INTANGIBILITY-AWARE EVALUATION OF CONSTRUCTION PROJECT SCHEDULES

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ABSTRACT

Schedules of complex civil engineering construction projects are dealt with. Complexity of the projects results from numerous factors. They include precedence relations between technological operations and multiple modes of their execution, limited availability of resources. Above mentioned factors cause that there usually appear numerous feasible construction project schedule alternatives. The choice of the best project schedule alternative requires application of multi-criteria decision analysis. Applied criteria usually pertain to time and cost of project execution, utilisation and nature of available resources etc. Utilisation of other, intangible, criteria due to influence of building activities on surrounding environment is also recommended. An intangibility-aware approach for multi-dimensional evaluation of construction project execution is presented. It is based on assessment of technological operation modes using a pair-wise AHP/ANP comparisons. Discussion of results of initial application of the approach is also included.

Keywords: project, civil engineering, construction site, schedule, graph, evaluation, optimisation, multi-attribute, technology operation, influence, surrounding, intangibility.

1. Introduction

Identification of optimal construction projects in civil engineering is complex due to several reasons. At first, different parties, numerous multi-mode technological operations and resources of limited availability are involved in construction activities. Realisation of all operations is required for successful project completion. At second, technological operations should be executed in order which results from precedence relations between operations. At third, project execution schedule can be evaluated using different criteria. The criteria pertain to both overall parameters of a project as well as parameters of individual operations. At fourth, some evaluation criteria correspond to intangible factors e.g. influence of a project or its component operations and on surrounding environment.

Identification of optimal project schedule requires means for effective intangibility-aware multidimensional project evaluation. An approach is presented in the paper which makes it possible. It is based on value derivation for intangible parameters of operations which are derived thanks to application of AHP/ANP.

2. Construction project schedule optimisation

Resource constraints and multiple modes of operations play important role in civil engineering construction projects. Scheduling problems with regard to construction projects in civil engineering are therefore considered as multi-mode resource-constrained project scheduling problems i.e. MMRCPSP

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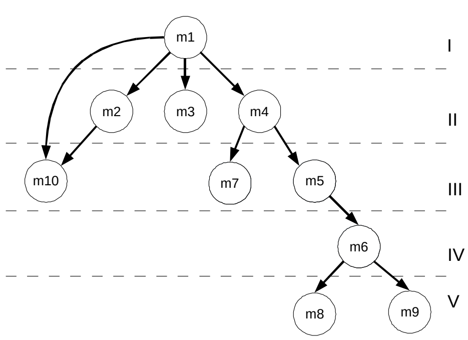
(Brucker et al. 1999). Construction scheduling problems deal therefore with allocation of appropriate modes to individual operations to deliver the best outcomes for the overall project. Application of appropriate criteria of a project schedule evaluation makes it possible.

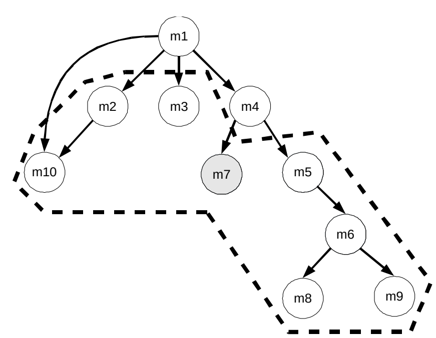
Different approaches are applied for their optimisation (Węglarz et al. 2011). Two main groups of approaches include exact (Hartmann & Drexl 1998) and approximation methods (Alcatraz et al. 2003; Mika et al. 2008). Exact methods are rather applicable in the case of smaller project instances and less complex optimisation problems. Approximation methods address problems the exact methods aren't inefficient for.

Construction projects in civil engineering are prone to aggregation of technological operations. It is therefore possible, even in the case of a very complex project,to reduce it to a form which is tractable for exact methods. In the case of insufficient aggregation of there are approaches which would make identification of a tractable form possible. For example, a multi-level disaggregation-aggregation procedure can be utilised. Application of such procedure would, however, require replacement of a single-stage optimisation procedure with a multi-stage procedure.

Possibility of aggregation of technological operations makes application of exact optimisation methods sufficent. A mixed linear programming (MIP)-based approach is applied with this regard. It makes use of several criteria. The criteria can be applied jointly or separately. Application of MIP approach makes including of (linear) resource constraints easy. Appropriate MIP programme results from a considered order of technological operations. A network model of a project is utilised to describe the order. Acyclic and assymetric Activity-On-Arc graph is applied with this regard. It is called a graph of operations of technological processes (Ambroziak 2007) or a technological graph of a project for short. Information about precedence relations between the objects is applied to define a feasible order. A graph model (graph of precedence) is utilised for definition of precedence relations between the operations. Fig.1a presents a precedence graph for a project (a multi-stand parking building) which consists of 10 technological operations. Basic parameters of the operations are presented in Tab.1. The operations belong to 5 levels. The levels pertain to different character of the operations. Operations which belong to the highest level aren't preceded by any other operation. Each level groups operations which can be realised in any order (independent operations). Operations which occupy In general, a group of operations can be accomplished in any order if only any of them isn't preceded, directly or indirectly, by any other operation of the group. A group of independent operations for m7 operation is identified in Fig1b.



a. A graph of precedence of operations



b. Indepenedent operations for operation m7

Figure 1. Illustration of precedence for a sample project (Dytczak et al. 2011)

Exclusive application of precedence relations doesn't usually produce a single activity network. Two different feasible alternatives of a technological graph of a project which correspond to the precedence graph in Fig.1a are presented in Fig.2. Multiplicity of feasible technological graphs of operations requires considering of their whole population to identify globally optimal project alternative. Approximation of the population can be utilised as well. Sequential, random and evolutionary generation of candidate schedules can be utilised with this regard.

Table 1. Characteristics for 10 technological operations of a sample project

Operation symbol	Operation description	Preceding operations
m1	Construction site arrangement	-
m2	Realisation of infrastructural terminals	m1
m3	Installation of external lighting	m1
m4	Earthworks for an overground floor and formation of slopes	m1
m5	Micropile driving to provide foundations for bottom plate and columns	m1, m4
m6	Erection of underground and overground floors	m1, m4, m5
m7	Building-site drainage and installation of a drainage for a building	m1, m4
m8	Finishing works	m1, m4, m5, m6
m9	Accomplishment of parking plates	m1, m4, m5, m6
m10	Delivery and assembly of fence and access control systems	m1, m2

Processing of data is easier during optimisation process when both a graph of precedence of operations and technological graph of a project alternatives are expressed in a consistent matrix form. Their forms obtained for the sample project are presented below (Eqn.1). The lower technological graph of the sample project alternative from Fig.2 is considered. The largest number of vertices for a technological graph equals to number of technological project operations plus one (see the higher graph alternative in Fig.2) because a single vertex expresses starting and ending events for the operations. An incidence $\mathbf{Q}_G$ matrix which consists of number of rows equal to number of the operations and number of columns equal to maximum number of vertices is sufficient to cover any possible order of operations. Each row of the matrix is devoted to a single operation and each column to a single vertex. Elements of the matrix which are equal to one (q_{Gij}=+1) inform that the i-th operation starts at the j-th vertex and elements equal to minus one (q_{Gij}=-1) indicate that the i-th operation ends at the j-th vertex.

Feasibility of a schedule doesn't depend on technological order of operations alone. Satisfaction of the order is, however, necessary to construct feasible schedules. Other important constraints come from resources availability and consumption. Consumption of resources results from a fundamental characteristic i.e. volume. A suitable unit is applied for measurement of an operation volume. Volumes of operations together with allocation of selected modes to operations gives values of characteristics for operations e.g. operation cost and duration. These values are applied to represent different modes of operations during identification of the best project schedule. The modes are identified by applied sets of technical resources. Sample sets of technical resources for m2 operation are presented in Tab.2. Volumes and sets of technical resources applicable in the case of project operations are listed in Tab.3.

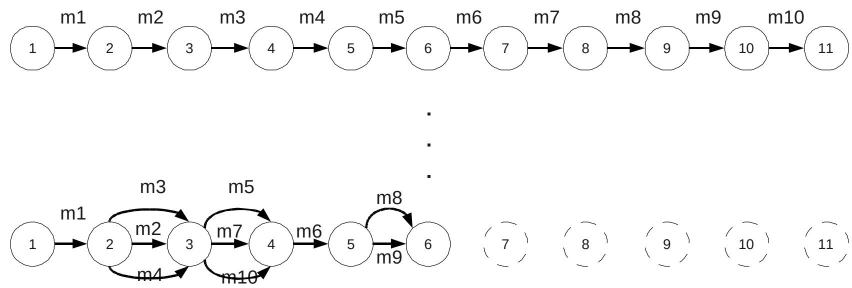


Figure 2. Alternative feasible graphs for a sample project characterised in Tab.1

$$\mathbf{Q}_{\mathrm{G}} = \begin{bmatrix} +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & +1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & +1 & -1 & +1 & -1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{1}$$

Table 2. Sample sets of technical resources applicable in the case of m2 operation

Set symbol	Purpose	Set composition
s3	Mechanised shallow earthworks	A joint excavator and bulldozer machine plus a manual working team; standard technology applied
s4	Highly mechanised shallow earthworks	A joint excavator and charger tractor plus a truck; efficient technology applied

Searching for the global project realisation optimum relies on identification of locally optimal project optimisation of a fixed structure. The rest of the paper is therefore devoted to the case of local optimisation.

Features of a whole project result from features of individual operations. Criteria of a project alternative evaluation come therefore from features of operations. However, both criteria which correspond to individual operations and and to which pertain to whole project are applied in the practice. The whole project criteria usually include cost and duration of project completion. Work effort of technical resources and consumption of building materials can be also utilised with this regard. Criteria which pertain to characteristics of individual technological operations can include: temporary intensity of consumption of financial or other resources, temporary number of involved technical resources.

Features of technological operations are included in the analysis using relative values. It makes reliable comparison of features of a different nature e.g. time, cost and resource consumption. Idealised or unitarised values of features can be applied with this regard. In the case of idealised priorites, the most preferable operation mode alternative due to a considered attribute is described by unitary priority and non-negative priorities for other alternatives correspond to a part of one. There is a slight difference in the case of application of unitarised priorities. The non-negative priority pertaining to the worst operation mode is always equal to zero. To obtain consistent outcomes of an analysis it seems necessary to define priorities on the basis of a complete set of operations. This is not hard in the case of tangible attributes. It can be, however, a challenging task in the case of reliable derivation of priorities for intangible features of operations. Application of AHP/ANP requires utilisation of additional tools because of limited capability of the method with regard to addressing large sets of evaluated objects.

Table 3. Volume and applicable sets of technical

Operation	Volume description
m1	Collecting, loading, transportation and unloading, assembly of 6 provisional construction site infrastructure buildings. Launch of construction site infrastructure.
m2	Assembly of a trafo station, a local sewage treatment plant, a pump station.
m3	Installation of 12 lighting stands, laying of an electric wire (500 m) and automatic lighting control central.
m4	Local shift and partial expedition (a 30 km range) of 10000 cubic meters of soil.
m5	Driving of 80 foundation micropiles and erection of 24 bearing columns.
m6	Realisation of 800 cubic meters of underground reinforced concrete structure and 320 t of steel overground structure.
m7	Laying of 300 m drainage pipes and assembly of 8 drainage sumps.
m8	Erection of 300 sq. meters of double-side plastered ceramic wall, 160 sq. meters of opaque glass walls, 80 sq. meters of double-glazed steel window panes.
m9	Realisation of 800 sq .meters of industrial floor plates with dilatations and oil setters.
m10	Installation of 100 meters of a fence in accordance with a design plans. Arrangement of 8 monitoring cameras and laying of 400 meters of a wire. Installation of 2 access control monitors and an automatic system of computerised registration.

It seems that initial clustering of similar operation modes will help at least a little to obtain trustworthy priorities. Cardinality of clusters should correspond to AHP/ANP tractability i.e. each cluster ought to consist of not seven plus minus two operation modes. Several levels of cluster hierarchy can be applied if a single cluster level isn't capable of delivering division of operation modes into clusters of sufficient number of components. Cluster hierarchy is similar to hierarchical AHP/ANP structures but differs from in one specific aspect. It is solely devoted to a single decision alternative feature.

Limitations of AHP/ANP capabilities cause that number of cluster hierarchy levels shouldn’t exceed a certain level. Up to seven levels are usually accepted with this regard. This limitation doesn't nevertheless influence the approach a lot as such number of hierarchy levels makes including of pretty large number of alternatives possible.

Overall feature of project schedule with regard to a certain attribute results from summation of relative attribute values for all selected operation modes. Application of relative feature evaluations are utilised during optimisation, computation of absolute values of tangible attributes requires separate summation over selected modes.

Application AHP/ANP is also the perfect choice for definition of relative importance of different optimisation criteria. It seems, however, that normalised values of priorities make better job in the case of linear goal function coefficients. Readible differentiation of importance weight values makes application of a sensitivity analysis easier. Such analysis would contribute to confidence about final results validity.

Presented approach is applied during optimisation for two purposes. The first deals with optimisation of local (with regard to considered structure of activity network) i.e. to allocation of a set of the best modes of operations die to considered criteria. A finite set of Pareto-optimal schedules (or its approximation) is thus identified. The second is devoted to evaluation of locally optimal schedules to identify a schedule(s) which are the best or very close to the best schedule(s).
Initial application of the approach to rather small problem instances delivers interesting results. We are sure, however, that its application to larger practical problems in civil engineering is necessary to prove its usefulness. The research is underway so the more interesting results are going to appear soon. They will be presented during the symposium.

3. Conclusions

Presented approach comprises a vital part of a procedure which helps to identify optimal or near-optimal construction schedule. It is novelty comes from coupling global optimisation of construction schedules in civil engineering with reliable addressing of intangibility. The procedure would therefore allow to attain more sustainable decisions with regard to a construction project planning and execution.

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