Construction Management

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Computational modeling of building process time behavior

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Summary

The network analysis methods present the main tool for building schedule execution by computer. The principal element of network, which is the building time behavior model, is the building process at various aggregating level. The networks topology models technological and organizational relativities of the building processes.

The classical network analysis methods mostly perceive an activity as one network element, with two events namely start and finish, not allowing the fact, that each building process has got its internal time structure, which is relatively complicated.

In the paper is in detail executed division of building processes and their time parameters. The internal time structure is explained by various graphical models and mathematically are defined the interaction continuities among internal events of one building process. The time structure of one building process, defined in this manner, consequently permit define mathematically the conditional ties - relations among processes so that the final mathematical model will represent the real building time structure.

KEYWORDS: building process, activity, milestone, dummy process, real process, aggregated process, summary process, network analysis, network, network topology, arc, node, earliest start, earliest finish, latest start, latest finish, process duration, date of an event, resource.

1. INTRODUCTION

Most building companies aim at integrated information management system, processing by computers in its every side. The main principle of such integration is saving of all primary and also processing data about particular building objects into properly ordered data bases and permanent reflection of these data into calendar time. Determining element of building management scheme, which allow modelling of data in time, is building schedule. Therefore is necessary to have a building schedule computational processing as at full just model of factual building processes behavior model.

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Network analysis methods present the main tool for the building schedules execution by computer. Particular methods allow mathematical modelling of the projects by networks. The holder of building production in network is operation, i.e. building process on various aggregating level. The network topology describes activities relative connection method in the model. Classical network analysis methods have general application, but in them using for building process mathematical modelling rise inaccuracies, which markedly reduce the final model quality, i.e. building schedule quality.

The processes relativities have got their particularities in building industry. The network building model topology should represent real technological and organizational relativities of particular building processes. In application of concrete network analysis method for building time behavior modelling by computer is possible define in network topology only such relations among processes, which actual method, applied for computer programme can mathematically define. Also modelling of the building process internal time, technological and spatial structure is possible only in dimension, which actual computer programme affords to its user.

2. COMPUTATIONAL MODELING OF BUILDING PROCESS TIME BEHAVIOR

The network analysis methods present the base of computer programmes for projects behavior mathematical modelling creation. The network analysis methods intended for mathematical modelling of building schedule should respect particularities of building process internal structure, as well as particularities of their interaction relativities. For suitable mathematical definition of relations between events, exact analysis of building processes and knowledge about their internal time structure is necessary.

2.1 The building processes division

The building process is process of production**,** whose final product is a building construction, a building object or a building (operation, activity, partial stage, object, complex process). Time of the process duration is the function of the production amount (content in financial or physical measure units) and of work force load. It has requirements on resources (operation articles and working means). It is possible to factorise the building process in term of time and resource assessment into real process and to him pertaining internal and external dummy processes. Complexity of the building process internal time structure depends on amount and mutual relativities of processes, which are aggregated in the process.

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It is possible to divide building processes in term of time and resource assessment in network into:

- **real process** – the building process part**,** which has requirements on resources, for all that the resources requirements are fragmented (calculated) equally for all its duration time,
- **dummy process** – it can not exist independently, it always connects on an event (start or finish) of other activity, process, process set up or milestone. It has not requirements on resources (it is not resource appreciated). Its time assessment is derived from the building process technological structure, whose component it is, or from technological and time structure of the process set up, on which it is fixed. Among dummy processes belong for example the process development, settlement and reduction, deferments and technological intervals between processes, next time determination of the processes set up or its parts time duration (summary process) etc.
- *Note: in arc-defined networks of the processes set ups is term dummy activity used for designation of not only dummy processes, but also for designation of knot of two activities events, such designation is not accurate and do not satisfy with actuality. In such denotation it means an "activity relation". Also between events of two dummy processes can be time relativity, i.e. their events can be each other relative by the relation.*

Next it is possible to divide **dummy processes** into:

- **internal dummy processes** (development, settlement, reduction), by change of their time assessment does not come directly about change of earliest and latest terms of the real process start and finish, into which are allocated, but they can influence time weight of relations on previous or following processes events.
- **external dummy processes** (deferments and technological intervals – i.e. necessary intervals before start and after finish of the real process or its part). Their events terms are defined by relativity towards other building processes. By the change of their time assessment and their events terms is possible to come about change of earliest and latest terms of the real process start and finish, into which they are allocated.
- **summary processes** – (also term process heading and the process set ups heading is used) indicate time interval from the start of the first to the end of the last from grouped processes. The terms of the summary process events vary only in dependence on events terms changes in the grouped processes set up.
- *Note: in some literature is for summary process applied term "aggregated process", what is suitable only for cases of time-evaluated processes net models without their resource evaluation. If the processes net model elements have requirements on resource, it is necessary to distinguish between summary and aggregated process.*

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- **aggregated process** – it arises by integration of several activities or building processes into one process. It involves time and resource evaluated real process and time evaluated dummy processes (while time evaluation of dummy processes can be nought). Its time and resource evaluation is derived from the process set up parameters, which are in this process aggregated, while requirements on resources are in its real process fragmented (calculated) equally for all its duration term.
- *Note: Resources requirements are in aggregated process fragmented (calculated) equally for all its duration term. If it means only formal aggregation of the processes into one title, in such term arose summary process has got characters or dummy process, has got its own time evaluation, derived from grouped processes events terms, but has not got own resources requirements. Resources requirements are calculated from grouped processes requirements and therefore they can be unevenly distributed during the summary process duration term. The summary process and the aggregated process have got different parameters, therefore should not be these terms each other replaced.*
- **milestone** – is created by one event, which indicates important project state, or its part, it has not got resource evaluation and has got nought duration term. Such event can but must not have in advance defined earliest, latest or stabile date.

2.2. Time parameters of the building process

Among time parameters of the building process belong:

- operation process duration (in elected measure units)
- process development date
- process reduction date
- process settlement date
- time deferment (in time units or in work amount %)
- technological interval (in time units)
- terms (non-calendar or calendar) starts or finishes of the process or its part (earliest, latest, bound earliest, bound latest or stabile term).

The time parameters of the building process can be defined by constant (by account, by calculi, stochastically, deterministically), or as variable, in dependability on other parameters of the process or other processes values.

2.3. Models of the building process time structure

There are many abstract models for formulation of the building process time structure:

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- verbal (time structure is stated by definition of parameters and their time evaluations),
- mathematic (time structure is stated by mathematical substances),
- graphical models (time structure is stated by graphical presentation).

For better visualise, better information relative density are all three types of the model normally applied together.

The building processes and their set ups network analysis, which is in its reality the complex of mathematical methods of the project modelling by networks, uses the combination of all three types of abstract models. The base is created by the network, which is supplemented by radical or computed values of time parameters, eventually by definition of the process and by particular mathematical apparatus, which serves for network elements parameters evaluation (arcs and nodes).

For mathematical and graphical formulation of relativities among particular time parameters of the building process or building process set up are applied such identifications:

i, j, k, ... – indexes for general identification of the process,
a, b, c, ... – indexes for identification of the partial processes,
A,B,C ... – indexes for identification of the aggregated processes,
(i+0), (k+0) till *(i+7), (k+7), ...* - indexes of the building process *I, k* events arcs,
t_i - process *i* duration term,
T_i - general identification of the process *i* event term,
U_i - general identification of the process *i* event,
Z_i - start of the process *i*,
K_i - finish of the process *i*,
Ro_i - development of the process *i*,
Us_i - settlement of the process *i*,
Zu_i - reduction of the process *i*,
Pr_i - technological interval of the process *i*,
Od_i - deferment of the process *i*,
tRo_i - development date of the process *i*,
tUs_i - settlement date of the process *i*,
tZu_i - reduction date of the process *i*,
tPr_i - technological interval duration date of the process *i*,
tOd_i - deferment of the process *i* duration date,
TZ_i - date of the process *i* start,
TK_i - date of the process *i* finish,
TRo_i - date of the process *i* development finish (settlement start),
TZu_i - date of the process *i* reduction start (settlement finish),
T_1Pr_i - date of technological interval finish after process *i* development,
T_2Pr_i - date of technological interval duration finish after process *i* finish,
T_1Od_i - date of deferment duration start before process *i* start,

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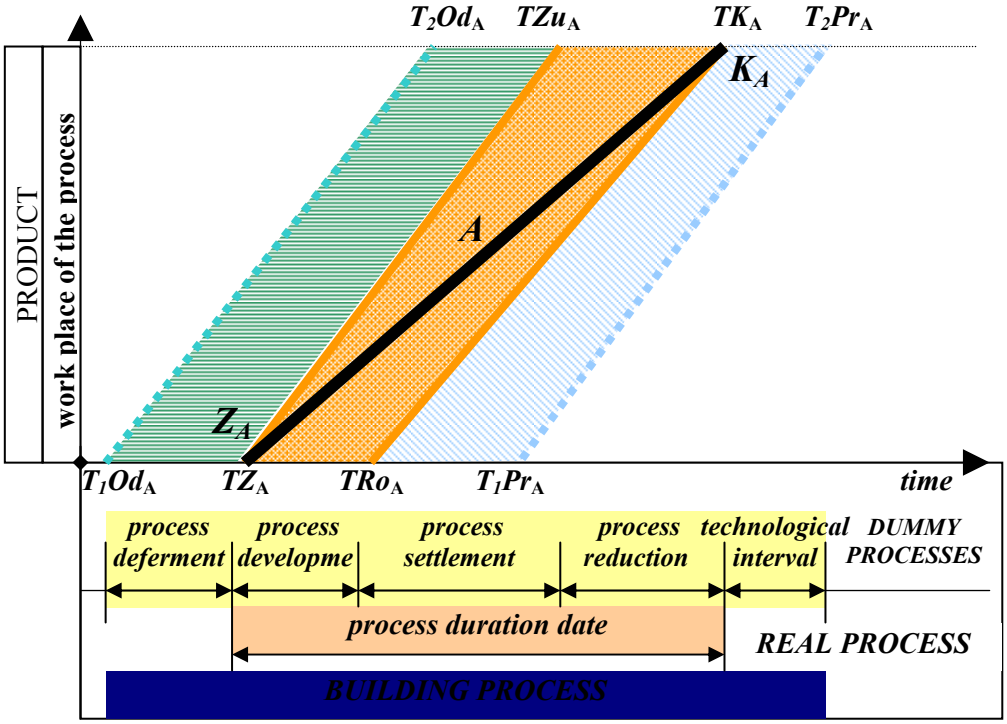
T_2Od_i - date of deferment duration start before process i reduction start.

For mathematical and graphical expression of relativities between parameters of the processes and the relations among processes in network of the process set up (for solution by network analysis), are applied following identifications:

NT - bound date (taken by real or relative calendar date),
TM - earliest event date, taken "by computation ahead",
TP - latest event date, taken "by computation aback",
ZM_i - earliest start of the activity i date,
KM_i - earliest finish of the activity i date,
ZP_i - latest start of the activity i date,
KP_i - latest finish of the activity i date,
ε_{ij} - time evaluation of the relation between events U_i and U_j

On the picture nr.1 is in time-spatial diagram image behavior of the building process A, which consists of the real process and to it pertaining dummy processes.



Picture 1. In time-spatial diagram presented behavior of the process ***A*** and to it pertaining dummy processes: deferment, technological interval, development, settlement and reduction of the process

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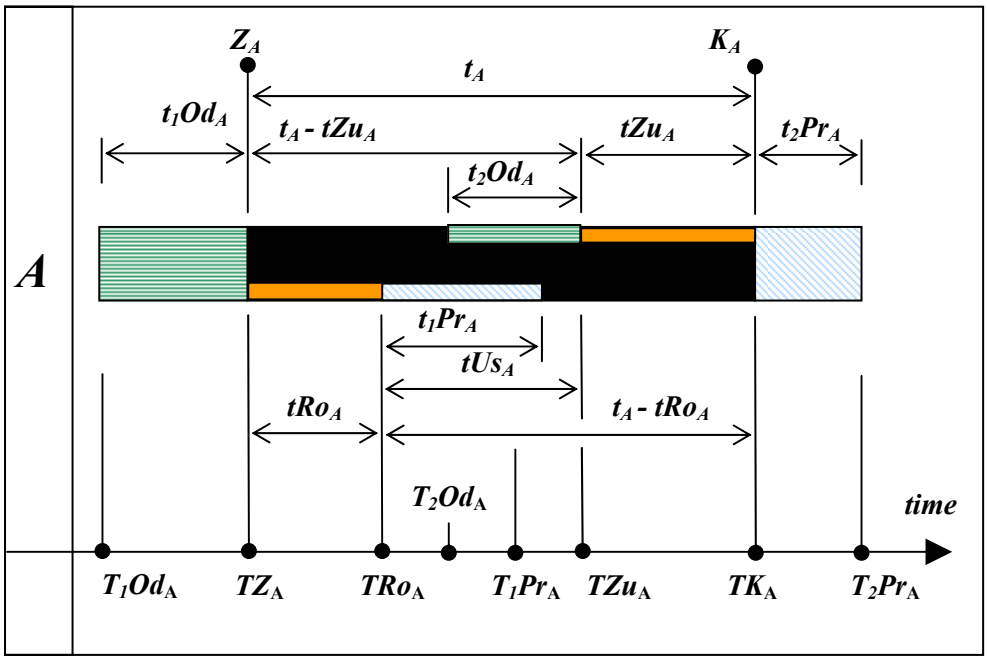
On the picture nr.2 is the same process presented in line schedule, where are equally graphically distinguished its real part and dummy processes: deferment, technological interval and development, settlement and reduction of the process.



Picture 2. Presentation of the process ***A*** and its real and dummy processes in line schedule

In case, that dummy processes, i.e. development, reduction and external dummy processes have got nought time evaluation and the process settlement date is the same as the process duration date, graphical presentation of the process *A* is in diagrams reduced into vector (Z_A, K_A).

In arc-defined network, which serves as a basis for mathematical building process model, one node of the net responds mostly to one building process. For specification of particular building process time parameters mostly only definition of parameters with their computed or taken time evaluation situated directly in the process node is applied.

Mathematical schemes for the terms of the building process (its real and dummy processes) events computation (earliest and latest), defined by actual network analysis methods, are fixed into verbal definition of the net elements and are not directly image of their graphical description. On the picture nr.3 is described the node, which presents the process *A*, where are in node presented the process time parameters evaluations (its real and dummy processes) and their events terms *TM* and *TP*.

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i	ZM_A	KM_A	tRo_A	TM_{Ro}	TP_{Ro}
	A		tZu_A	TM_{Zu}	TP_{Zu}
			t_1Pr_A	TM_{Pr1}	TP_{Pr1}
			t_2Pr_A	TM_{Pr2}	TP_{Pr2}
t_A			t_1Od_A	TM_{Od1}	TP_{Od1}
	ZP_A	KP_A	t_2Od_A	TM_{Od2}	TP_{Od2}

Picture 3. The node of node-defined network, which presents the building process ***A***, where are by definition presented time parameters and events terms of real and dummy processes of the process ***A***

Such node is then one element (node), which is in node-defined diagram consequently interconnected by arcs presenting technological and organizational knots among processes. Definition of these arcs consists of relation type identification and its time evaluation. Methods of description and definition of relations among processes have got particular network analysis methods different, but in principle all the methods have got for certain processes relativities styles defined concrete mathematical algorithms for underlying processes events terms determination.

Note: In computer processing and accounts in processes net is necessary identify (by constant or by account in dependability on other process parameters values) for particular processes (net nodes) only duration dates of their real and dummy processes and relation type between processes. Time evaluation of the terms is accounted automatically following defined mathematical algorithms for method relations, which is used by software. The outputs are then mostly processed in line schedule or in time-spatial diagram.

If is necessary directly graphically express mathematical relativity between events terms of one building process, as well as among events terms of all process set up, it is suitable to describe network as arc-evaluated. The number of the net model elements is on the one hand several fold enlarged, because one net node responds to every process event, which must be tied in the network by one or by several arcs with different event of one or several processes. On the other hand right formed, described and evaluated arc-defined diagram enables to define correctly the mathematical relations among particular real and dummy processes events.

Note: In computer processing and accounts in processes net is not necessary to draw the network topology. The processes parameters processes, as well as processes relativities can be taken for example column ally. The network analysis and its mathematical apparatus is the toll, which enables from like that taken data to form a flexible building model and to show the outputs for example by line schedule form.

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2.4. Description of events and building process behavior by arc-defined network

For the building process description (its internal technological structure, i.e. real process events relation and into him pertaining dummy processes) by arc-defined network (see picture nr.4), seven time evaluated arcs with following evaluation are necessary:

t_A - process A duration date – (real process, which is resource evaluated)

tRo_A - process A development date,

tZu_A - process A reduction date,

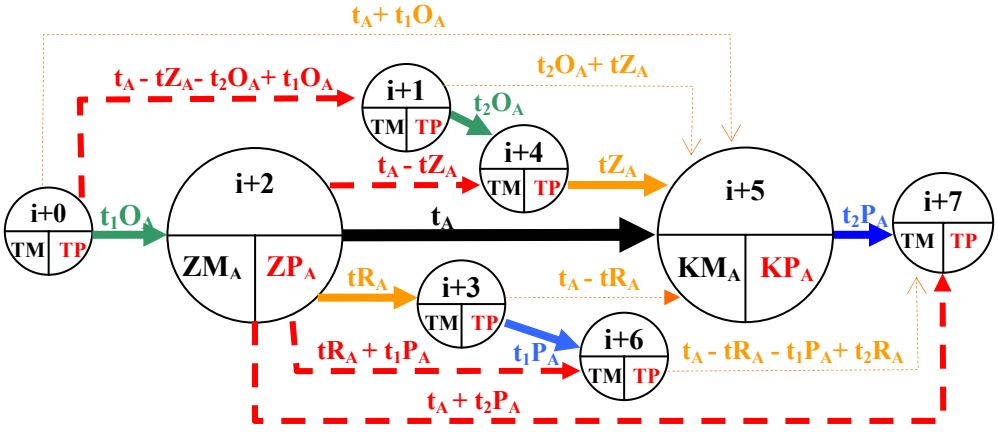
t_1Pr_A - technological interval after process A development duration date,

t_2Pr_A - technological interval after process A finish duration date,

t_1Od_A - deferment before process A start duration date,

t_2Od_A - deferment before process A reduction start duration date.

The settlement date tUs_A of the process A has not any own arc, it is only time interval between events TRo_A and TZu_A and can acquire plus, nought and minus value (description of arc for the process settlement is not necessary, it does not extend to terms accounts in the process inside).



Picture 4. Arc-defined network of the process A with description and time evaluation of the arcs (relations and behavior) and nodes (events) of real process and dummy processes

Dummy process can not exist independently, it is always tied to event (presented by node) of other process (real or dummy), with which has got same time evaluation at least in one node, i.e. has got at least one generic node with other process. For six dummy processes of the process A events description, only six other nodes are therefore necessary.

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2.5. The arcs evaluation in arc-defined network of one building process

On the picture nr.4 is described arc-defined network of one building process.

By fat continual line is arc of the real process described, dummy processes are described by thinner continual line. Orientation of the arcs is presented by arrows. By linear fat line are described assistant arcs, which are used in mathematical account of *TM* and by linear thin line are described assistant arcs, which are used in mathematical account of *TP*.

The arcs evaluation in arc-defined network of one building process is inscribed on the picture nr.4. The assistant arcs evaluation is mathematically derived from the real process *A* and its dummy processes time evaluation.

2.6. Account of the events terms of one building process TM and TP

Each arc-defined network must verify one formal condition: „ the net has to have one input and one output node". Completion of the condition is necessary for the net numbering and for mathematical account of the events terms by "method ahead" and also by "method aback". From counted values *TM* and *TP* is possible to define critical path behavior in the net model. Regards of relativity, i.e. relations among particular events of the building process *A* real process and dummy processes can not create a cycle. The algorithm of the terms account by "method ahead" by "method aback" inside the process is the same as in classical method CPM. The difference is only in net arcs perception. The net arcs create not only real process and dummy processes, but also relations among particular events within the process.

Numbering of one building process network nodes is derived from number *(i+0)* of entry process node. While nodes events *(i+1)* till *(i+7)* respond to events described on the pictures 1 and 2 as follows:

node *(i+0)* - $\boldsymbol{T_1Od_A}$ - date of deferment before process *A* start duration start,
node *(i+1)* - $\boldsymbol{T_2Od_A}$ - date of deferment before process *A* reduction start duration start,
node *(i+2)* - $\boldsymbol{TZ_A}$ - date of the process *A* start,
node *(i+3)* - $\boldsymbol{TRo_A}$ - date of the process *A* development finish (settlement start),
node *(i+4)* - $\boldsymbol{TZu_A}$ - date of the process *A* reduction start (settlement finish),
node *(i+5)* - $\boldsymbol{TK_A}$ - date of the process A finish,
node *(i+6)* - $\boldsymbol{T_1Pr_A}$ - date of the technological interval after process *A* development finish,
node *(i+7)* - $\boldsymbol{T_2Pr_A}$ - date of the technological interval after process *A* finish duration finish.

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By mathematical account by „method ahead“, which runs following arcs orientations, i.e. following described arrows, are in particular nodes defined values of *TM*. The node *(i+0)* is beginning node with known value *TM*, if $t_1O_A=0$ and $t_2O_A=0$, then beginning node is the node with index *(i+2)* and with value ZM_A. From arcs evaluation and from value $TM_{(i+0)}$ are counted values $TM_{(i+1)}$ and ZM_A, consequently from value ZM_A are counted values *TM* in nodes *(i+3), (i+4), (i+5), (i+6)* and *(i+7)*.

Account by „method aback“ runs non-following the arcs orientation. Account begins in node with index *(i+7)* and value $TP_{(i+7)}$, if $t_1P_A=0$ and $t_2P_A=0$, then begins in node with index *(i+5)* and with value KP_A. From the value $TP_{(i+7)}$ is counted value $TP_{(i+6)}$ and value KP_A in node with index *(i+5)*. Consequently from the value KP_A are counted values *TP* in nodes *(i+4), (i+3), (i+2), (i+1)* and *(i+0)*.

Accounts of one process events dates are in the process set up tied by relations to dates of technologically or organizationally related processes. It depends on actual network analysis method possibilities, which relations among process events defines, into what volume is possible by relations in network model serious technological and organizational relativities of the building processes, i.e. into what volume can relations allow internal complexity of the building processes and their structures. It is not eligible in praxis to draw complicated networks. The network of one building process presents in principle only one element in processes set up network. In node-evaluated network the building process can be presented only by one net node and for example in schedule only by vector. The analysis of one process internal structure is the bases for mathematical definition of such relations among processes, which enable in processes models creation by network analysis method, allow the building industry particularities.

3. CONCLUSIONS

Unlike activities in other economic sector, the building process has got relatively complicated its own internal time structure. Classical network analysis methods mostly apprehend the activity as one network element, with two events namely start and finish. Besides simplified perception of the building process, some classical network analysis methods have got limited number of mathematically defined mutual relations among processes events (start and finish), what is the problem in the building process technological relativity definition in creation and especially in tuning of building time behavior mathematical model.

In the article the output of one building process time structure internal analysis is description of its arc-defined net model. In one process network are defined arcs, i.e. events relating to one process and arc, which each other interconnect the

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process events. Mathematical evaluation of the arcs is derived from duration date of building process real process and dummy processes. One building process values events dates are mathematically derived from input and output net node values.

Perception of the building process through its internal structure consequently enables definition within concrete network analysis method such relations among processes events, which enable model the building process with its special technological and organizational relativities of the processes. In each computer programme for building time planning lays an actual network analysis method. The program ability to discharge its user requirements, which rise in creation and tuning of building time plan model in pre-production, production and realization stage of the capital project, depends on its mathematical apparatus.

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