the unimodal distribution is symmetric relative to the mathematical expectation, the corresponding mode is calculated as the arithmetic mean of the two extreme estimates. For example, if the total random duration/time is determined by a multitude of random works, then, because the central limit theorem applies to this case, its graph is defined by a normal distribution, which just happens to possess the property of symmetry [4]. In all other cases, to determine a mode of a random variable, respective representative statistics is required, on the basis of which one can use the regression analysis to restore the probability density function of the random duration. But then a contradiction arises in accepting the *PERT* method and the use of the beta distribution therein, as a factor of reliable management [5]. In the organizational design of construction works, however, the most typical situation is precisely the lack of representative statistics and therefore the determination of the most probable duration should proceed from a priori preset extremes.

Pessimistic durations of works are precisely those necessary and sufficient parameters of random works used in the *PERT* method. However, it should be noted that existing methodologies for generating pessimistic work schedules do not fully reflect all the practical situations that arise in construction scheduling. There are various methodologies defining the characteristics of random work durations, but each of them has its own merits and drawbacks, yet almost all of them are based on the past experience and background taken into consideration.

The methodology based on the application of mathematical statistics methods can be used whenever the statistics reflect a representative sample, as this requirement directly affects the error of the result [6]. It should also be noted that a special domain, called nonparametric statistics, has been dedicated for the statistical analysis of small samples [7]. A certain difficulty arises every time it is necessary to estimate the delay of complex works, with only part of these works being fully completed. A cost metric is used to reduce all volumes of the work to a single indicator. However, the labor involved, which mainly causes a delay, is not proportionate to the corresponding cost of the works. In the theory of measurement, this problem is referred to as data non-homogeneity and it is quite clearly revealed in the monograph [8]. In its applied aspect, the monograph [9], in order to hold to the homogeneity of results reflecting construction delays, presents statistics separating contracts with fixed and floating costs of construction projects. And this is only one characteristic determining the adequacy of the statistics transfer to future construction. Therefore, if reliable statistics are scarce or inadequate, given the future conditions, the applicability of mathematical statistics methodology is highly questionable.

The methodology of expert judgement or evaluation is another means of predicting the untimely performance of works. A significant disadvantage of its application is that it represents a fundamentally subjective way of measurement [8]. And so it is used only in extreme cases — for example, when planning the construction of unique facilities [10]. Another disadvantage of using this methodology is forming an adequate team of experts. There is no universal methodology governing this process in principle, although various methods for assessing the concordance of opinions surely exist. One example is Spearman's rank correlation available for judgments presented in a ranking scale [11].

In some cases, an analogy can be used between the spatial diminution of an observed physical object and the temporal uncertainty of the random duration of a work attributed to the future, as outlined in [12]. However, while data on the radius of curvature and height of observation above the surface are used in determining the spatial diminution of an object, data on the temporal planning horizon are pretty much artificial in terms of their origin [13].

The presented brief analysis indicates the limitations of the *PERT* methodology. Therefore, the practical purpose of our research is to develop such a methodology for generating probabilistic construction schedules that would ensure, to the maximum extent possible, a viable tool for finding pessimistic work durations, with instrumental implementation of the proposed method to be oriented towards the application of up-to-date project management software. As such, we chose *Microsoft Project*, since it allows visualizing pessimistic schedules of works through the *PERT* module.

METHODS

Consider an arbitrary work whose duration could be preset using the following limits: the minimum value of a and the maximum value of b and these characteristics can be treated as optimistic and pessimistic durations. Let us denote the moment of a pessimistic start of the work by the letter p and assume that this duration is determined by respective connections with the previous works. The $b = a$ case determines the traditional calculation of deterministic schedules described in numerous academic works [2, 3], and the alternative option, where $b > a$, determines the formation of a probabilistic work schedule.

In the methodology we suggest, to calculate pessimistic work durations, we will use the discount rate, denoted by the letter E. This rate is set as the main parameter included in the calculation of various criteria for assessing the economic efficiency of investment projects [14]. The discount rate used is part of the calculation of the discount multiplier, which, purely formally, shows the relative decrease in the value of money over time:

$$k_d = (1+E)^{-t}, \tag{2}$$

where t is the moment of time, when the relative depreciation in the value of money becomes apparent.

In [15], the ratio of discounted duration to a simple payback period used as the maximum pessimistic job performance index was suggested to determine the pessimistic durations of the works. This approach became known as the discounted duration method. However, under this approach additional information on the payback or income-generating period would be required to calculate pessimistic work schedules. If such information is not available, it is possible to simulate the income-generating part of the cash flow, based on calculating the minimum value of the virtual sale as defined in [16]. Yet, with this approach, we encounter with degeneracy in the characteristics of both payback periods, because under a one-shot sale of a built asset, both values of the payback periods will be determined by the planned duration of construction works. This negative circumstance can surely be eliminated by replacing the instantaneous virtual sale by an equivalent annuity, though in this case many additional conditions are added to the set problem, which artificially complicates the calculation methodology. Therefore, we'll further present an improvement of the discounted duration method outlined above.

Analyzing the change in the discount factor over time, we come to the conclusion that any income generated or payment made at the beginning of the project will be higher than the income or payment assigned to the end of the project. As a result, assuming that the duration of the work is unchangeable, it appears that if it is done at the beginning of the project, the unit cost of doing the work will be higher than if it is done at the end of the project. The given example shows that the deterministic schedule does not take into account the reduction in costs associated with money value depreciation over time. If we assume that the unit cost of doing the work shall not change over time, the duration of the work must increase and this increase should be inversely proportionate to the discount factor.

Note the following circumstance. It is assumed that the decrease in the value of money over time is only used as an estimation characteristic. Extrapolating this assumption to the subject of interest to us, related to the increase in the work duration over time, the latter can also be interpreted as a valuation characteristic determining a pessimistic increase in the duration of the work(s) in question.

Taking this provision as a foundation, in order to quantify the pessimistic duration, we'd need to consider any work consisting of small elements. Then each small element of the optimistic duration divided by a discount factor would determine its corresponding pessimistic duration. It follows from this assumption that the pessimistic duration can be calculated using the following formula:

$$b = \int_{p}^{p+a} (1+E)^{t}\, dt = \frac{(1+E)^{p} \cdot \left[(1+E)^{a} - 1\right]}{\mathrm{Ln}(1+E)}. \tag{3}$$

As can be seen from formula (3), the calculation of the pessimistic job duration depends on the following values: the discount rate used as a constant parameter, the work start date associated with the calculation of the schedule preceding this work, and the deterministic duration of the job being calculated. The algorithm for calculating a pessimistic schedule is reduced to the following steps.

Step 1. The deterministic schedule is generated according to the given calculation method using optimistic durations of works.

Step 2. The zero point in time for the beginning of pessimistic and optimistic schedules is found.

Step 3. For all activities that start at the zero point in time, the pessimistic durations and corresponding pessimistic endings of the works are calculated.

Step 4. The pessimistic beginnings of subsequent activities or works are also determined, as prescribed by the critical path method.

Step 5. Pessimistic durations and terminations are calculated for the activities with pessimistic beginnings.

Step 6. If the list of activities/works is not exhausted, return to step 4 would be required; otherwise the calculation of the pessimistic schedule is thought to be completed.

Note the following specifics of the above algorithm. At step 5, the pessimistic durations are calculated; however, the pessimistic duration determined through other alternative methods can be used to implement the algorithm instead of the duration calculated via formula (3). Also, this algorithm allows the use of any time constraints presented in project management software. Therefore, the above sequence of actions can be considered universal enough for the purpose of forming any variants of pessimistic scheduling.

RESULTS AND DISCUSSION

Table 1 shows an example of calculating a pessimistic work schedule, whose optimistic (deterministic) version is calculated using the critical path method for early event dates. In the schedules presented, the discount rate is 30 % per annum, all event dates and durations are shown in months, whereas the relevant input data are practically equivalent to those included in the residential construction duration standards[1].

If both calculated work schedules are entered into *Project Expert (PE)* and, at the same time, the economic environment of this 4-building development project is simulated therein, the calculation may result in obtaining all of the cost-effectiveness evaluation criteria for the given project in case of its deterministic and pessimistic delivery [17]. This is a very useful feature whenever the *PE* software is used, given that its basic functionality, related to sensitivity analysis, does not include the calculation of performance indicators for pessimistic schedules of works.

The methodology presented above can also be applied to the calculation of construction flows, carried out according to different principles outlined in [3]. Table 2, assuming the same input or source data, shows the results of calculating a pessimistic schedule of works corresponding to the flow organization of construction works, relying on the method of continuous use of resources (CUR).

The peculiarity of the algorithm applied to this method of construction organization is that the calculated deployment periods are used to form such timing of events, at which continuous performance of the same type of works on all buildings is observed. Further, the algorithm is fully adequate to the previous example, but its application to form a pessimistic schedule does not result in maintaining the continuous use of resources. This, in our opinion, is not the main point, since the main priority in forming a pessimistic schedule of works is the calculation of pessimistic deadlines, which

Table 1. Optimistic and pessimistic schedules calculated using the CPM

Stages of work		Preparation			Ground zero			Above-ground portion			Interior works		
Number of buildings		Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish
1	Plan	0	1	1	1	3	4	4	4	8	8	3	11
	Pessimistic	0	1.01	1.01	1.01	3.17	4.18	4.18	4.58	8.76	8.76	3.76	12.52
2	Plan	1	2	3	4	2	6	8	4	12	12	2	14
	Pessimistic	1.01	2.09	3.1	4.18	2.24	6.42	8.76	5.06	13.82	13.82	2.77	16.59
3	Plan	3	2	5	6	3	9	12	6	18	18	4	22
	Pessimistic	3.1	2.19	5.29	6.42	3.57	9.99	13.82	8.67	22.5	22.5	6.84	29.34
4	Plan	5	1	6	9	2	11	18	5	23	23	3	26
	Pessimistic	5.29	1.13	6.42	9.99	2.54	12.53	22.5	8.64	31.14	31.14	6.13	37.27

Table 2. Optimistic and pessimistic schedules calculated using the CUR method

Stages of work		Preparation			Ground zero			Above-ground portion			Interior works		
Number of buildings		Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish
1	Plan	0	1	1	1	3	4	4	4	8	14	3	17
	Pessimistic	0	1.01	1.01	4	3.38	7.38	8	4.98	12.98	17	4.5	21.5
2	Plan	1	2	3	4	2	6	8	4	12	17	2	19
	Pessimistic	1.01	2.09	3.1	7.38	2.4	9.79	12.98	5.55	18.53	21.5	3.27	24.77
3	Plan	3	2	5	6	3	9	12	6	18	19	4	23
	Pessimistic	3.1	2.19	5.29	9.79	3.84	13.63	18.53	9.62	28.15	28.15	7.74	35.88
4	Plan	5	1	6	9	2	11	18	5	23	23	3	26
	Pessimistic	5.29	1.13	6.42	13.63	2.75	16.38	28.15	9.78	37.93	37.93	7.11	45.03

1 SNiP 1.04.03–85*. Duration of construction and margin in building industrial facilities and structures.

Table 3. Optimistic and pessimistic schedules calculated using the CFE method

Stages of work		Preparation			Ground zero			Above-ground portion			Interior works		
Number of buildings		Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish	Start	Duration	Finish
1	Plan	0	1	1	1	3	4	4	4	8	8	3	11
	Pessimistic	0	1.01	1.01	1.01	3.17	4.18	4.18	4.58	8.76	8.76	3.76	12.52
2	Plan	4	2	6	6	2	8	8	4	12	12	2	14
	Pessimistic	4	2.23	6.23	6.23	2.34	8.57	8.76	5.06	13.82	13.82	2.77	16.59
3	Plan	7	2	9	9	3	12	12	6	18	18	4	22
	Pessimistic	7	2.38	9.38	9.38	3.81	13.19	13.82	8.67	22.5	22.5	6.84	29.34
4	Plan	15	1	16	16	2	18	18	5	23	23	3	26
	Pessimistic	15	1.4	16.4	16.4	2.93	19.33	22.5	8.64	31.14	31.14	6.13	37.27

determine the pessimistic cash flow, being the basis for calculating the performance criteria.

Similarly, pessimistic schedules of works are formed according to a flow-based method related to the principle of continuity of works on each building (see Table 3), which was given the name of the Continuous All-Front Endeavour (CFE) method.

Now let us analyze the applicability of the results of calculating pessimistic durations in the *PERT* module of Microsoft Project, for which we should consider the specifics of setting the probable work duration. As was noted above, this duration is relevant only for unimodal distribution density functions. But if we consider symmetric distribution functions, we can calculate the average duration for different distribution types using variations of weight coefficients. For example, taking $w_1 = 3$, $w_2 = 0$ and $w_3 = 3$ and using formula (1), we can calculate the average time of any symmetric distribution and it is not necessary to preset its most probable value. As for asymmetric distributions, their relevance can be justified by determining the asymmetry coefficient, though its calculation will require additional statistical data which, as has already been noted, are extremely limited. Therefore, in our view, the *PERT* analysis can be limited to the setting of only two parameters, one being the planned duration and the other the pessimistic duration.

CONCLUSION

The presented article has given the methodology, its justification and practical examples related to the formation of pessimistic schedules of works, depending on the discount rate, which by its main purpose is used to assess the economic efficiency of investment projects.

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Формирования вероятностных расписаний строительных работ в программе Microsoft Project

Метод *PERT* позволяет формировать и анализировать вероятностные расписания строительных работ. В программах управления проектами данный метод представлен в форме информационного инструментария. Однако для полноценного использования этого метода требуется информация по пессимистическим продолжительностям работ. Для ее получения может быть использован ряд методологических подходов, основанных на теоретических положениях математической статистики и методах экспертной оценки. При таких подходах принципиальным моментом является то, что получаемые выводы базируются на знаниях и данных, полученных в прошлом. Однако нужные для *PERT*-анализа данные могут либо вообще отсутствовать, либо быть нерепрезентативными, либо не отражать конкретную специфику планируемого проекта. Поэтому для выхода из подобного рода ситуаций авторами разработана методика дисконтирования продолжительностей работ, позволяющая формировать пессимистические расписания работ. Практическая полезность предлагаемой методики заключается в том, что расчет пессимистических продолжительностей работ поставлен в зависимость от дисконтной ставки, которая по своему основному назначению используется для оценки экономической эффективности инвестиционных проектов, а поэтому всегда является актуальным параметром для любого разрабатываемого строительного проекта.

Ключевые слова: *управление проектами, планирование вероятностных расписаний строительных работ, оценка экономической эффективности проекта, методы поточного строительства, PERT-анализ строительных проектов*

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