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MODELING TECHNOLOGICAL AND ORGANIZATIONAL VARIANTS OF BUILDING PROJECTS

MODELOWANIE WARIANTÓW TECHNOLOGICZNO- -ORGANIZACYJNYCH PRZEDSIĘWZIĘĆ BUDOWLANYCH

Abstract

The paper addresses the possibility to utilize alternative-decision networks to model and analyze technological and organizational variants of building processes [1]. The undetermined structure of such networks makes it possible to simultaneously model any given number of variants of the scrutinized project and, as a result of the network's analysis, to select the solution (variant) which is optimal within the set criterion. The paper attempts to broaden thevertex set of the subject network by adding two logical formulas on the side of the peak entrance: namely „and" and „or" to make the modeling of certain technological and organizational relationships of a construction enterprise easier. Introducing new vertices into the network required extending the mathematical model used to determine the optimal technological and organizational variant of the analyzed enterprise.

Keywords: network models, technological and organizational structure, optimization

Streszczenie

W artykule zwrócono uwagę na możliwość zastosowania sieci alternatywno-decyzyjnych do modelowania i analizy wariantów technologiczno-organizacyjnych procesów budowlanych [1]. Niezdeterminowana struktura takich sieci umożliwia jednoczesne zamodelowanie dowolnej liczby wariantów realizacji rozpatrywanego przedsięwzięcia oraz w wyniku analizy takiej sieci, wybór rozwiązania (wariantu) optymalnego w sferze ustalonego kryterium. W artykule podjęto próbę poszerzenia zbioru wierzchołków przedmiotowej sieci poprzez dodanie dwóch form logicznych od strony wejścia do wierzchołków, a mianowicie „i" oraz „albo", aby uprościć modelowanie niektórych zależności technologiczno-organizacyjnych rozważanego przedsięwzięcia budowlanego. Wprowadzenie do sieci nowych wierzchołków, wymagało rozszerzenia modelu matematycznego służącego do wyznaczenia optymalnego wariantu technologii i organizacji rozważanego przedsięwzięcia

Słowa kluczowe: modele sieciowe, struktura technologiczno-organizacyjna, optymalizacja

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Symbols

Y, U	–	sets
$[Y, U]$	–	graphs
$\{\lambda_{i,j}\}$	–	matrix elements
$\langle y_i, y_j \rangle$	–	ordered pair: y_i – antecedent, y_i – consequent
Γ_y	–	set of direct consequents y
Γ_y^-	–	set of direct antecedents y
$\pi^+ r$	–	output half-degree (the number of arcs originating from a node)
$\pi^- r$	–	input half-degree (the number of arcs reaching the node)

1. Introduction

Each irregular process, which is commonly defined as an atypical – regarding structure and organization – individual project, should have its reflection in a delivery project. In such a project, to describe its technological and organizational structure (as well as the parameters of the process in question), graph-based mathematical objects of special nature are utilized. Such objects are commonly referred to as networks. Their broad scope makes it possible to effectively plan the process so that, as a consequence, we can obtain an optimal delivery project. Such networks are a convenient tool of creating correct schedules for the realization of processes.

The subject literature [e.g. 2–6] gives the opportunity to get acquainted with the basic issues of network planning, as well as grants the possibility to find multiple examples of their practical implementation.

The criteria for networks' division include a division based on their logical structure which can be determined or non-determined. Networks of a determined structure (i.e. canonic networks) are suitable for modeling processes for which technologies and organizational connections are univocally established. Non-determined structure networks, on the other hand, take into account variants of technological and organizational occurrences in the process being modeled. If it turns out that certain variants of such process will be coming into existence in a random manner, the network which models such a process will be called a stochastic network [e.g. 2, 5–7]. If it turns out that the aforementioned variants of the process will come into existence in deterministic conditions, the network which models such a process will be called an decision network [1, 5].

Research studies [1] which first proposed the concept of alternative-decision networks introduced a definition of such a network based on a special, network-specific graph which allowed modeling of both: technological and organizational variants of the project.

Objectives of the work: The author of this article introduces additional emitters and receptors into the structure of the subject networks. The application of such emitters and receptors facilitates modeling of certain technological and organizational relationships which are typical for construction projects. Introducing new nodes into the network required broadening the mathematical model used to establish the optimal technological

and organizational variant of the project in question by adding new, node-specific limiting conditions. Subsequently, their correctness was proven [8]. Additionally in the paper, practical examples of such networks' application in construction were presented.

2.1. Objectives with alternative-decision networks

a network is given whose graph $G = [Y, U]$ where Y stands for any finite set of elements (nodes); U: non-empty, two-segment relationship $U \subset Y \times Y$ and $|Y| \geq 2$, and meets the following requirements: it is consistent and acyclic – there exists exactly one initial node and at least one goal node in the graph. A node $y \in Y$ of the network is described as an event and is the element that expresses, from one side, the reaching of a certain state or goal manufactured by determined subsets of arcs, and from the other side, for other determined subsets of arcs acts as a condition for their realization. Based on the description presented above, the node can be divided into two parts:
– **receptor** that determines the conditions of reaching a given state (receptor activation),
– **emitter** that determines the conditions of the realization of certain actions that are symbolized by the arcs.

In the defined network, we can single out six possible, two-segment combinations (nodes) of the network, including the four newly introduced by the author of this paper, characterized by the following receptors and emitters that are presented in the table (Fig. 1).

RECEPTOR EMITTER	and	or	either
Canonic	◯	⬡	⬯
Decision	⬭	⬠	⬚

Fig. 1. Nodes of an alternative-decision network (source: own work)

In the alternate-decision network under the question, we can also distinguish two subsets of arcs:
a) set $U_A \in U$ containing so-called alternative arcs, the interpretation of which is as follows: An alternative arc is an arc originating from the node with the decisive emitter. It is assumed that only alternative arcs originate in the node with the decisive emitter. In order for the previous assumption to make sense, we also assume that at least two of such arcs must originate from the aforementioned node. A situation where alternative arcs originate from the initial node should be excluded. For that reason, we assume that the initial node of the network in question should not hold a decisive emitter;
b) set $U_k \in U$ that contains so-called canonic arcs, the interpretation of which is as follows: A canonic arc is an arc originating from a node with a canonic emitter. We assume that only canonic arcs can originate from a node with a canonic emitter. A graphical interpretation of both an alternative arc and a canonic arc is presented in Fig. 2.

This last assumption pertains to the goal node of the defined network, which is preceded in the path by at least one node with a decision emitter. A path in a graph $G = [Y, U]$ should be understood as a sequence of arcs in which the end of each arc overlaps (through a node) with the beginning of the subsequent arc.

a) - ▶

b) ────────────────────▶

Fig. 2. Graphical interpretation of arcs:
a) alternative, b) canonic (source: [1])

2.2. Allowable structures (allowable sub-networks)

Non-determined logical structure of the decision-alternative network in question contains certain allowable structures (allowable sub-networks) which will represent selected technological and organizational variants of the modeled process. An allowable structure (allowable sub-network) in an alternative-decision network can be described as a sub-network based on a graph $G^* = \left[Y^*, U^* \right]$, where $Y^* \subset Y, U^* \subset U$ are non-empty. That graph has to meet the following requirements: it is consistent and acyclic. The initial node of graph, $G = [Y, U]$ of alternative-decision network is also the initial node of, $G = [Y^*, U^*]$ contains at least one goal node that belongs to graph $G = [Y, U]$ of the alternative-decision network. If a node with a canonic emitter in graph $G = [Y, U]$ of an alternative-decision network belongs to a graph $G = [Y^*, U^*]$, then all directly subsequent consequents of the node will also belong to it. If a node with a decision emitter in the graph $G = [Y, U]$ of the alternative-decision network belongs to the graph $G = [Y^*, U^*]$, then one and only one direct subsequent nod belongs to that graph. Consequently, following the second definition, each allowable structure (allowable network) of an alternative-decision network can be described by using a row vector characterized in the following way:

$$A = \left\{ \lambda_{ij} \right\}, \quad \text{where} \quad \lambda_{ij} = \begin{cases} 0 & \text{for } y_i, y_j \notin U^* \\ 1 & \text{for } y_i, y_j \in U^* \end{cases} \text{which for} \quad r, s \in Y$$

3. Binary extreme issue

each alternative-decision network contains a finite number of allowable structures (allowable sub-networks) and it is known that it has to possess, as the properties of such networks dictate, at least two such structures. In the course of further analysis, we will be interested in the way of determining the allowable structure and making the determined allowable structure of the considered network such an allowable sub-network that will be also optimal in terms of the adopted section criterion.

In order to solve the above task, a binary extreme issue, presented in short by the symbol (BZE), must be formulated.

$$\sum_{i,j \in U} c_{ij} \lambda_{ij} = \mathbf{min} \left(\text{or } \mathbf{max} \right) \tag{2}$$

with limiting conditions:
for $s \in Y$ („canonic" emitter)

$$\sum_{r \in \Gamma s} \lambda_{sr} = \pi^+ s \tag{3}$$

for $r \in Y$ (receptor „and", „canonic" emitter)

$$\pi^+ r \lambda_{ir} - \sum_{j \in \Gamma r} \lambda_{rj} = 0 \ \ \text{for} \ \ i \in \Gamma_r^- \tag{4}$$

for $r \in Y$ (receptor „or", „canonic" emitter)

$$\pi^+ r \lambda_{ir} - \sum_{j \in \Gamma r} \lambda_{rj} \le 0 \ \ \text{for} \ \ i \in \Gamma_r^- \sum_{j \in \Gamma r} \lambda_{rj} - \sum_{i \in \Gamma_r^-} \pi^+ r \lambda_{ir} \le 0 \tag{5}$$

For $r \in Y$ (receptor „either", „canonic" emitter)

$$\sum_{i \in \Gamma_r^-} \pi^+ r \lambda_{ir} - \sum_{j \in \Gamma r} \lambda_{rj} = 0 \tag{6}$$

for $r \in Y$ (receptor „and", „decision" emitter)

$$\sum_{i \in \Gamma_r^-} \lambda_{ir} - \sum_{j \in \Gamma r} \pi^- r \lambda_{rj} = 0 \tag{7}$$

for $r \in Y$ (receptor **„or"**, **„decision"** emitter)

$$\sum_{i \in \Gamma_r^-} \lambda_{ir} - \sum_{j \in \Gamma r} \pi^- r \lambda_{rj} \le 0 \ \ \ \sum_{j \in \Gamma r} \lambda_{rj} \le 1 \ \ \ \sum_{j \in \Gamma r} \lambda_{rj} - \sum_{i \in \Gamma_r^-} \pi^+ r \lambda_{ir} \le 0 \tag{8}$$

for $r \in Y$ (receptor **„either"**, **„decision"** emitter)

$$\sum_{i \in \Gamma_r^-} \lambda_{ir} - \sum_{j \in \Gamma r} \lambda_{rj} = 0 \ \ \ \ \ \sum_{j \in \Gamma r} \lambda_{rj} \le 1 \tag{9}$$

Limitation for variable λ_{ij}

$$\lambda_{ij} = \begin{cases} 0 \\ 1 \end{cases} \tag{10}$$

An objective function (commonly referred to as a criterion function) formulated for (BZE) is the most basic of all the possible functions where: c_{ij} is a constant value, the load of the graph arc $y_i, y_j \in U$ of an alternative decision network and λ_{ij} is a variable (decisive) determining if a given arc $y_i, y_j \in U$ belongs (or doesn't belong) to an optimal structure (that is the best one allowable within the accepted selection criterion) in an alternative-decision network. Additional conditions (4), (6), (7), (9) are the consequence of the author's introduction of the aforementioned additional nodes into the network structure.

4. Technological and organizational structures in construction

below, an example of modeling variants of technological and organizational of foundation works as a part of a construction project. Fig. 3 shows a fragment of an alternative-decision network that models the elevation of foundation for two buildings simultaneously. Table 1 contains data on the net cost of each task. Then the author has established a minimum cost as a criterion for selecting the optimal variant of technological and organizational of foundation works.

Table 1

Data on the net cost of each task within the foundation works (source: own work)

SYMBOL OF TASK	DESCRIPTION OF THE TASK	UNIT OF MEASURE	QUANTITY OF UNITS	UNIT PRICE	VALUE
A1	Groundworks for construction nr 1	[m³]	600	43	**25800**
A2	Groundworks for construction nr 2	[m³]	600	43	**25800**
B1	Foundation formwork traditional for construction nr 1	[m²]	140	60	**8400**
B2	Foundation formwork traditional for construction nr 2	[m²]	140	60	**8400**
C1	Assembly and disassembly of tower crane for construction nr 1	[Set]	1	2600	**2600**
C2	Assembly and disassembly of tower crane for construction nr 2	[Set]	1	2600	**2600**
D1	Foundation formwork system for construction nr 1	[m²]	140	41	**5740**
D2	Foundation formwork system for construction nr 2	[m²]	140	41	**5740**
E1	Reinforcement manual for construction nr 1	[T]	2.20	4022	**8848**
E2	Reinforcement manual for construction nr 2	[T]	2.20	4022	**8848**
F1	Prefabricated reinforcement for construction nr 1	[T]	2.20	4063	**8939**
F2	Prefabricated reinforcement for construction nr 2	[T]	2.20	4063	**8939**

G1	Reinforcement manual for construction nr 1	T	2.20	4022	**8848**
G2	Reinforcement manual for construction nr 2	T	2.20	4022	**8848**
H1	Task apparent for construction nr 1	–	–	0	**0**
H2	Task apparent for construction nr 2	–	–	0	**0**
I1	Concreting using ready-mixed concrete pump for construction nr 1	[m³]	64	320	**20480**
I2	Concreting using ready-mixed concrete pump for construction nr 2	[m³]	64	320	**20480**
J1	Concreting using a tower crane with container for construction nr 1	[m³]	64	328	**20992**
J2	Concreting using a tower crane with container for construction nr 2	[m³]	64	328	**20992**
K1	Concreting using ready-mixed concrete pump for construction nr 1	[m³]	64	320	**20480**
K2	Concreting using ready-mixed concrete pump for construction nr 2	[m³]	64	320	**20480**
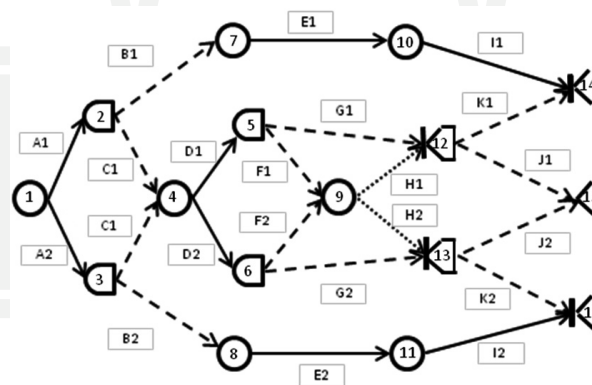
Fig. 3. A fragment of an alternative-decision network that models the elevation of foundation for two buildings simultaneously (source: own work)

Table 2 shows the result of optimization in the form of a vector of decision variables which defines the cheapest variant of technological and organizational the foundation works (optimal structure of the network model) (Fig. 4). Calculations were made using the application "Solver" in Microsoft Office.
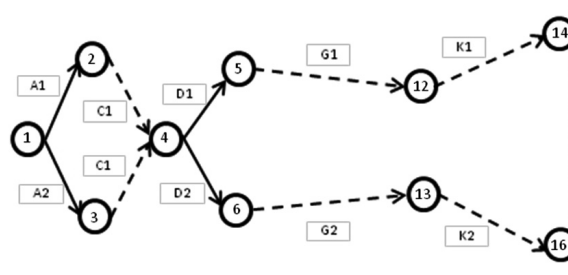
Fig. 4. The optimal network model, which showing
the dependencies technological and organizational of
foundation works whose execution cost is the lowest
(source: own work)

Table 2

Optimal solution to the extreme binary issue (source: own work)

Arcs	1–2	1–3	2–4	2–7	3–4	3–8	4–5	4–6	5–9	5–12	6–9	6–13	7–10	8–11	9–12	9–13	10–14	11–16	12–14	12–15	13–15	13–16			
	1	1																					2	=	2
	1		1	1																			0	=	0
		1			1	1																	0	=	0
			2				1	1															0	=	0
				1									1										0	=	0
					2		1	1															0	=	0
						1								1									0	=	0
							1		1	1													0	=	0
								1			1	1											0	=	0
									2						1	1							0	=	0
										1					1				1	1			0	=	0
																			1	1			1	≤	1
											2				1	1							0	=	0
												1				1					1	1	0	=	0
																					1	1	1	≤	1
													1				1						0	=	0
														1				1					0	=	0
cij	A1	A2	C1	B1	C1	B2	D1	D2	F1	G1	F2	G2	E1	E2	H1	H2	I1	I2	K1	J1	J2	K2	ΣcijΛij		
Λij	1	1	1	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0	0	1	126936		

(left margin label: Limiting conditions)

4. Conclusions

In construction, networks of a determined structure of connections, which depict univocally a certain organization and technology used to deliver a planned project, are primarily used for planning construction projects. Analysis methods developed for these networks make it possible to effectively resolve the project's schedule regarding parameters determined for it, such as delivery time, delivery cost, or the availability of resources. Unfortunately, all attempts at creating variants of schedules with either partial or complete changes in technology or organization of the planned project, require the reformulation of a new network model and subsequently the repetition of the following stages of its analysis.

The concept to solve this issue can be using the properties of alternative-decision networks, the non-determined logical structure of relationships, makes it possible to create variants of projects regarding their technology and organization.

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