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A CONCISE REVIEW OF METHODS OF CONSTRUCTION WORKS DURATION ASSESMENT

SYNTETYCZNY PRZEGLĄD METOD OKREŚLANIA CZASU REALIZACJI ROBÓT BUDOWLANYCH

Abstract

This paper presents a concise review of some methods and techniques that are used for assessing how long construction works (namely – activities or work tasks in terms of programming) will take. As background for the discussion, some definitions are given and preliminary remarks are made. Chosen methods and techniques for the assessing of construction works duration are presented and briefly discussed. Additionally, some results from the author's initial research on the construction works duration are presented.

Keywords: construction works duration

Streszczenie

W artykule przedstawiono zwięzły przegląd niektórych metod i technik, które są wykorzystywane do oceny, czasu realizacji robót budowlanych (w podziale na zadania harmonogramu). Jako tło i wprowadzenie do dyskusji przedstawiono uwagi wstępnej definicje związane z omawianą problematyką. Zaprezentowano i krótko omówiono wybrane metody i techniki oszacowań czasu realizacji robót budowlanych. W artykule przedstawiono i wykorzystano w analizach wyniki obserwacji czasu realizacji wybranych robot budowlanych.

Słowa kluczowe: czas realizacji robót budowlanych

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1. Introduction

The Construction projects need planning to provide success in terms of time, cost and quality. It is therefore expected that construction projects will be completed within an accepted time, on budget and with the expected level of quality. Project planning is performed at different stages, at different levels and by different participants of the project. According to Cooke and Williams [3] project planning during the design stage and project planning during the construction stage can be distinguished. Considering levels and participants of a project [3]: project planning is carried out by the client/project manager, pre-tender planning is carried out by the tendering contractors, pre-contract planning is carried out by the main contractor and contract planning is carried out by the main contractor and subcontractors may be mentioned.

According to Hendrickson and Au [4]: „Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks”.

The thoughtful and reasonable planning process of a construction project should involve some general steps. A logical approach involves [3]: getting a feel for the project, establishing the key project dates, establishing the key activities or events, assessing how long these activities will take, establishing the sequence and deciding which programming technique to use.

In this paper it is the author focuses on one of the most important steps of the construction planning process – that is construction works duration assesment. Durations of activities (which correspond to scopes of construction works according to accepted division of the whole project) form the essential information for programming and scheduling. Adequate assessment enables a planner (or a team of planners) to prepare a realistic model for the execution of construction works in terms of time.

2. Definitions and preliminary remarks

Activities in terms of construction planning are the operations or processes that occur in the course of a construction project which consume both time and resources [2] (in some cases they may consume time only). Other terms commonly used are: „task” or „work task”. The terms „work tasks” or “activities” are often used interchangeably in construction plans to refer to specific, defined items of work [4].

Programmes may be defined as [2]: a statement of a plan or some part or detail in positive terms in words and diagrams. Breaking a construction project down leads to definition of a component parts derived from the whole scope of construction works. This may also be a work breakdown structure which includes different levels of information aggregation, in other words, component parts may be ordered through a hierarchical structure. Breaking down a construction project should allow for a reasonably accurate estimate of activity durations and the required resources (compare Hend and Au [4]).

Activities that are defined as basic components of a construction programme should meet some fundamental needs [2]:

- they describe as fully as the information allows, the scope of works of the project,
- each activity must be independently capable of having a duration and when necessary a resource requirement ascribed to it,

- they must be capable of being used to provide the adequate monitoring of progress,
- they must be significant, having regard to the purpose of the programme.

A duration in terms of construction planning may be defined as [2] the time required or available for the completion of an activity. All durations must be expressed in a common unit of working time. Depending on the information aggregation which is adopted for different levels of work breakdown, structure units of working time are working hours, working days, working weeks etc.

During the construction stage of the project resources, that are necessary to complete a certain scope of works can be considered (according to Marcinkowski [6]) as passive or active. One can define building materials, construction products, construction members, prefabricated elements etc as passive resources, while workers and construction equipment, construction machines etc can be described as active. Active resources are especially important in construction planning as their effort is measured with working time influencing the effect of a specific production [6].

3. Different approaches to assessing construction works duration

Any assessment of activities duration for the purposes of planning a construction needs some input information (compare [2]):

- work breakdown structure of a project including a list of activities (work tasks),
- adopted construction technologies for certain activities (methods of execution to be adopted),
- quantities of construction works covered by each activity,
- information about active resources employed by the activity and production rates of that resource.

According to a guide published by the CIOB [2] a duration may be derived by calculation, quotation or assessment:

- calculation – an arithmetical calculation based on the known quantities or units and the production rates for the resources to be used,
- quotation – use of a duration stipulated or obtained from a specialist source (especially in case of specialist work, construction pauses, manufacturing or delivery periods, commissioning or fitting out periods etc.),
- assessment – based on limited data or on experience from previous projects.

Other divisions of methods include [3] stresses on the availability of information:

- assessing duration activities based on judgement and experience – at the early stages of a project, when little information is available,
- calculations considering relationships between the quantity of work and the anticipated output or rate of production – when detailed information about the project has been provided.

Połośki [7] takes other criteria into consideration and mentions three possibilities for assessing the duration of activities:

- assessed duration is deterministic,
- duration is assessed by the use of a technique adopted for PERT analysis and beta – optimistic, pessimistic and most probable durations are assessed,
- duration is considered by use of probability distribution (e.g. normal, lognormal, triangular) and its parameters.

All authors who have considered the problem of assessing construction works duration agree that the anticipated output of production is essential for calculations of the time required for the activities (and thus construction works). This information may be expressed in many different manners as: production rate of an active resources, productivity of a standard crew, time required to complete a unit of work (reciprocal of productivity or production rate).

This information can be obtained from different sources e.g.: feedback from previous projects, data gathered and processed by the contractors (and subcontractors), work studies carried out by contractors (and subcontractors), accepted published data, specialist advice. (Data gathered by contractors and subcontractors or the effects of their work studies, which are usually restricted for internal use only).

4. Chosen methods of construction works duration calculation

4.1. Methods used for deterministic duration assessment

Basic formulas adopted for assessing how long the activities will take are presented by Cooke and Williams [3]:

$$\frac{\text{Quantity}}{\text{Output_per_hour}} = \text{Hours} \quad (1)$$

$$\frac{\text{Hours}}{\text{Number_of_hours_per_day}} = \text{Days} \quad (2)$$

$$\frac{\text{Days}}{\text{Number_of_days_per_week}} = \text{Week} \quad (3)$$

In the formulas above duration expressed in hours (1), days (2) or weeks (3) is actually calculated on the same basis of known quantities of construction works and anticipated output.

According to Hendrickson and Au – the estimation of activity durations may be based on historical records of particular activities and their average durations. „Since the scope of activities are unlikely to be identical between different projects, unit productivity rates are typically employed for this purpose [4]”. The following formulas correspond with this approach:

$$D = \frac{A}{PN} \quad (4)$$

where:

- D – duration of an activity,
- A – quantity of a certain construction task – number of measurement units calculated for a certain construction task,
- P – the average productivity rate of a standard crew for a certain construction work (measured in number of measurement units per working hour),
- N – the number of crews assigned to the task.

Other option is to use unit production time which is a reciprocal of P :

$$D = \frac{TA}{N} \quad (5)$$

where:

T – the time required to complete a unit of work by a standard crew (measured in working hours per measurement unit of a certain construction work).

4.2. PERT method and use of probabilistic distributions

PERT is a commonly known method of project analysis where the durations of activities are estimated with the probabilistic beta distribution method. The beta distribution method is used to characterize activity durations, since it can have an absolute minimum and an absolute maximum of possible duration times. [4] Assuming the duration time of an activity is a random variable t , a stands for absolute minimum and b stands for absolute maximum – the form of the density function for $t \in \langle a, b \rangle$ is given below [1]:

$$f(t) = \frac{1}{\beta(p, q)(b-a)^{p+q-1}} (t-a)^{p-1} (b-t)^{q-1} \quad (6)$$

where:

$$\beta(p, q) = \int_0^1 x^{p-1} (1-x)^{q-1} dx \quad (7)$$

Consequently the distribution curve depends on the parameters p and q . (Series of transformations are explained in details by Cyunel and Biernacki [1]). Assessment of activity duration with use of beta distribution requires in practice three parameters – optimistic duration (absolute minimum), most likely duration and pessimistic duration (absolute maximum) which are essential for this approach. For the purpose of the analysis of mean duration t_e can be calculated as a weighted average where three parameters a , m and b are present:

$$t_e = \frac{a + 4m + b}{6} \quad (8)$$

where:

- a – optimistic duration of an activity,
- m – most likely duration of an activity,
- b – pessimistic duration of an activity.

(In the formula (8) weights of the parameters for a , m and b are equal 1, 4 and 1 respectively. These are the default weights. However different values of weights may be applied according to the skewness of the distribution).

To allow for uncertainty in activity duration, other probabilistic distributions can be applied. An activity duration might be assumed to be a normal distributed or a triangular distributed random variable. The probability of experiencing a particular activity duration is taken into account (compare [4]). Normal distribution is easy to work with, as it only needs two parameters (it is often used as an approximation of beta distribution). The biggest advantage of triangular distribution is that it only needs three values to be unambiguously determined: minimum value, most likely value and maximum value of random variable [5]. The form of the density function for triangular distribution for $t \in \langle a; b \rangle$ is given below:

$$f(t) = \begin{cases} \frac{2(t-a)}{(b-a)(m-a)}, t \in \langle a; m \rangle \\ \frac{2}{(b-a)}, t = m \\ \frac{2(b-t)}{(b-a)(b-m)}, t \in \langle m; b \rangle \end{cases} \quad (9)$$

where:

a, m, b – defined exactly the same as in equation (8).

(Apart from the distributions introduced above, application of other distribution types such as uniform, lognormal, Student's t – distribution is also possible – as presented in the literature on the subject).

5. Examples of duration assessment for chosen type of construction works

Plastering works have been chosen as an example for construction work analysis, for the application of the methods described above. Technological assumptions for the plastering works are:

- type of plaster – one coat gypsum plaster applied to walls, concrete substrate,
- method of application of a plaster – with use of a mechanical plastering machine,
- building type – residential, multistorey buildings.

Assumed quantity of a plastering works equals to 2500 m². It was assumed that the standard crew consists of four workers and the number of working hours per day equals to 8.

5.1. Application of methods for deterministic duration assessment

Duration assessment was based on two types of sources of information:

- published information – widely available (in Poland) cataloged information regarding the normative consumption of a resources necessary for different construction works,
- observations which were carried out by the author during his practices on construction sites for two different subcontractors (subcontractors are marked here as A and B).

On the basis of this published information [8] it was assumed that the normative time required to complete a unit of the plastering work equals to 0.319 w-h/m². Thus the normative

productivity is $1/0.319 = 3.135 \text{ m}^2/\text{w-h}$. The productivity of a standard crew: $P = 4*3.135*8 = 100.3 \text{ m}^2/\text{w-h}$. On the basis of these observations, for subcontractor A (the first three and the last two of twelve observations are shown in the table 1) it was calculated that the average productivity rate for a single worker equals to $3.6 \text{ m}^2/\text{w-h}$, (sample standard deviation calculated respectively equals 0.308). Productivity for a standard crew: $P = 4*3.6*8 = 116.0 \text{ m}^2/\text{day}$. (As the number of workers in a crew was changing at the time of the observations the average crew productivity was not taken into account).

Table 1

Observations of the durations of plastering works – subcontractor A

| No. | Number of workers in a crew | Hours per day | Number of days | Measured output [m ²] | Time required to complete a unit of work by a single worker [w-h/ m ²] | Time required to complete a unit of work by a crew [w-h/ m ²] | Measured productivity of a single worker [m ² /w-h] | Measured productivity of a crew [m ² /w-h] |
|-----|-----------------------------|---------------|----------------|-----------------------------------|--|---|--|---|
| 1 | 4 | 8 | 3 | 392.5 | 0.245 | 0.061 | 4.1 | 16.4 |
| 2 | 3 | 8 | 4 | 342.0 | 0.281 | 0.094 | 3.6 | 10.7 |
| 3 | 4 | 8 | 3 | 378.5 | 0.254 | 0.063 | 3.9 | 15.8 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 11 | 3 | 8 | 3 | 244.5 | 0.294 | 0.098 | 3.4 | 10.2 |
| 12 | 4 | 9 | 2 | 234.0 | 0.308 | 0.077 | 3.3 | 13.0 |

On the basis of observations for a subcontractor B (the first three and the last two of ten observations are shown in the table 1 are shown in the table 2) – average productivity for a single worker is equal to $3.0 \text{ m}^2/\text{w-h}$ (sample standard deviation calculated respectively equals 0.163). Productivity for a standard crew $P = 4*3.0*8 = 96.0 \text{ m}^2/\text{day}$. (As the number of workers in a crew was changing at the time of the observations the average productivity of a crew was not taken into account).

It is easy to notice that productivity for a standard crew and thus the durations presented in the table 4 differ quite significantly. Observations for subcontractor A allow for the assumption of the shortest duration, whilst observations for subcontractor B allow for assumption of the longest duration. Published information gives the assessments in between.

Observations of the durations of plastering works – subcontractor B

| No. | Number of workers in a crew | Hours per day | Number of days | Measured output [m ²] | Time required to complete a unit of work by a single worker [w-h/ m ²] | Time required to complete a unit of work by a crew [w-h/ m ²] | Measured productivity of a single worker [m ² /w-h] | Measured productivity of a crew [m ² /w-h] |
|-----|-----------------------------|---------------|----------------|-----------------------------------|--|---|--|---|
| 1 | 4 | 8 | 3 | 302.5 | 0.317 | 0.079 | 3.2 | 12.6 |
| 2 | 4 | 9 | 3 | 321.5 | 0.336 | 0.084 | 3.0 | 11.9 |
| 3 | 3 | 9 | 4 | 332.5 | 0.325 | 0.108 | 3.1 | 9.2 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 9 | 4 | 10 | 2 | 214.5 | 0.373 | 0.093 | 2.7 | 10.7 |
| 10 | 5 | 8 | 3 | 358.5 | 0.335 | 0.067 | 3.0 | 14.9 |

Comparison of durations assessed with use of equation numbers (4) is presented in the Table 3.

Table 3

Assessed durations of plastering works (assumed quantity 2500 m²)

| Source of information | Productivity for a standard crew P | Assessed duration D | |
|--------------------------------|--------------------------------------|-------------------------|-------------------------|
| | | Number of crews $N = 1$ | Number of crews $N = 2$ |
| Observations – subcontractor A | 116.0 m ² /day | 21.55 ~ 22 days | 10.76 ~ 11 days |
| Published information [8] | 100.3 m ² /day | 24.92 ~ 25 days | 12.46 ~ 12 days |
| Observations – subcontractor B | 96.0 m ² /day | 26.04 ~ 26 days | 13.02 ~ 13 days |

5.2. Application of triangular distribution for duration assessment

For the observations presented in tables 3 and 4 triangular distribution of activity duration was approximated. On the basis of the information shown in the tables 3 and 4, necessary durations to complete assumed quantity (2500 m²) of a plaster were calculated at first. Each of the observations was a basis for a calculation – thus for subcontractor A, the author obtained 12 results and consequently for subcontractor B – 10 results. Due to the inconsistencies in number of days and number of workers in the crew, the results were calculated on the basis of adjusted productivity of a crew per day. The results of this approximation are presented in the figure 1. In the graphs, the horizontal axes represent assessed durations t_i (results of calculations were rounded up to full days), the vertical axes represent the reciprocal of frequency of t_i .

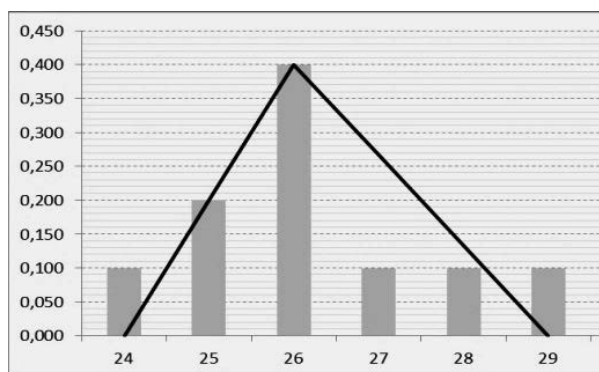


Fig.1. Approximation of duration distribution with use of triangular distribution on the basis of – a) observations made for subcontractor A; b) observations made for subcontractor B.

Estimated parameters (as explained in subsection 4.2) of the distribution: \hat{a} , \hat{m} and \hat{b} as well as \hat{t}_B (expected value) and $\hat{\sigma}$ (standard deviation) are set together in the Table 4.

Table 4

Parameter estimates of triangular distribution of a plastering works duration

| Basis of approximation – observations | $\hat{a} = \min\{t_1, t_2, \dots, t_n\}$ | $\hat{m} = \text{mode}\{t_1, t_2, \dots, t_n\}$ | $\hat{b} = \max\{t_1, t_2, \dots, t_n\}$ | \hat{t}_τ | $\hat{\sigma}$ |
|---------------------------------------|--|---|--|----------------|----------------|
| – subcontractor A | 19 | 21 | 25 | 21.7 | 1.247 |
| – subcontractor B | 24 | 26 | 29 | 26.3 | 1.027 |

(Despite the small cardinality of observations which constituted a basis for the assessments of durations, for the purpose of the approximation of triangular distributions, the analysis of correctness of fit was based on the ‘chi-square test’. To make this possible it was assumed that the density function for parameters a and b took values higher than zero – but still close to zero. Chi-test values were $p = 0.0328$ for the approximation shown in Fig. 1a) and $p = 0.0014$ for the approximation shown in Fig. 1b). These results indicate a good fit of distributions as $p < 0.05$, however, these results must be treated with caution due to the aforementioned small cardinality of the observations).

6. Conclusions

The methods presented in the paper correspond with the problem of construction works duration assessment. Durations may be assessed either as deterministic values or described with probabilistic distributions.

In the case of methods applied for the assessment of deterministic durations, the results depend on the choice of information source. The analysis shown in the paper reveals differences in durations assessed for exemplary construction works (namely plastering works) based on published sources and observations carried out for two different subcontractors. Differences in such calculations may be caused by several factors such as: skills and qualifications of workers, demanded quality of completed construction works, organizational constraints etc. Any assessment regarding duration may therefore require some adjustments.

Work studies carried out for specific performers (workers, crews, contractors) are helpful when they include the inter-individual variability in duration assessments.

The application of probabilistic distributions allows the inconsistencies in durations, which may result from inconsistencies in productivity, changing situation in the construction site or other randomly appearing factors. Use of probabilistic distributions may be helpful in more advanced analysis concerning durations of construction works (for example risk analysis). However, if probabilistic distribution is applied to represent activities durations (that is durations of certain scopes of construction works) the problem is increased since one must apply statistic methods, moreover usually three parameters are required.

It is the author's intention is to continue the research and to compare the durations assessments made on the basis of different probabilistic distribution types.

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