IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Schedule Quality Assessment by Utilization of Working Resources

To cite this article: Roman Marcinkowski and Anna Krawczynska-Piechna 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 112092

Schedule Quality Assessment by Utilization of Working Resources

Roman Marcinkowski [1], Anna Krawczynska-Piechna [1]

[1] Warsaw University of Technology, Faculty of Civil Engineering Mechanics and Petrochemistry, 09-400 Płock, Łukasiewicza 17 St., Poland

anna.krawczynska@pw.edu.pl

Abstract. Schedule optimization is closely associated with the utilization of resources. Basing on Adamiecki's Law of Harmony, it is proposed that the schedule quality should be assessed by the effects of resources' downtime. According to authors' approach, scheduling consists in allocation of resources' work. All available resources generate total availability of work. Schedule quality assessment should be made by evaluating under-allocated work. It is a difference between total work available and work that is actually allocated as a result of the analysed schedule. Therefore, under-allocated work stands for resources' underutilization. Under-allocated work should be cost-evaluated over time with regard to particular resources or whole groups of resources (i.e. particular contractor's resources – if construction is performed by several contractors). The goal of the schedule optimization is to minimize cost of under-allocated work, especially in short-term planning horizon. The proposed method of harmonization assessment can be used in order to assess and compare any schedules, even those planned by independent schedulers for the same scope of works.

1. Introduction

Many scientific dissertations, articles and textbooks have been written about the harmonization of work and project scheduling [1]. The problems of scheduling optimization take a special place in the literature [2-7]. These problems are related to various organizational systems of undertakings, implementation conditions and planners' aspirations. In terms of organization in the construction sector, projects such as "complex of operations" [5] are distinguished, ventures implemented using stream methods related to single-type processes, homogenous and heterogenous. Implementation conditions are defined by models ordering task implementation, time limitations imposed on tasks and limitations of resources' availability. Planners' goals are described by various criteria functions, by means of which the quality of schedule is being assessed. Unfortunately, the optimization of schedules is done rarely, mainly as an auxiliary analysis in the project implementation planning.

Optimization of construction schedules is related to the use of resources. According to [8], the "**Harmonization of work** is the selection of cooperating contractors of a specific work (here, venture), and synchronization of their work in time, basing on the law of harmony formulated by K. Adamiecki, which reads: "(…) *if work is performed by several units or assemblies, the better the economic effect is obtained the more precisely the interacting units or assemblies are matched and the more precisely their time of operation is taken into account* (…)".

The schedule of works facilitates the achievement of harmony of work in project planning. Aiming to achieve work harmonization, we assign resources to tasks (we allocate active resources to perform specific tasks), set the technological order and deadlines for tasks. These issues, despite many scientific elaborations, are practically resolved through the skills and experience of the planners. Of course, many methods have been developed to optimize schedules, but they are packed with constraints, which eliminates their application to solve real planning problems.

A common technique for project scheduling is to place a set of tasks on a time scale with the analysis of resource needs (on a time scale). This technique can be effectively supported by computer application for planning and controlling project implementation. The most popular are: MsProject, Planista (a Polish application), Primavera Project Planner, ProjectManager, Super Project, Pertmaster (Primavera Risk Analysis), Project Planning Timeline or Artemis. All these programs perform troublesome (for the planner) analyses, generate various listings and charts, check and inform, whether the defined by the planner limitations (i.e. technological order of tasks, directive deadlines, defined calendars, resource availability, etc.) are met. The planner can correct the previously arranged schedule, run experiments, obtaining global and detailed characteristics of the schedule. These characteristics are the basis for assessing the quality of the organizational solution, and in case of not accepting them, making another attempt to make a better schedule.

The paper presents the method of an objective, according to the authors, assessment of the schedule quality, based on the law of harmony. It should be recalled, that the shortest cycle of construction project performance is not an objective criterion for the schedule quality. Construction entrepreneurs, when planning building performance, do not aim for a quick implementation of individual construction (projects), but for the harmonious involvement of resources. It is about creating such schedules that meet constraints placed upon the plan and minimize resources' downtime.

2. Resources in schedule optimization

As it has already been stated, significant schedule constraints result from resources' accessibility. Due to a different method of modelling their accessibility and needs, two types of resources are being distinguished: *active* and *passive* ones [9].

The active resources are not consumed within the project performance. Their effort in construction works performance is measured by the working time (e.g. man-hour, machine-hour). The availability of resource results from the resource occupancy and is characterised by the level or profile of employment on a time scale (figure 1a). These resources determine the efficiency of a task performance.

The passive resources are subject to wear during the building performance. They may be needed to carry out the action: before initiating the action or after its completion, as well as the needs of the resource can be determined by the function of the quantity on a time scale. The availability of these resources (expressed in units characteristic for them) usually results from the intensity of deliveries (quantities on a time scale). This, in turn, is reduced to the function of aggravated supply of resources (figure 1b). The function of the totalled delivery is balanced with a similar function of "total consumption of resources" (determined by the intensity of consumption, which results from the schedule). Passive resources primarily define the logistic effort. They can cause a slowdown in building performance or changes in performance's concept, scope of works or technology.

The construction processes carried out by specific technologies are characterized by the prism of resources. For each highlighted process, the work inputs of active resources and the consumption of passive resources are determined. Both these characteristics are referred to as inputs.

The unit input values are the basis of computer-aided construction production management. They create KNR data bases, are useful in cost evaluation, harmonization of works and resources' management. In many cases, schedule optimization does not take into account all constraints on resources. And rightly so. Being aware of the complexity of the scheduling optimization task, only the constraints that actually occur should be considered. However, there is *no schedule optimization without resource analysis*.

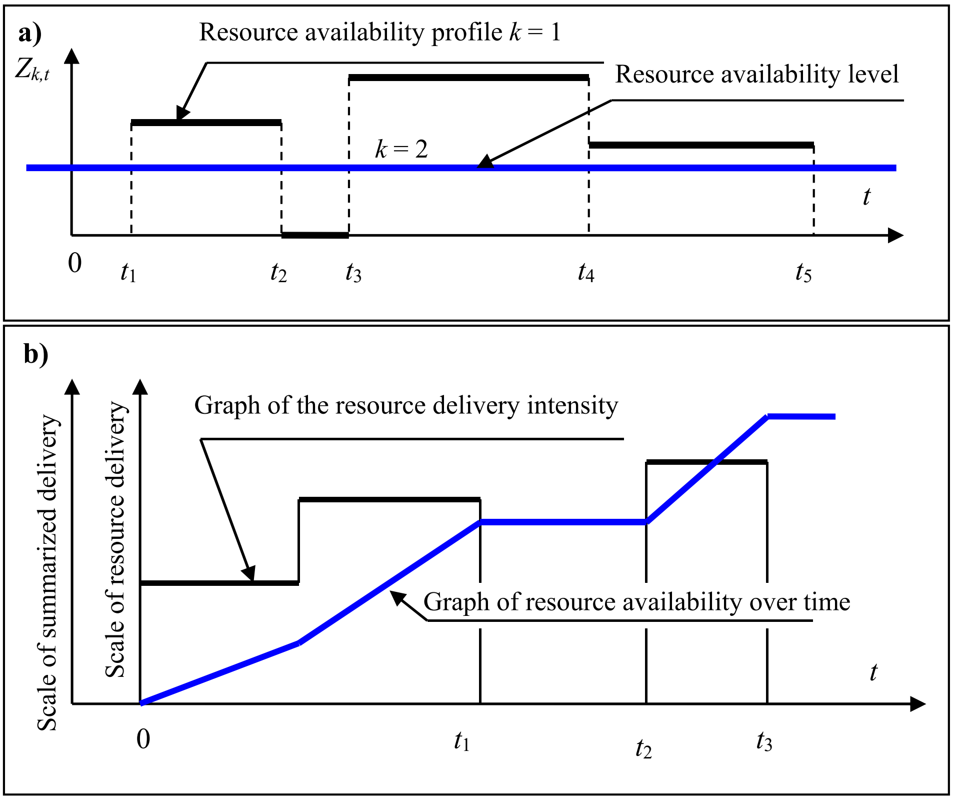

Figure 1. Graphical interpretation of resource availability restrictions: a) for active resources, b) for passive resources

3. Evaluation of the resource use as a schedule quality assessment

The production schedule implements the vision of using working resources over time. Its purpose is to eliminate unreasonable breaks in work of available resources, assigned to complete a particular set of construction tasks.

Resources (means of work) are very diverse. The downtime of one resource may be insignificant in relation to the fuller use of another one. Therefore, a synthetic indicator is needed to assess resources' utilization. It is proposed that such an indicator should be based on the *costs of losses due to the downtime of labour resources*. Each active resource provides the contractor (employer) certain financial benefits while working. They result from so called indirect costs and a profit calculated on the basis of indirect costs, labour and equipment costs. The percentage rate of indirect costs varies between 45-80 % of direct costs. Knowing unit costs of labour and machines, it is not difficult to determine the costs of losses as a loss of potential income during resources' downtime. This loss comes from the loss of funds that the entrepreneur would gain from the overheads calculated for the direct costs of working resources.

The unit loss cost (per unit of time) c_l due to the downtime of the l-th resource can be calculated with the following formula [9]:

$$c_l = c_l^j \cdot \frac{w_{kp}}{100} \cdot \left(1 + \frac{w_z}{100}\right), \tag{1}$$

where: c_l^j – unit labour cost of the l-th resource, w_{kp}, w_z – percentage ratios of indirect costs and profit.

Such indicators should be determined for all active resources (hereinafter – the set $\{S^a\}$) used to perform works in the planned building project.

The “under-allocated work” concept is known in the project scheduling. Computer applications display this characteristics over time for all the analysed resources. It is the difference between the work available and work that is actually allocated as a result of the analysed schedule. Therefore, it stands for resources’ underutilization. Under-allocated work should be cost-evaluated over time with regard to particular resources or whole groups of resources (i.e. particular contractor’s resources – if construction is performed by several contractors) of not using the resource. If we assume that for a given resource *l*, the construction contractor *z*, of the time interval $\langle T; T+t \rangle$ the $N_{zl}(t)$ resource’s work demand is known (determined on the basis of the schedule) and availability (specified by a number) of this resource is $p_{zl} > 0$, then we can determine the *utilization rate of the resource* according to the formula (2) or the loss cost due to the under-allocated work of the resource – with formula (3):

$$\alpha_{zl}(t) = \frac{N_{zl}(t)}{p_{zl}(t) \cdot t}, \tag{2}$$

$$c_{zl}^{p}(t) = [p_{zl}(t) \cdot t - N_{zl}(t)] \cdot c_l \ . \tag{3}$$

Summing up the costs for all resources owned by a given construction contractor, we can plot histograms of costs of losses for under-allocated in the adopted time scale. However, in order to assess harmonization quality, it is proposed to calculate an appropriate evaluation index for the period of time *t,* according to the formula:

$$C_z(t) = \frac{\sum_{l \in S^a} \{\alpha_{zl}(t) \cdot c_l \cdot p_{zl}\}}{\sum_{l \in S^a} \{c_l \cdot p_{zl}\}} \quad \text{for } \{(z,l)\}: (c_l \cdot p_{zl} \neq 0). \tag{4}$$

To compare project schedules carried out by various contractors, we should aim to establish the assessment index in an absolute scale. However, because the harmonization of work is variable in time, and the production activity of particular contractors is practically endless, this index should be determined as a function of time.

The *resources utilization index* $C_z(t)$ is a quantitative expression of the schedule quality, or more precisely – *quality of the harmonization of works*. If the value of this indicator approaches to 1, the schedule is of a high quality, otherwise, if it approaches to 0, it is a signal that the work of resources has not been harmonized. The resource utilization index can be carried out for each implementer individually, for the entire schedule and in both cases – at any time period of time. Such analyses are illustrated with the example below.

4. The example of the schedule quality analysis

In order to assess the schedule quality, the following must be known for the distinguished contractors:

- availability of resources (labour and machines) – the amounts of particular resources assigned to particular schedule tasks (if this availability varies over time, it is necessary to know the resource availability profiles in a time scale);
- labour demands for particular resources as a function of time (for example on particular days of the schedule under consideration);
- resource unit downtime costs – a potential loss due to the downtime (under-utilization) of each resource in a unit of time (i.e. within 1 hour).

Let’s analyse the quality of works’ harmonization in tasks performed by two brigades, according to the schedule shown in figure 2.

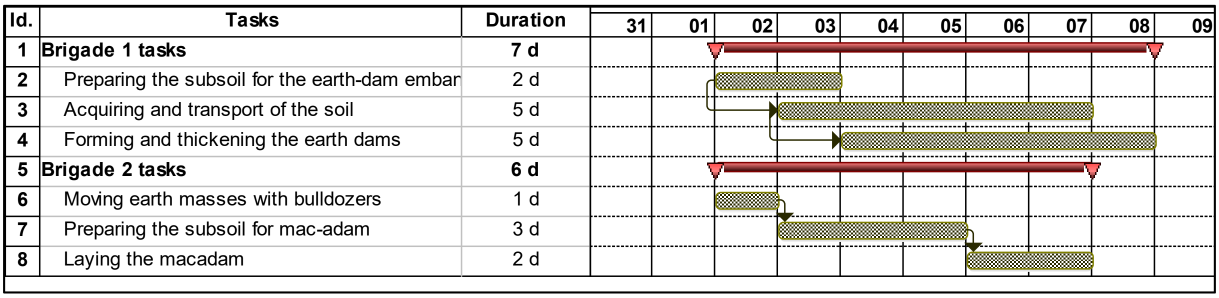

Figure 2. An example schedule of works for two brigades.

All the resources assigned to particular brigades and their availability profile (availability in time) can be found in figure 3 (Brigade 1) and figure 4 (Brigade 2). The coefficient $\alpha_{zl}(t)$, required to calculate the quality index, according to the formula (4), can be generated directly in MsProject Resource Usage view, as it shown in figure 3 and 4.

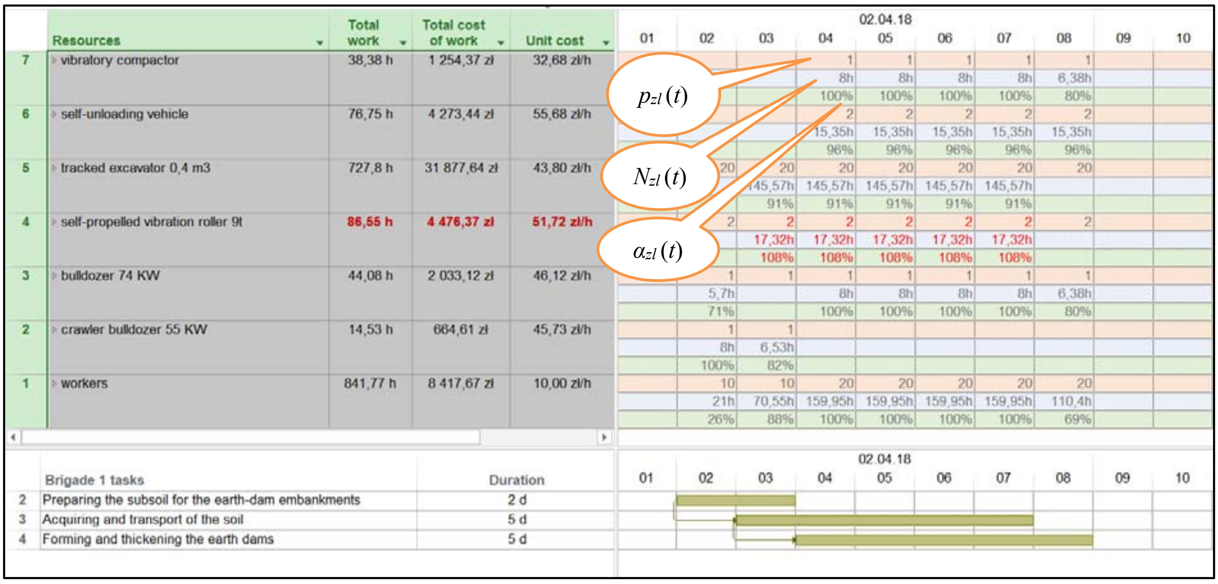

Figure 3. Brigade 1 work analysis – MS Project widow view.

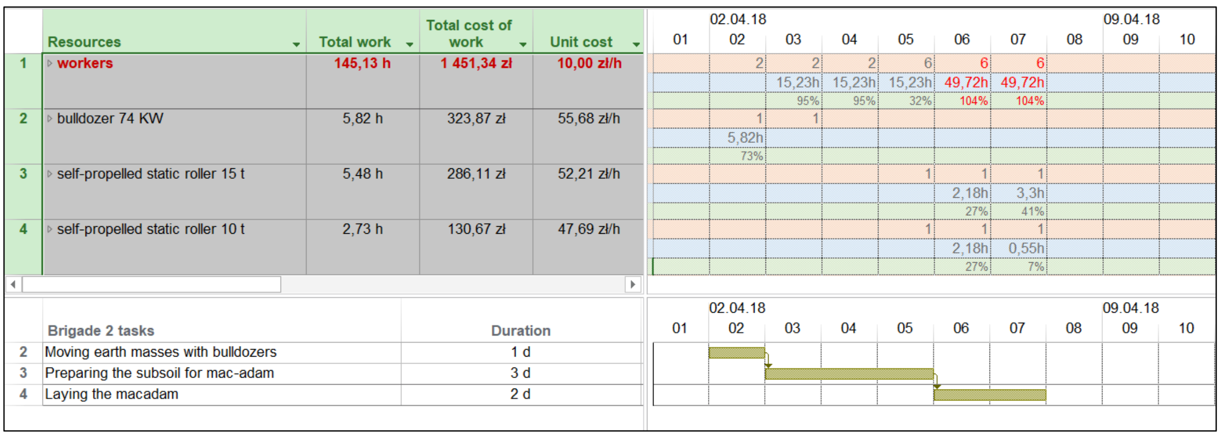

Figure 4. Brigade 2 work analysis – MS Project widow view.

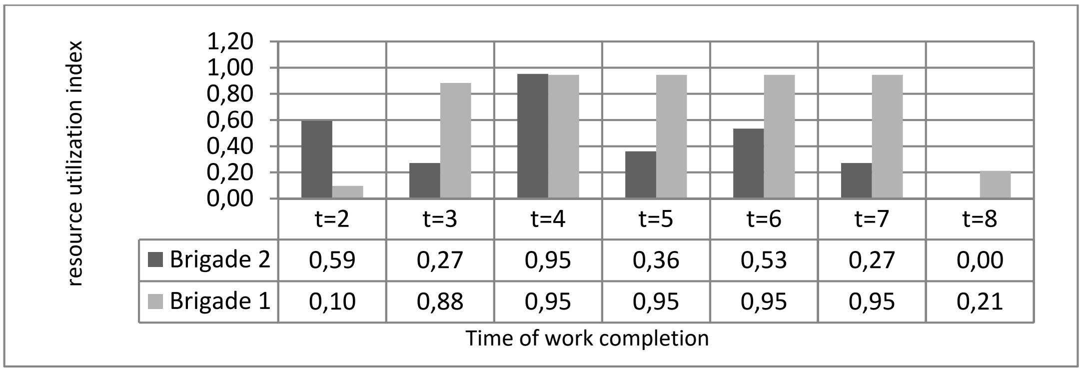

Figure 5. A histogram showing the harmonization (and resources' utilization) assessment in particular days of the project.

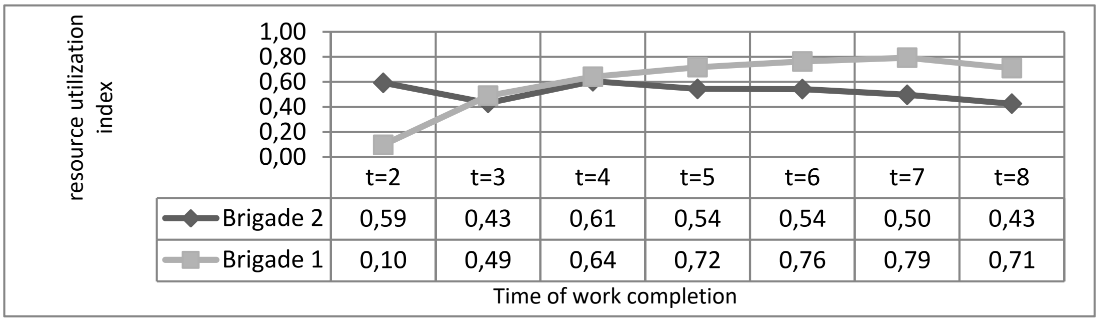

Figure 6. A graph showing the harmonization (and resources' utilization) assessment function in a variable period of time counted from the beginning of the project.

Figure 5 presents a histogram showing the assessment of harmonization and resources' utilization in particular days of the project implementation. This chart was created using formulas (2) and (4) and assuming an 8-hour working day. For each day, the resources' utilization rates were calculated for each resource, and then the assessment index was obtained with formula (4).

Graphs in figure 6 illustrates the harmonization assessment function in a variable period of time, counted from the start of the project to the time defined on the coordinate axis. Therefore, it can be read from the graphs, that the coefficients of resource utilization in the whole performance are equal to 0,71 for Brigade 1 and 0,43 for Brigade 2, which means that work of Brigade 1 is better harmonized and resources' utilization is better.

The planner, however, may not always take into account the entire work schedule. Especially, when the scope of works for individual implementers will change through the arrival of new tasks, which were not included in the analysed schedule. In this case, it will be more important to harmonize the work of resources in a short-term horizon. The charts presented above contain all the information in this regard.

5. Conclusions

The proposed method of harmonization assessment can be used in order to assess and compare any schedules, even those planned by independent schedulers for the same scope of works. The clue of the presented approach lies in the dependence of the assessment on time and making the assessment in a uniform scale from 0 to 1, where 1 stands for a complete harmony in resources' utilization and 0 stands for an inactivity of the implementer.

References

[1] O. Kapliński, "Report of the Section of the Committee for Civil Engineering in the term 2007-

2010”, *Archives of Civil Engineering,* vol. 57 (1), pp. 5-16, 2015. (in Polish)
[2] R. Słowiński, and J. Węglarz, *Advances in Project Scheduling*, Amsterdam: Elsevier, 1989.
[3] P.W. Swenson, “Project Analysis Tools for Cost and Schedule Improvement”, *AACE International Transactions, Denver, Colorado*, 1999.
[4] Z. Hejducki, M. Rogalska, *Time coupling methods construction scheduling and time/cost optimization*, Wrocłwa: Oficyna Wydawnicza Politechniki Wrocławskiej, 2011, ISBN 978-83-7493-588-3 (in Polish)
[5] F.B.Talbot, “Resource constrained project scheduling with time – resource trade – offs: the nonpreemptive case”, *Management Science*, vol 28 (10), 1982.
[6] E. Plebankiewicz, M. Juszczyk, and J. Malara, “Estimation of task completion times with the use of the PERT method on the example of a real construction project”, *Archives of Civil Engineering,* vol. 61 (3), pp.51-62, 2015.
[7] W. Bożejko, Z. Hejducki, M. Rogalska, and M. Wodecki, “Time couplings method in construction project management”, *Materiały Budowlane*, vol. 6, (524), pp. 11-12, 2016, ISSN 0137-2971, (in Polish)
[8] K. Adamiecki, *Organization Studies*, Warsaw: PWE, 1985. (in Polish).
[9] R. Marcinkowski, “Optimization of planning decisions based on labour demands”, In: T. Kasprowicz (Ed.), *Inżynieria przedsięwzięć budowlanych. Rekomendowane metody i techniki*, vol. 91, pp. 126-140, 2015, (in Polish)