THE NNM - METHOD AND A MODEL OF CO-OPERATION BETWEEN AN AUTOMATED CENTER WITH A CONCRETE MIXING-PLANT AND TRUCK-MIXERS

Andrzej Więckowski[1], **Wladyslaw Buczkowski**[2]
Cracow University of Technology, Poland
Miroslaw Skibniewski[3]
Purdue University, USA

Abstract: The Network Numerical Modelling (NNM) methods was developed to aid in project mapping (representation), planning, analysis and control. In NNM models each real process is restricted by its predecessor and successor, represented as edges and vertexes on a directed graph. The introduced "moment of incidence" expresses the level of an activity execution advancement determining the event occurrence. Vertex activation takes place for the equal value of the incidence moment and the threshold value of reception that expresses the necessary conditions for the event occurrence. Emission to the edge leading from a vertex after its activation takes place when execution of a given process during a simulation experiments is certain (probability 1). Deterministic and stochastic receptors and emitters (similar to GERT networks) are discussed, as well as decisive receptors with individually declared input conditions. The NNM model is demonstrated using the example of a concrete mixing plant automated centre with truck mixers.

Keywords: Project model; Network, GERT; Construction.

1. INTRODUCTION

In modelling of construction project execution one encounters engineering and organisational processes of well known and stable characteristic as well as poorly structured and unstable ones. Stochastic project networks (where the evolution of the corresponding project is no longer uniquely determined) were introduced first by H Eisner in 1962 and A. Pritsker with his research team developed the GERT convention with the system of logical symbols of receptors and emitters. The GERT method involves determination of one parameter of the given edge whereas the parameter to be determined expresses the time of project realisation and the probability of a process occurrence, but generally, in order to obtain the correct solution to the model it is necessary to reduce the networks using the theory of probability and graph theory equations. As it proves to be a time-consuming task, the analysis is usually limited to the simplest models involving few events only. GERT methods, on the other hand, usually involve simulations. First of all, a deterministic network is created for each individual model processing. This is an element from the set of options that are possible and defined in relation to probability of an individual edge or vertex occurrence. The next stage involves simulation of the process duration and followed by recounting execution. Basing on the results of statistical analysis for individual models, the probability of process occurrence and process duration can be defined.

Unlike the methods discussed in the previous section, the NNM method is based on applications of the edge function representing the advancement of process realisation, the logic of a vertex activated when certain conditions are fulfilled and the emission function representing the feasibility of successor processes.

The NNM method may have the following applications:

- optimising the efficiency of individual, cooperating multi-phase systems (while some of the mono-phases are only partly automated)
- determining possible dates, types and volumes for scheduled tasks

[1] E-mail: andrzej@itob.wil.pk.edu.pl
[2] E-mail: wbuczkowski@wp.pl
[3] E-mail: mirek@purdue.edu

- investigating complex construction projects (such as life cycles of civil engineering projects with respect to the structure and interdependence of processes involved in building, long-term operations, repair, maintenance, modernisation, demolition and

2. BASIC CONCEPTS THE NUMERICAL NETWORK MODEL

The NNM model has been constructed according to the „two-nodes" rule, i.e. a initial and a final event limit the realisation of every activity on a directed graph that is represented by edge (arc) and a vertex (nodes).

The Numerical Network Model of process is where the network is constructed so, that the edge a_i, $i = 1,\dots,n$, $i \in I$, represents an i-th activity, and the vertex v_j, $j = 1,\dots,m$, $j \in J$, represents an j-th event[1].

The *incidence* ω_{ij} between an edge a_i and a vertex v_j represents the direct interdependence between an i - th process and an j - th event:

$$\omega_{ij} := \begin{cases} -1, & \text{if the edge } a_i \text{ is incident to the vertex } v_j, \quad (1a) \\ 1, & \text{if the edge } a_i \text{ is incident out of the vertex } v_j, \quad (1b) \\ 0, & \text{in other cases.} \quad (1c) \end{cases}$$

The value of incidence $\omega_{ij} = 1$ indicates that the accomplishment of an i-th activity immediately depends on an j-th event while $\omega_{ij} = -1$ indicates that the occurrence of an j-th event immediately depends on an i-th activity.

A Function x_i *of Edge* a_i describing a relationship that represents an advancement level of an i - th activity is defined as follows:

$$x_i := \begin{cases} 0, & \text{if an } i \text{ - th activity, represented by the edge } a_i \text{ has not commenced yet,} \quad (2a) \\ 0 < x_i < 1, & \text{if an } i \text{ - th activity, represented by the edge } a_i \text{ goes on,} \quad (2b) \\ 1, & \text{if an } i \text{-th activity, represented by the edge } a_i \text{ is accomplished.} \quad (2c) \end{cases}$$

An Incidence Moment μ_{ij} of an edge a_i of the vertex v_j is defined as a multiplication product of a value of function x_i and an incidence value ω_{ij} of the edge a_i on the vertex v_j:

$$\mu_{ij} := x_i \omega_{ij}, \quad (3)$$

where: x_i - edge function of a_i.

The incidence moment symbolizes the progress of a continued activity in the j-th vertex upon the completion of the process represented by the i-th edge: $\mu_{ij} = -1$, because according to 1a and 2c, it is: (the i-th edge comes to the j-th vertex), as well as (the i-th activity was completed). During the time interval T, at the instant $t = t_a \in T$, the value of the edge function equals $x_i(t_a) = -1$.

2.1. Event et vertex

In the network model under consideration, a vertex represents an event, so, it is required that it should reflect the attainment of a specified state, for which, on the one hand, definite initial conditions necessary for the state to be attained must be fulfilled, i.e. it should reflect an activation, on the other hand, the activation creates certain output conditions.

A vertex is characterised by Fig. 1, [4, 5]:
- receptor R which describes input conditions necessary for the activation to take place,
- activation A,
- emitter E which describes output conditions created by the activation.

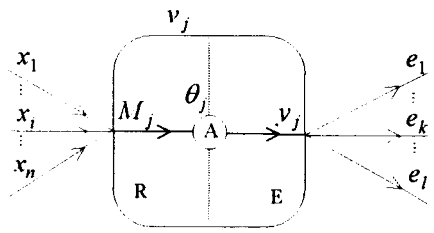

Fig. 1. Model of a vertex v_j mapping an j-th event.

To check whether or not the process execution progress ful fills the event incidence conditions, i.e. the vertex activation, at input in the receptor R, the threshold value of reception and the reception moment are determined.

A *threshold value of reception* θ_j is meant a sum of incidence moments μ_{i^*j}, necessary for the activation of a vertex v_j as demanded from the edge a_{i^*}, $i^* \in I^*, I^* \subset I$ from among all edges a_i, directed towards a vertex v_j:

$$\theta_j := \sum_{i^* \in I^*, I^* \in I} \mu_{i^*j}, \quad (4)$$

[1] Denotations and indices have the same characteristics throughout the entire text unless their new definition is introduced.

where: - incidence moment of edge a_{i^*} about vertex v_j; upon the completion of the activity, the value μ_{i^*j} changes according to (3).

i^* and I^* - index i^* and set I^* of edges a_{i^*} respectively, necessary for the activation of a vertex v_j.

A *reception moment* M_j about the vertex v_j (at the instant t) is a sum of the incidence moments μ_{ij} of all the edges a_i incident into the vertex v_j:

$$M_j := \sum_{i=1}^{n} \mu_{ij} , \qquad (5)$$

where: μ_{ij} - the incidence moment of the edge a_i directed towards the vertex v_j; according to (3), it is an actual value of a moment, for example, at the instant $t = t_a$.

2.2. Receptors

In order to map the diversity of the input conditions within the NNM method, five types of receptors have been characterised. Four receptors: the deterministic „and", next „with releases", „inclusive-or", „exclusive-or" describe the input conditions corresponding to GERT [1, 3]. A closer approach to those receptors according to the NNM method is presented in [3, 4]. As for the receptor „decisive", the input conditions are individually declared with regard to those being mapped as thereafter.

Deterministic receptor „and", $[\wedge]$. The activation of a vertex with a receptor $[\wedge]$ represents the first accomplishment of every i - th activity which is considered as immediately indispensable for an j - th event to happen.

Receptor „with releases", $[\forall]$. The activation of a vertex with a receptor $[\forall]$ symbolises the accomplishment of s activity from among all those i - th activity, appearing depending on according to the direct occurrence of an event v_j.

Receptor „inclusive-or" (IOR), $[\vee / \wedge]$. The activation of a vertex with a receptor $[\vee / \wedge]$ exclusively symbolises the first accomplishment (i.e. for the first time) of an i^* - th activity from among all those i - th activity, that directly decide on the occurrence of an event v_j.

Receptor „exclusive-or", (EOR), $[\vee]$. The activation of a vertex with a receptor $[\vee]$ symbolises each and every accomplishment of one i^* - th activity from among all those i - th activity, that directly decide on the occurrence of an event v_j.

A *decisive receptor* $[d]$, Fig. 2. In the above described receptor $[d]$, the reception conditions were assumed „in advance". As for the decisive receptor $[d]$, such conditions are individually specified (declared) according to this part/fragment of the reality that is being represented. It is declared that an edge $a_{i''}$, selected from among all the edges a_i, oriented towards the vertex v_j, and foreseen by the reception system u, must be executed $l_{i''}$ - th times.

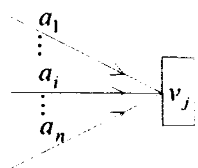

Fig. 2. Decisive receptor $[d]$.

The activation of a vertex with a receptor $[d]$ means that from among all the i - th activity that directly decide on the occurrence of the event v_j in accordance to the individually declared reception system u the execution of each i'' - th activity as required by this system, must be completed $l_{i''}$ - th times.

2.3. Activation

The *activation of a vertex* v_j, was applied to describe a state in which a threshold value θ_j as requested by a relevant corresponding receptor equals the reception moment M_j from all the edges a_i oriented towards this particular vertex:

$$\theta_j := M_j . \qquad (6)$$

where: θ_j - threshold reception value of vertex v_j, M_j - reception moment at the vertex v_j (from all edges a_i incident into the vertex v_j), is called the activation of vertex v_j.

An *activation function* y_j of the vertex v_j is defined as follows:

$$y_j := \begin{cases} 1, \text{ In the case when } \theta_j = M_j , & (7a) \\ 0, \text{ In all other cases.} & (7b) \end{cases}$$

2.4. Emitters

At the output, Fig. 1, in the emitter E, an emission function e_k is determined for every edge a_k incident out of the vertex v_j.

An *emission function* e_k of vertex v_j into the edge a_k means the relationship representing a possibility to commence a k-th activity, $k = 1,\dots l$, $k \in K$, that is immediately dependent on the occurrence of an j-th event:

$$e_k := y_j \omega_{jk} p_{jk}, \tag{8}$$

where:

y_j - the value of the activation function of vertex

ω_{jk} - the value of the incidence of edge a_k incident out of vertex v_j,

p_{jk} - the probability of commencing the activity represented by edge a_k, directed out of the vertex v_j, in the experiment under consideration.

A *probability* p_{jk} of entering upon the edge a_k, from the vertex v_j represents a chance meaning that in the given experiment the commencement of a k-th activity is possible upon the occurrence of a j-th event occurs:

$$p_{jk} := \begin{cases} 1, \text{ provided that in the given experiment, after activation of vertex } v_j \text{, entering upon the edge } a_k \text{ is the certain,} & (9a) \\ 0, \text{ in other cases.} & (9b) \end{cases}$$

In the NNM method, three types of emitters are characterised. The 'deterministic' and 'stochastic' emitters characterise the output conditions that comply with GERT, [3]. A more detailed description of those emitters with regard to the NNM method is given in [4]. In the case of the 'decisive' emitter, below there are indicated conditions of an individual output declaration.

Deterministic emitter $[\times \wedge]$. A vertex equipped with the deterministic emitter symbolises that the occurrence of an j-th event, generated a possibility to commence every immediately dependent k-th activity.

Stochastic Emitter $[\times \vee]$. A vertex with a stochastic emitter symbolises that the occurrence of an j - th event generated a possibility to commence one k^* - th event from among all other, immediately dependent k - th events. The possibility of commencing the k^* - th event results from the probability of its realisation.

Decisive emitter $[\times d]$. A vertex with a decisive emitter expresses that the occurrence of a j- th event, created a possibility to commence every single k^w - th activity, that has been declared by an output system w, from among all the directly dependent k - th activity.

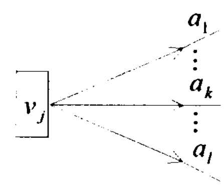

Fig. 2. Decisive emitter $[\times d]$.

2.5. Realisation of edges

A change in the value of the emission function e_k, according to (9a), takes place at the instant t_j^a of the activation of the vertex v_j, i.e. exactly when the j - th event occurs. The edge a_k is entered upon if the value of the emission function equals $e_k = 1$ (or it is not entered upon if $e_k = 0$, cf. (8)). Thus, when $e_k = 1$, i.e. at the moment t_j^a, the edge a_k is entered upon. In consequence, the instant t_k^- - at which the edge a_k was entered upon (commencing the k - th activity) is: $t_k^- = t_j^a$.

And the instant t_k^+ - when the k - th activity has been accomplished - is:

$$t_k^+ = t_k^- + t_k(\iota), \tag{10}$$

where: $t_k(\iota)$ - duration of the k - th activity, for example the value of the realisation time random variable in the actual ι - th simulation experiment, or a *constant* in case of a deterministic activity.

The edge a_k was entered upon and the activity was accomplished, so:

- the value of the emission function into the k-th edge is set to zero: $e_k = 0$,
- the value of the edge function according to (2c) equals: $x_k = 1$.

2.6. Notation in the NNM method

In order to construct a vertex v_j having required input and output characteristics, a suitable receptor and a suitable emitter from among those as listed in Fig. 3, 4 should be applied. Each of the five receptors can be connected with each one of the three emitters. As a result, fifteen vertex variants are obtained and this means that there are very many possible ways to describe technological and organisational relationships.

Receptors		
Deterministic „AND"	[∧]	(
Inclusive-or „IOR"	[·/·]	<
Decisive	[*d*]	[
„With Release"	[∀]	∈
Enclusive-or „EOR"	[∨]	K

Fig. 3. The NNM symbols of receptors.

Emitters		
)	[·∧]	Deterministic
>	[·]	Stochastic
]	[·*d*]	Decisive

Fig. 4. The NNM symbols of emitters.

The activity and node characteristics can be tabulated as set forth in table or in the graphic model. Provided the description is slightly changed according to the GERT principles and when additional conditions for receptors and decisive emitters are introduced into this notation, we obtain a convention to be used in the graphical model under the NNM method which complies with Fig. 5. Depending on the conditions of an emitter, an edge, a receptor, and the vertex activation, the description is as follows:

a – *process's name* or its *code*,

b - in the case of a stochastic emitter:
the probability of taking the edge, as for a deterministic emitter, the probability equals 1.0 and can be omitted; as for a decisive emitter, instead of the probability, it is written a code of *a system of outgoing edges*, i.e. of a subset of edges $a_{k''}$ that contains only edges $a_{k''}$ in a set of all outgoing edges; the edges $a_{k''}$ are planned to be taken (declared for the taking operation) upon the vertex activation,

c - *a distribution type and parameters* that are characteristic for a given edge,

d - in the case of a deterministic and stochastic receptors, the description does not exist;
in the case of a decisive receptor: *a system of oncoming edges*, i.e. a subset of u edges that contains only the edges $a_{i''}$ from among all the edges oncoming the vertex v_k; those edges are planned (declared) and, so, they enable the activation of this vertex; when it is required that the edges must be repeated several times, a certain number of repetitions is determined in the description: *as well as a code of a system of edges.*

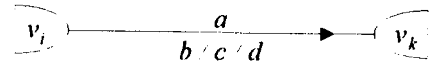

Fig. 5. Notation in a NNM graphic model: v_i, v_k - preceding and ensuing vertices, respectively, a – process name or its code, b – probability that an edge will be taken or a code of a system of outgoing edges, c – distribution type and parameters, d – number of repetitions and code of oncoming edges

3. EXAMPLE

A company has at its disposal an automated plant for concrete mix production with the capacity (theoretical) 60 m3 per hour and n=3 truck mixers. In the period of maximal work intensity the transportation services are subcontracted to outside companies (n*=7 concrete mixers are hired). 82 % of the service orders G are known at least the day before. The remaining orders G* are carried out on a day to day basis. For the existing work conditions we have to determine the probability of shutdown and the shutdown time for the plant, company's mixers and hired mixers as well as probability, lead times and waiting periods.
Basing on the analysis of orders and concrete mix production system in the previous periods, we present the network model NNM for process execution assuming the collaboration between the concrete mix production unit and the transport trucks, Fig. 6.

The interpretation of the NNM model is as follows:
The edges: (S,2) *Submitting of scheduled orders;* (1,2) *Reporting of additional (current) orders;* (2,3) *Periods of a defect-free operation at a certain work-stand and their completions;* (3,4) *Shutdown of a work-stand owing to a failure;* (2,5) *Periods of an arranged job (between breaks) and their completions;* (5,6) *Break for employees;* (2,7) *Preparation of a work-stand;* (7,8) *Mixing and loading concrete;* (2,9) *Starting points when truck-mixers belonging to the concrete mix plant begin to work;* (2,11) *Operation commencing of other truck-mixers hired;* (8,10) *Moving the possessed transportation means onto the building site (travel onto the site);* (8,12) *Moving the foreign transportation means onto the building site (travel onto the site);* (10,9) *Unloading of the means of transportation possessed and their return;* (12,11) *Unloading of the foreign means of transportation and their return;* (8,F) *Completion of the operation on a work-stand;* (4,F) *Completion of the operation on a work-stand owing to the long failure correction time;* (9,F) i (11,F) *Completion of the operation of:*

the possessed and foreign transportation upon the accomplishment of orders; all other remaining edges showing „zero” times represent the mutual interdependences.

Should many *m* - production work-stands with 2 vertices be present, two additional edges II,...,*m* will head off. In such a case, a block of all the processes pertaining to the work-stand- one that is denoted as edges I and I* on the drawing, must be repeated *m*-times with the specific characteristics appearing typical for each additional work-stand.

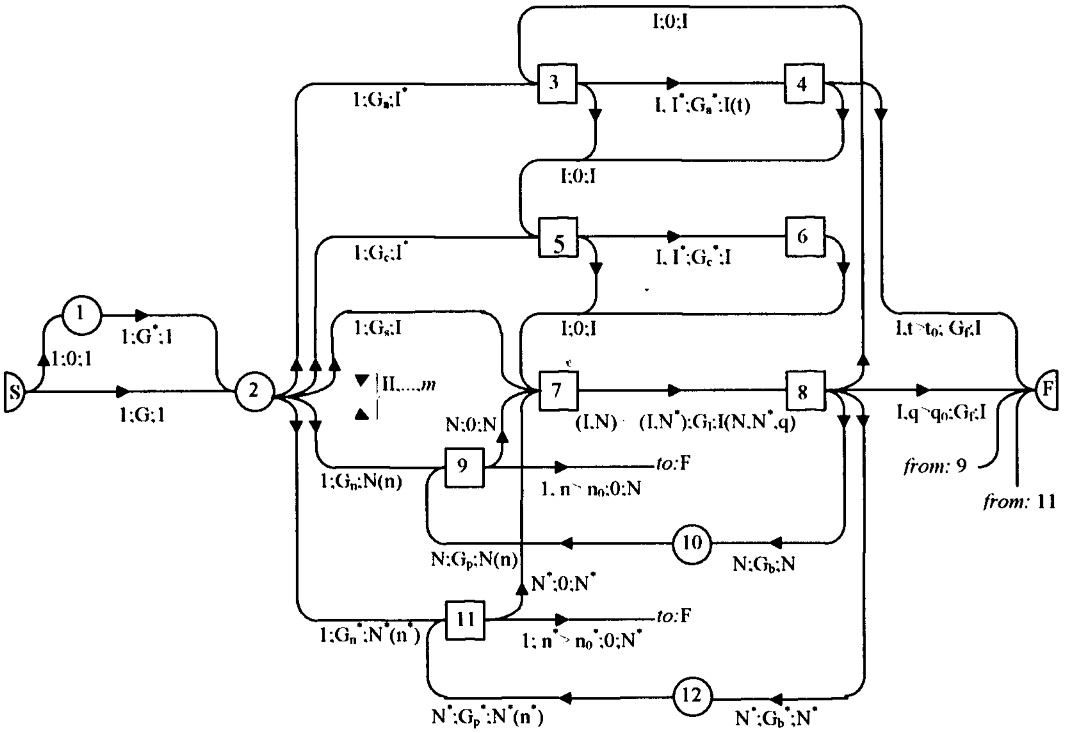

Fig. 6. The NNM-model showing the co-operation developed between an automated center with a concrete mixing-plant and trucks-mixers.

4. CONCLUSIONS

The NNM method uses the edge function and the reception moment, which represent the advancement of process execution, and the vertex with the threshold activation value which stipulates the conditions necessary for process occurrence and with the emission function indicating whether it is possible to execute certain processes during the simulation experiment after the event occurs. The method affords a uniform notation and analysis of models involving deterministic and stochastic elements, the conditions being as in GERT, as well as models with decisive elements. In the case of decisive receptors and emitters, the conditions can be uniquely declared and vertex activation can be planned (involving the selected incoming edges and emission to the selected outgoing edges).

The description of the 5 receptors and 3 emitters and creation of 15 vertexes to be used as repeatable elements allows for representation of many real engineering and organisational structures and for analysis of complex processes and production systems.

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