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An integrated model as a tool for implementing an enterprise management method

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Abstract. An integrated enterprise management model based on information about enterprise activities was developed. The integrated model formalizes enterprise management methods, including information systems caused by digitization of production and the economy as a whole and involves implementation and consolidation of effective management methods which can be adapted to changing conditions at the information systems level. The problem of labor-intensive implementation and development of information systems which requires phase implementation (phasing involves decomposition) is solved by constructing a model structure divided into levels and sub-models. This approach to the model structure can be used for phased implementation based on the analysis of the KPI system, business processes and the organizational structure of the enterprise. The complex model is a tool for implementing the management method and analysis of structural functional description of enterprise’s activities. The analysis results indicate the need for reorganization, changes in business processes or modification of key indicators.

1. Introduction
There are many different methods for managing an enterprise: advanced lean manufacturing concepts with RFID support [1]; service engineering [2]; strategic cost management [3]; quality management system [4], continuous improvement (Kaizen) [5], risk management [6]. The methods contribute to the following criteria: “just in time” (Just-in-time), for a given cost, risk accounting.

The variety of methods is caused by complex tasks, management object and constantly changing environmental conditions. Existing management methods are not fully formalized and represent a set of specified methods and rules. Implementation of a specific method is performed using software products and regulatory documents whose requirements take into account features of the enterprise. In this regard, implementation and monitoring of management techniques is not a trivial task.

It should be taken into account that in real production conditions, various information technologies have already been implemented and are being used. They solve some or all the management tasks. These methods are as follows: SCADA, KPI, BPM, data warehouses. There are systems that deal with management (planning) of the enterprise at different levels: MES, ERP, CAD, process control systems, etc. From a technical point of view, the methods have to be implemented through integration and add-on over the existing information environment of the enterprise.

Implementation and control of management techniques require a single model describing activities of the enterprise. Using this model, various criteria can be applied. This model will be heterogeneous, since different aspects of activities are described by different classes of tasks; the submodels will be interconnected by data flows. The article proposes an algorithm for formation of the structure (component model) of the complex model.
2. Structure of an integrated enterprise management model
For the phased implementation, the component model is described at different levels and in different classes of models:
- at the level of the component model structure (decomposition of the complex model) in the form of a component (information) model;
- at the top level of abstraction in the form of mathematical models of evaluation and management according to the set principles (e.g., “just in time”, “for a given cost”, “accounting for risks”) or their combination; the submodels correspond to elements and subsystems of the component model [7];
- at the level of data storage in the form of an infological model describing the enterprise and its activities;
- at the applied level in the form of design solutions for information systems implementing the models;
- at the documentary level in the form of an enterprise management policy (guidance documents and information system settings).

The component model receives data on the tasks of the enterprise processes from the business process management system and links them to the key indicators, being an integrator of data from various systems (ERP, BPM, KPI, CAD TP, MES, etc.) required for assessing and controlling enterprise activities.

3. Component (information) model as a complex model structure
To apply the methodology to a specific object (enterprise), it is necessary to take into account its structure and features. The component model is required for flexible adjustment of the mathematical model and its submodels to the requirements of a particular enterprise and its modification when the structure is changed, business processes are reorganized, etc. Therefore, it uses the data of the infological model to determine its structure, and the data of the mathematical model and its sub-models - to determine its nodes.

To describe the component model, we introduced a series of notation.

Let us assume that there is a component model \( M = \{M_1, \ldots, M_p\} \), where \( M_i \) is a submodel that corresponds to the structural functional unit of the object (enterprise). To decompose the organizational structure, one can use the existing enterprise structure which is a layered (multi-level) system, ranging from the top management level (upper) to the level of workshops or an automated workplace. To describe activities of the enterprise, it is logical to decompose the organizational structure of the enterprise and consider performance indicators for bottom and top management levels:
1. at the top modelling level, there is a single node describing activities of the enterprise as a whole;
2. network nodes (objects) are departments of the enterprise;
3. ribs connecting the nodes are flows (material, informational, financial, labor, energy, etc.) of the enterprise;
4. nodes have unique identifiers at the current level and a level index;
5. data from the upper or lower level or from nodes of the same level are input to the nodes;
6. estimates by control levels are calculated based on the aggregation of these nodes.

This structure can be used if there are no additional links between the levels, i.e. level unit \( i \) has connections only with level \( i - 1 \) and \( i + 1 \). But in reality, depending on activities, the structural organization can change. Therefore it is recommended to use a structure without a clear division into levels based on the graph that allows for description of the functional (hierarchical) and project or matrix structure elements of the organizational structure (departments, positions, employees).

Let \( V \) be a set of vertices (nodes) of the object. For the vertices, conditions a) - b) of the first variant will be satisfied and the following conditions will be added:
1. any node can be connected to another node;
2. a node has a unique identifier;
3. a node may relate to several levels; \( \{u_1, \ldots, u_h\} \subset \{1, 2, \ldots, K\} \)
4. g) a node does not necessarily model a particular subdivision, it can display one of its functions (for example, management of project activities of several subdivisions).

Let $E_i$ be a set of edges describing flows between the nodes of complex model $M_i$, then $E = \{E_1, E_2, \ldots, E_p\}$ is a set of all edges of $M$.

In this case $M$ can be represented as a set of graphs $M_i = \{V, E_i\}$, where $i = 1, p$. The estimates for the control levels are obtained on the basis of subgraphs formed from nodes belonging to the same level, or activities.

If the company is a fairly large object, the graph is difficult to construct. For the first variant, the principle of decomposition (and construction) of the model can be structural-functional, starting from the top level; for the second variant, it is necessary to consider the principle of decomposition, the order of description of the nodes, the level of specification (the ability to implement the model not at all levels at the same time) and dependence of the parameters of the nodes. When choosing a functional decomposition method, the model nodes correspond to the tasks (procedures) of business processes.

Calculation of indicators (estimates and parameters) in the transition from one node to another, it is necessary to describe the corresponding conversion function $P_{ij}$, where $i$ is the number of the node for which the calculation is performed, $j$ is the identifier of the calculated parameter. Functions are set at the design and modeling stage for the arc connecting the model nodes. Functions can be described both analytically and algorithmically. When moving from the lower management level to the upper one, the most common conversion is aggregation of values by nodes (e.g., the sum of labor costs for workshops, the number of parts produced, etc.).

The total of all functions forms set $P$. Then $P_{ij}$ can be represented as: $P_{ij} = f_{ij}(G_{ij})$, where $G_{ij} \in P$.

The component model is a way of combining models that describe nodes within which the control method is applied. Criteria and limitations of the component model are the criteria and limitations described in the mathematical model of the methodology and applied to integral (aggregated) indicators at the top-level node and the criteria and limitations of the models that formalize the nodes.

The total of criteria and limitations is set when the model is implemented at a particular enterprise taking into account its features and management method.

4. Algorithm for forming the structure of the component model

In practice, with existing automated systems, the component model can be constructed using data from KPI, BPM systems and descriptions of the organizational structure of the enterprise.

The structure of the organization is represented as a hierarchy (tree), but in some cases it may have a more complex structure and be displayed as a graph. Therefore, to describe the structure of an organization, we can use a multitude of vertices (divisions) and a multitude of vertices of connections between these vertices which describe the hierarchy of departments:

$$F = \{\text{Dep}, \text{Arc}_\text{dep}\}, \text{Arc}_\text{dep} = \{\text{Dep}_\text{Input}, \text{Dep}_\text{Output}\},$$

where Dep, Dep_Input, Dep_Output are departments.

To describe functions of the organization and its departments it is necessary to describe its business processes. There are a lot of notations to describe business processes (DFD, BPMN, UML and others). They can be reduced to a graph with different types of vertices:

$$\text{BP} = \{\text{El}, \text{Arc}_\text{el}, \text{Parent}\}, \text{El} = \{\text{Name}, \text{Type}, \text{Value}\}, \text{Arc}_\text{el} = \{\text{El}_\text{Input}, \text{El}_\text{Output}\},$$

where El, Parent, El_Input, El_Output are the elements of the business process, Type is the different types of elements (task, branch, performer, event, etc.), Value is the value of the element named Name.

To decompose the structure, only tasks (operations, procedures) and executors are required. When including project activities of the organization, labor resources have to be described:

$$\text{Emp} = \{\text{FIO}, \text{Dep}, \text{Post}\},$$
where $FIO$ is an employee, $Dep$ is a department, $Post$ is a position, $Value$ from $El$ can take values of $FIO$ or $Dep$ or $Post$ (the executor is an employee, department, an employee holding a specific position).

The purpose of the model is to evaluate and control. Therefore, to decompose the model, data on the goals of the organization are required. For this purpose, key performance indicators are used. To describe them, a graph can be used, since the indicators are related to each other. In this case, the graph will not necessarily be connected (some vertices may not be associated with the graph, since the connection will be described through the attributes of the indicator). The link means that one indicator is used to calculate another one ($P$):

$$KPI=\{\text{Asses, Acr\_asses}\}, \text{Asses=}\{\text{Name, Function, Measure, Directory}\},$$
$$\text{Directory=}\{\text{El, Dep}\}, \text{Acr\_asses=}\{\text{Asses\_Input, Asses\_Output}\},$$

where Name, Asses\_Input, Asses\_Output are the indicators, Function is the procedure or the function for calculating indicators (it does not matter for decomposition). Measure is the unit of calculation (it does not matter for decomposition). Directory has its own structure indicating a set of measurements corresponding to the indicator value (as in the multidimensional model of data representation). For the purposes of decomposition, only measurements of the department, business processes and elements of business processes are required.

To form the complex model structure, the following input data are required: $F, Bp, Emp, KPI$.

The algorithm for forming the structure of a complex model includes the following steps:

1. Construction of the graph or the tree based on the organization structure on the basis of set $F$.
2. Addition of nodes (second level decomposition) corresponding to BP business processes. Business processes are associated with the node-departments which are the executors of tasks (or the executive-employee works in this department or the position is assigned to this department). Indicators corresponding to business processes (characterizing the whole process rather than the a separate task), are related to the added nodes.
3. Addition of nodes (third level decomposition) corresponding to El tasks (node type = "task/function"), they are linked to the corresponding business processes. Indicators corresponding to the tasks (characterizing a separate task) are linked to the added nodes.
4. Addition if a link from the graph of key performance indicators (set Acr\_asses).

The nodes of the graph will correspond to submodels $M_{i}$, some of which can be simple and entered from outside (from another system or manual input), while others represent complex simulation models. As part of the indicators, there are generally accepted methods of calculation, for others, the value is a non-trivial task. Specific sub-models are constructed for a specific enterprise taking into account its features.

The graph is too complicated to be visualized (it has a large number of elements), therefore, for simplicity of perception, it is recommended to transform the graph into the tree with repeated vertices.

The final vertices of the graph are nodes of the lower level model. They need submodels calculating key indicators. Higher level indicators are integral lower level indicators; they require indication of the calculation method (sum, average, etc.). Integral indicators are determined based on the presence of Acr\_asses if there are indicators with the same name Name, but different Directory values. The Function parameter is specified as a calculation function for these indicators.

The resulting decomposition will allow for an analysis of the compliance of the KPI system, business processes and organizational structure. A number of rules are proposed:

1. If there are vertices (divisions and business processes, and tasks) for which there is no performance indicator, it is necessary to specify the input data (this means that there is no control).
2. If a vertex (subdivision) does not have a business process attached to it, it is necessary to specify the input data (the subdivision might not have been involved in the main activity and reorganization of the activity or structure is required).
3. If the indicator is not attached to either the department or the business process, it is necessary to specify the input data (they might not have been entered or the indicator should be deleted).
4. For the tree leaves which are indicators, the sources of data should be determined (sensors, external databases, manual input, etc.), and for the indicators above the tree $P_i$ are calculated (the calculation method is based on the input indicators).

5. If an indicator is at a higher level, independent of the lower located nodes, this may indicate insufficient specification or the need for adding a submodel for this node. The results may indicate the need for reorganization, changes in business processes or modification of key indicators.

5. Conclusion
The complex model can be applied to economic entities and their parts (groups of enterprises, enterprises, departments, etc.). Simulation was based on the relational model of data representation in the Oracle DBMS. The approach determines the structure of the model for the enterprise on the basis of available information about its activities. The approach can be used for phased implementation of the methodology for managing enterprise activities (phased description of the sub-models, modification of the KPI systems, business processes and organizational structures)

The research is a part of the federal program aimed at describing typical submodels. The results can be used for building models of enterprise management and implementing enterprise management methods.

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