THE EPC THEORY.
BASIC NOTIONS OF ENTERPRISE PROCESS CONTROL

Miroslaw Zaborowski
Academy of Business in Dabrowa Gornicza, Department of IT, Poland

Corresponding author:
Miroslaw Zaborowski
Academy of Business in Dabrowa Gornicza
Department of IT
Cieplaka 1C, 41-300 Dabrowa Gornicza, Poland
phone: +48 32 2622805
e-mail: m.zaborowski@neostrada.pl

Received: 25 August 2010
Accepted: 13 September 2010

Abstract
The essential part of the theory of Enterprise Process Control (the EPC theory) is a formal
description of the framework EPC system. It is a universal reference model of integrated
management and process control systems for all enterprises, regardless of their trade and
size. Basic notions of the EPC theory have been presented in the paper. Certain defini-
tions of broadly known terms (e.g. organizational system, process, resource, control unit,
functional layer) are slightly different than the ones that are most often formulated. The
purpose of these modifications is precise presentation of relationships between defined no-
tions. Furthermore many new notions (functional subsystem, functional unit, transition
unit, information place, reengineering layer, readiness variant, organizational resources and
the like) have been introduced. They are necessary for presenting organizational and func-
tional structure of the framework EPC system. The EPC theory has deductive nature and
its notions are formulated on the basis of the more general, previously defined ones.

Keywords
management systems, multilevel systems, business processes, reference model, UML.

Scope and potential applications
of the EPC theory

The first reason to begin a research work for cre-
ating a theory of enterprise process control (EPC)
was a need of such a simulation system for integrat-
ed planning and control in which it would be pos-
sible to compare alternative decision making meth-
ods (e.g. the MRP and the Kanban methods [1], ap-
plied to the same production system). So the first
area of the EPC theory is a formal description of the
framework EPC system in which one can replace
individual decision algorithms and other information
processing procedures without changing its structure
as a whole.

Later on it was noticed that if the elaborated
model is really universal, then it may be used as
a universal kernel of real management and process
control systems. It is assumed here that there is
a “1 to 1” relationship between the set of identifiers
of procedures (e.g. services of SOA (Service Orient-
ed Architecture [2]) or stored procedures of relation-
al databases [3]) in their external repositories and
the set of their numbers in the framework EPC sys-
tem, from which they are called. Furthermore it is
assumed that the “1 to 1” association exists also be-
tween information elements of the framework EPC
system and rows of tables of relational data struc-
tures of real management and process control sys-
tems in enterprises. These assumptions will be dis-
cussed in the second and the third of planned pub-
lications on the EPC theory from the series, which
encompasses the following items:
1. Basic notions of Enterprise Process Control.
2. State and couplings between transitions in EPC
   systems.
3. Data structure in EPC systems.
4. Couplings between productive, preparatory and
   administrative processes in EPC systems.
5. Direct control subsystems in EPC systems.
Problems of IT solutions, which may be used for connecting a framework EPC system with external procedure repositories and with a database of a user, are important for practical implementations but they are not subjects of the EPC theory.

The framework EPC is a universal reference model of the integrated management and process control systems. However this model is essentially different than reference models delivered by vendors of ERP (Enterprise Resource Planning) software. First, this is not a branch model, but a universal model. Second, it encompasses not only the ERP level, i.e. the management level in an enterprise, but also the level of management in its organizational cells and the level of control inside its workstations. Third, its description was not arise inductively, as description of functions of offered software in its former applications, but deductively, as the system of notions and relationships between notions concerning information flow in enterprise management and process control systems. This description was named the EPC theory. Issues of analysis of mutual relationships between its facts (which is a substance of each theory) [4], have been presented in the form of sets of objects and relationships between them. The relationships have been defined as subsets of Cartesian products of the proper sets and as equivalent to them associations in class diagrams of the UML language [5, 6]. The side advantage by presentation of these diagrams is possibility of using them in the preliminary design of the framework EPC system.

The early version of the EPC theory, published in the 2008 year [7], was named the ERC theory (Enterprise Resource Control), because EPC systems may be considered to be extensions of well known ERP systems. The ERC system (like the EPC system) is a multilevel, multilayer system [8] of enterprise process control, but description of its structure is based on Colored Petri Nets (CPN) [9, 10]. For the present version of the EPC theory the Unified Modeling Language (UML) [5, 6], which is better known and easier to use than CPN, is a tool of modeling systems. Data processing procedures in systems designed with the use of the UML may be written using all popular programming languages, whereas “code segments” of transitions in CPN simulation models have to be written in the SML language [9] (or in its extensions, e.g. the CPN ML). For many languages recording and reading data from database tables, which are associated by relationships “1 to many”, may be performed with using simple embedded SQL instructions. In the case of CPN ML it requires writing special procedures for searching data in nested lists of records, whose fields may be lists of records.

From the EPC theory point of view this problem became crucial, when it was noticed that the framework EPC system may be used in real management and process control systems of enterprises, not only to modeling such systems.

The EPC theory may be applied to describing control of every productive process in enterprises, including continuous and discrete manufacturing processes, service processes, as well as data processing for customer needs. The application area of the EPC theory also encompasses management of auxiliary processes, such as overhauls, repairs, trainings and the like, as well as all internal administrative processes.

The tentative thesis of the EPC theory is the statement, that every management or process control system, irrespective of size and branch of an enterprise in which it is implemented, may be mapped, with all its functions and data, in the structure of the framework EPC system. The thesis is vital not only because of declared universality of the framework EPC system but also for the reason of educational usefulness of the EPC theory. Generality of the EPC theory may not be formally proven, because it would require verification of all management and control systems, but it may be justified by demonstrating its usefulness for analysing and designing real management and control systems, as well as by its comparisons with standards concerning declared application areas. Therefore the second area of the EPC theory, beside description of the framework EPC system, is a research of its conformability

- with existing methods of business process modelling, e.g. BPMN (Business Process Model and Notation [11]), EPC (Event Driven Process Chain) of the ARIS Platform [12] (EPC diagrams should not be confused with discussed here EPC systems) etc.,
- with currently known standards of information processing systems for management and control in enterprises (MRP II [13], ISA-95 [14, 15], IEC 61499 [16, 17], WFMC standard [18]),
- with descriptions of these systems from manuals and publications (the MRP method [19], the Kanban method [1], the Follow-up Production Control method [7, 20], scheduling methods for discrete production processes [21], structure of production management systems [22], workflow management models [23, 24], reference models of information systems for enterprises [25, 26], examples of management engineering problems [27], classical structures of automatic control systems [28, 29], examples of control of continuous and discrete elementary processes inside workstations etc.), as well as
• with examples of practical applications of information processing systems to enterprise management and to automatic control of industrial processes.

The main application field of the framework EPC system is a widely comprehended business process management, which encompasses not only modeling and reengineering, but also executive management and calling procedures, which are needed for it.

As is well known, initially business people were concentrated on allocation of resources to activities. Business processes were considered only as superior structures for activities. Smith and Fingar in the book “Business Process Management. The Third Wave” [30] named this period, i.e. 1920–1990, the first wave of BPM. During the second wave, i.e. since 1990, attention has been directed to processes, because their issues are important for customers and their structures have significant impact on enterprise performance. Structural changes of business processes are considerably frequent because of frequent changes of enterprise functioning conditions and for the reason of needed improvements. Unfortunately, every change of business process structure required structural changes in information systems supporting current management. These changes, out of necessity, were performed by IT systems developers, which could hardly understand their business purposes. It caused significant losses resulting of unsatisfactory effects of the changes and too long time of introducing them [30]. In opinion of Gartner (quoted in [2]) nowadays “processes managed in software” are not already “barriers to change”, but development of systems improving cooperation between business people and IT people is still continued.

Smith and Fingar noticed that at the beginning of the third wave of BPM, i.e. around 2000, the leading companies of the world economy started a development work, whose aim is that results of changes, introduced by business process designers with using simple graphic tools, are immediately visible in practice of current business management, without need of any corrections of existing software [30]. It requires to unite systems of current management and control with systems supporting business process reengineering. The motto of the book [30], endorsed by the BPMI (Business Process Management Initiative) and WFMC (Workflow Management Coalition), is “Don’t bridge the business-IT divide, – obliterate it!”. In opinion of Smith and Fingar realization of the third wave of BPM demands requires elaborating a new abstract data type describing business processes and introducing the “business processes” to information systems as new building blocks of software.

The EPC theory suggests achieving the same goal by using the well known relational data model in a new way. Its essence is immediate and automated correction of the structure of software, which is used for current business process management, as reaction to the changes of business processes structures, introduced by a process designer. The graphic tool supporting process designing is the add-on of the framework EPC system. One can build an entire EPC system connecting the framework EPC system, which is described here, with external procedures repositories and with a relational database of a user.

On the question of integration of ERP, MES and SCADA-PLC systems [15] the EPC theory suggests equally radical solutions. Instead of building interfaces between these systems, e.g. such as described by the ISA-95 standard [14], one can build an EPC system, whose functions encompass tasks of all organizational levels of an enterprise, and in this way remove the need of building these interfaces. Obviously, it removes only structural problems of the interfaces, but not technological problems of information transmission between computers and other technical devices which are included in an integrated system.

Organizational levels and functional layers

The organizational system is a part of an EPC system, which is designed for executing a determined set of processes. Analogously, each organizational subsystem belonging to the given system is designed to perform a determined set of activities, which are stage activities of processes located in this system. The organizational level, he H, is a set of organizational systems situated in the same level of the enterprise hierarchy tree. Typically an EPC system has five organizational levels:

h = 5 the system embracing the supervisory unit over the primary organizational system,

h = 4 the primary organizational system which encompasses the enterprise and its environment: customers, suppliers, banks, natural environment and the like,

h = 3 production plants which encompass their departments,

h = 2 organizational cells which encompass their work centers,

h = 1 workstations (elementary organizational systems) which encompass their direct control subsystems or other elementary subsystems.

Apart from organizational subsystems there are working subsystems in organizational systems. They are arrangements of parallel organizational
subsystems with input or output products located in common sets of border places. Organizational level of working subsystems are not higher, but the same as for their component organizational subsystems. In a typical EPC system they are:

\[ h = 3 \] enterprise, composed of one or many production plants,
\[ h = 2 \] departments, composed of one or many organizational cells,
\[ h = 1 \] work centres, composed of one or many workstations.

In small enterprises there are only 4 organizational levels (there are no organizational cells from the level \( h = 2 \) and workstations belong directly to the plants). In very large enterprises (e.g. in great factories of chemical industry) may be 6 of them (there is an additional level between plants and cells).

For each level of the framework EPC system, except of the highest and the lowest level, there are 5 functional layers:

\[ j = 3 \] coordination of working subsystems in organizational systems,
\[ j = 2 \] allocation of working subsystems tasks to organizational subsystems (in elementary systems – direct control or elementary data processing),
\[ j = 1 \] reengineering (internal structure changes) for organizational subsystems and their functional subsystems (in elementary systems – processing input signals into measuring signals of basic control objects),
\[ j = 0 \] data transfer between control units of organizational systems and their administrative subsystems,
\[ j = 4 \] scheduling orders for executive subsystems (which are also organizational systems of a lower level).

In practice certain functions of a given layer may be executed by control units belonging to the higher layers (which belong to the same or to the higher levels). Then in corresponding implementation of the framework EPC system such a layer is neglected.

Each layer \((h, j) \in H \times JF\) has its own time scale, \( h \in H \). Formally, the numbers of time scales and organizational levels are equal, but a time scale is the same only for four higher layers of a given level, whereas in a scheduling layer decisions and reports are worked out with shorter time periods, which is proper for the lower level. Moreover, different time scales may have the same length of sampling period (for higher levels – planning period). They are formally distinguished in order to keep common numbering of organizational levels and their time scales. For this reason in the framework EPC system it would be possible that lengths of planning periods for coordination and scheduling layers of the same organizational level are equal. It is not a problem, if we consider a coordination layer and a scheduling layer from two different enterprises, for which the framework EPC system is a reference model, but for the same enterprise it would be meaningless. In such cases either a scheduling layer or other layers of a given level are neglected.

The specification of functional layers is presented below, with exemplary planning periods, for a typical 5-level EPC system:

- supervisory reengineering for the primary organizational system (month),
- data transfer for the supervisory administrative office (month),
- supervisory scheduling for the primary organizational system (month),
  - coordination planning in the primary organizational system (month),
  - allocation planning for plants in the enterprise (month),
  - reengineering for plants of the enterprise (month),
  - data transfer for the administrative office of the enterprise (month),
  - master scheduling for plants of the enterprise (24 hours),
- coordination planning for departments in a plant (24 hours),
- allocation planning for organizational cells in a department (24 hours),
- reengineering for organizational cells (24 hours),
- data transfer for the administrative office of a plant (24 hours),
- executive scheduling for organizational cells (hour),
  - coordination planning for work centers in an organizational cell (hour),
  - allocation planning for workstations in a work center (hour),
  - reengineering for workstations (hour),
  - data transfer for the administrative workstation of an organizational cell (hour),
  - executive scheduling for workstations (second),
- coordination control for elementary subsystems in a workstation (second),
- elementary data processing, especially data processing for direct control of basic control objects (second),
- receiving input signals and emitting measurement signals of basic control objects (second).

The notions of organizational levels and functional layers are known since a long time [8]. Multilevel organizational structure of enterprises is obvi-
ous and it does not require any comments. A working subsystem is a simple generalization of a work centre [13]. Functional layers of coordination, allocation and scheduling, with the presented here order, exist in many different management systems and it is taken into account in many methods of decision optimization [21]. Specificity of the EPC theory referring to these notions consists only in a statement that these layers exist in each organizational level except of the highest and the lowest ones. An assumption of the same time scale for a coordination layer and a scheduling layer of the higher level is also specific to the EPC theory. The layers of reengineering and administrative data transfer are absolutely new in models of management and process control systems. Presenting the sets of direct control units and direct control objects as the layers of elementary data processing and basic control objects, defined in the same way as other layers of an entire enterprise is also a new idea.

Presenting reengineering as one of control functions of an organizational system means that the design of the internal structures of its organizational subsystems (and its modifications) is made inside this system, not in its environment, on the basis of information which is available in it. The administrative data transfer launches administrative processes (office processes), which replace these actions of business process control that require additional resources and/or consume more time than one planning period. Introduction of the layer of basic control objects results from the assumption that systems of direct control belong to the set of organizational units of an enterprise. Wider discussion of these notions, as well as many other terms which are introduced in this paper, requires separate publications. Herein structural relationships between discussed notions are presented. Then one can verify if these notions are consistent. Certain terms specific to the EPC theory were wider presented in the early monograph [7].

**Organizational units and control units**

Organizational systems, working subsystems and organizational subsystems, including preparative and administrative subsystems, as well as elementary subsystems (for direct control or elementary data processing) are organizational units, \( s \in S \). Functional layers are sets of such control units \( (s, j) \in SJ \subset S \times JF \) that have similar functions but concern different organizational units.

Fig. 1. Object diagram for couplings between control units of the exemplary organizational system.
Fig. 2. Object diagram for couplings between control units of the exemplary organizational system and its reengineering control unit as well as its administrative functional unit.

Fig. 3. Class diagram for transition units and data processing phases.
Fig. 4. A conceptual component diagram for control of functional subsystems in the exemplary organizational system.
Fig. 5. Class diagram for functional subsystems in functional layers.

Relationships of dependency between control units in a simple exemplary organizational system have been presented by means of the object diagrams (Figs. 1, 2) and the component diagram (Fig. 4) of the UML language [5, 6]. The acronyms of classes, which are used in these diagrams, are explained in the class diagram of functional subsystems (Fig. 5). The exemplary system consists of three working subsystems. The first of them is composed of two organizational subsystems. The second and the third ones have single organizational subsystems. The third one is an administrative subsystem. Therefore it does not participate in processes of the system (Figs. 7, 8). Activities, which are located in such a subsystem, replace these procedures located in control units from higher layers (Figs. 1, 2, 4), which require separate resources and their execution times may not be neglected. Therefore between a control unit of administrative data transfer and higher control units of a given organizational system there are relationships of realization [5, 6], specifically – realization of control procedures by means of administrative activities.

The control in any control unit must take into account the internal structure of subsystems submitted to this unit. This structure is designed in a corresponding control unit of reengineering. Therefore all control units $(s, j) \in SJ$ of a given organizational system $(sn, 3) \in S \times \{3\}$ have direct relationships of de-
pendency with the reengineering unit, which is superior in relation to this organizational system (Fig. 2).

Transition units and data processing phases

Each control unit \((s, j) \in SJ \subset S \times J\) is composed of two system transition units (Fig. 3), \((s, j) \in TJ \subset S \times J\). The transition unit is a set of transitions which are sites of data processing procedures in control units. Each transition corresponds to exactly one transition procedure \(f \in F\), but the same procedure from the transition procedure repository may be called by different transitions. Thus transition procedures are not permanently bound up with transitions, what assures the proper flexibility of an EPC system. Transitions belonging to the decision transition unit \((s, j) \in TJD \subset TJ\) process decisions from higher layers and information from lower layers into decisions concerning lower layers. Transitions belonging to the information transition unit \((s, j) \in TJI \subset TJ\) process information from lower layers into information for higher layers.

In the framework EPC system succession of initiating actions of transition units at beginning times of planning periods is precisely determined. The data processing phase is a set of transition units whose actions are initiated by the same synchronizing pulse. In the EPC system with 21 layers, like in the above-presented example, there are 42 data processing phases. Each of them is identified by the time scale number and by the phase number for a given time scale, \((h, j) \in HJ \subset H \times J\) (Fig. 3). Each system transition unit \((s, j) \in TJ \subset S \times J\) is identified by the organizational unit number and by the phase number. The number of the time scale \(h\) is not required because it univocally depends on the numbers of the phase and the organizational unit.

For information transition units \((s, ji) \in TJI \subset TJ\) the numbers of data processing phases \(ji \in \{0, 1, 2, 3, 4\}\) are the same as the numbers of corresponding functional layers. For decision transition units \((s, jd) \in TJD \subset TJ\) they are numbers \(jd \in \{5, 6, 7, 8, 9\}\), which in a given functional layer satisfy a condition: \(jd + ji = 9\). In conclusion, the functional layer, which was previously defined as a set of control units, may be also interpreted as a set of transition units, which is subdivided into two subsets: information and decision data processing phases.

In the set of data processing phases \((h, j) \in HJ\) of the same time scale „h” the order of phases, i.e. the succession of actions of belonging to them transition units at a given beginning time \(t \in T\) of the sampling period \((h, t) \in H \times T\), is compatible with their number. It means that in a given sampling period the information transition units act before the decision ones, in the set of the information ones – the units from lower layers before the ones from higher layers and in the set of decision units – the units from lower layers after the ones from higher layers. At special beginning times of sampling periods that belong to different time scales (e.g. at the beginning of the day, which is also the beginning of its first hour and the beginning of its first second) after the information phase of scheduling executive orders \((j = 4)\) the EPC system pass to the higher information phase of administrative data transfer \((j = 0)\) which begin actions with a longer time scale. At the beginning times of all other sampling periods after the information phase of scheduling \((j = 4)\) the corresponding decision phase \((j = 5)\) occurs.

Functional subsystems

The control unit of coordination planning controls its organizational system and, at the same time, it is a main gate for communication between this system and control units belonging to higher layers of the EPC system. For those control units the organizational system is a functional system, which executes orders coming from them and send to them corresponding reports. Each of those control units (except of reengineering units), is in contact only with coordinative control unit of the controlled organizational system and “does not see” the inside of this system. Thus, from the point of view of control units, which control a given organizational system and belong to the higher functional layers, the coordinative control unit is a functional unit, which receives decisions and send information.

Analogous conclusions may be formulated also for other control units in the EPC system. Each control unit is also a functional unit corresponding to exactly one functional subsystem. This simple observation is one of the main issues of the EPC theory. Precise connection of basic notions from four different areas – management engineering, production engineering, software engineering and modeling discrete in time control systems for control objects with continuous or discrete state – is possible owing to this observation together with presenting control units as pairs composed of decision and information control units.

In higher organizational levels \((h > 1)\) successive functional layers correspond to the following functional subsystems (Fig. 4):

\[ j = 3 \quad \text{organizational systems (which are also executive subsystems of higher level),} \]
In conclusion, the set of all functional subsystems in the EPC system may be subdivided into subsets of executive, working, structural, administrative, organizational, elementary and basic subsystems $SJ = SK \cup SL \cup SX \cup SD \cup SH \cup SE \cup SB$ (Fig. 5). Moreover, the executive subsystems $(s, j) \in SJ$ and the control units $(u, y) \in SY$ may occur between a given functional unit and control in spite of their structural constraints (in the diagram of Fig. 4 most of couplings between the layers that are not adjacent have been hidden for simplicity). The only condition refers to the couplings between control units belonging to different organizational levels. In such cases the functional unit should be a coordinative unit (because it is a functional unit of an organizational system) or should belong to the layer, which is lower than the layer of the superior control unit in its own organizational level.

**Information places and information layers**

Data structure of the EPC systems is like in relational databases [7]. Such data recording, in tables or in single records, is quite common in practice. It refers to relational databases [3], which are applied to most of management systems and to databases of lower level control systems, as well as to memory of direct control devices. The relational database of the EPC system stores not only current information and decisions which are processed in the system but also the structure of the system itself. E.g. the list of enterprise customers is a part of the specification of all organizational units of the EPC system. The other example is a list of associations of activities with resources, which are required to execute these activities. Thus functioning of couplings between reengineering control units and subordinate to them functional units (Fig. 2) relies on updating (appending or deleting rows) those segments of the database tables describing the EPC system structure which are needed for particular functional units.

In the EPC theory it is assumed that the set of all rows of all tables of the EPC database may be subdivided into separable subsets called **information places**, $m \in M$ [31]. The specified row of a given table belongs to the information place “mx”, if there is such a unique index for this table that the information place number “m” is one of its attributes and $m = mx$ for this row. Analogously, the specified row of a given table belongs to the **information cluster** determined by the tuple $(x_1, x_2 \ldots x_k)$, if there is such a unique index for this table that contains attributes $a_1, a_2 \ldots ak$ and $a_1 = x_1, a_2 = x_2 \ldots ak = xk$ for this row.

The information places are classified into the **system places** $m \in MS$, i.e. places of information concerning functional subsystems, the **resource places** $m \in MR$, i.e. places of information concerning located resources, the **synchronizing places** $m \in MJ$, i.e. places of information concerning data processing phases and the **structural knowledge places**
m ∈ MW, i.e. places of information concerning kinds of activities and kinds of resources, as well as their parameters and relationships between them. Places of information concerning the transition procedures and the kinds of administrative information, which are discussed hereunder, also belong to the structural knowledge places.

In the EPC system all information places m ∈ M = MS ∪ MR ∪ MJ ∪ MW have common numbering. Apart from this numbering, information places within specified subsets may be identified just as entities, which are described by information contained in these places. E.g. system places may be identified by pairs (s, j) ∈ SJ, which are identifiers of functional subsystems. One can say that dependencies MS(SJ) and SJ(MS) are mutually univocal (Fig. 5).

As is well known, rows of tables (more formally: tuples of relations) in relational databases correspond to objects of classes in object-oriented data model [3]. In the EPC theory the tables of the database of the framework EPC system, which are not subclasses of other tables, are called “kinds of administrative information” or shortly: information kinds, i ∈ I. In other words, each table of the database of the EPC system is an information kind or a subclass of certain information kind. Then for each such a table its primary key or one of its unique indexes is a primary key of certain information kind. Furthermore, each row of each table of any EPC system corresponds to one and only one row of certain information kind. It is important for practical implementations, because the number of all information kinds is relatively small. The complete specification of the tables of the information kinds, together with their key attributes, will be presented in the third of planned papers on the EPC theory. There will be also presented the list of all 27 key attributes of these tables, which are named structural attributes. Considering declared universality of the framework EPC system the total number of structural attributes seems to be very small.

Rows in tables of information kinds are called information elements (i, d) ∈ DI ⊂ I × D. For each information element the number of the information place, m(i, d) ∈ M, containing this element, is one of its attributes. The located information (m, i) ∈ IM ⊂ M × I is a set of those information elements of the kind i ∈ I, which belong to the information place m ∈ M.

Among information clusters one should distinguish activity information clusters (m, a) ∈ AM ⊂ MS × A, for which a ∈ A are activity kinds numbers, and resource information clusters (m, r) ∈ XRM ⊂ MR × R, for which r ∈ R are resource kinds (Fig. 6). System and resource information places m ∈ MS, m ∈ MR (Fig. 7), as well as contained in them activity information clusters and resource information clusters (Fig. 8) form information layers, which are located between functional layers. Subsets of information places sets, as well as subsets of information clusters sets, which correspond to particular information layers (Fig. 6) are separable subsets: MS = MK ∪ MX ∪ MA ∪ ML ∪ MH ∪ ME ∪ MB, AM = AMK ∪ AMX ∪ AMA ∪ AML ∪ AMH ∪ AME ∪ AMB, MR = MRK ∪ MRL ∪ MRH ∪ MRE ∪ MRB, XRM = XRMK ∪ XRLM ∪ XRMH ∪ XRM E ∪ XRM B. Each information layer has the same number as the functional layer which is placed immediately below it: j = 2 coordinating information of working subsystems,

j = 1 reengineering information of structural subsystems,

j = 0 administrative orders,

j = 4 allocating information of organizational subsystems,

j = 3 executive information of executive subsystems (organizational systems of lower level).

It also concerns the allocating information layer, but its number (j = 4) is not less by 1 than the number of allocation planning (j = 2). It is neither the number j = 1, nor j = 0, because these functional layers do not participate in functional processes of a given organizational system (Fig. 7, 8). Therefore in corresponding information layers there are no resource places (and no corresponding resource clusters). In the reengineering information layer (j = 1) instead of resource places m ∈ MR there are structural knowledge places m ∈ MW. Resources, which are processed in administrative subsystems (j = 0), are information elements, so they already have got their own places in the structure of organizational systems.

Process structure

After APICS, the business process is a set of logically related tasks or activities performed to achieve a defined business outcome [32]. In the EPC theory this definition is similar but different – the business process is a functional process, i.e. an ordered set of functional activities and separating them located resources. The purpose of a given business process or the purpose of the business process which is superior in relation to a given process is to satisfy customer needs. The exemplary structures of functional processes are shown in the object diagram (Fig. 8) for above-presented simple organizational system (Fig. 1, 2, 4, 7).
Fig. 6. Class diagram for information places and information clusters.
Fig. 7. Object diagram for the exemplary organizational system structure.
Fig. 8. Object diagram for functional processes of the exemplary organizational system.
The functional activity \((s, j, a) \in SJA \subset SJ \times A\) is determined by the activity kind, \(a \in A\), and the functional subsystem, \((s, j) \in SJ \subset S \times J\), in which this activity is performed (Fig. 9), whereas the functional process \((sn(s), 3, p) \in SJP \subset SJ \times P\) by the process kind, \(p \in P \subset A\) and the organizational system, \((sn, 3) \in S \times \{3\}\). The process is an activity of the higher level, \((sn, 3, p) \in SJP \subset SJA\) (Fig. 10).

The located resource \((m, r) \in RM \subset MR \times R\) is determined by the resource kind, \(r \in R\) and by the resource place, \(m \in MR \subset M\). The functional activity may also be defined as a located activity \((s, a) \in SA \subset S \times A\) that is performed in the organizational unit \(s \in S\) and observed at the functional layer \((h(s, j), j) \in HJ\).

Functional subsystems from successive layers correspond to the following functional activities (Fig. 10):

- \(j = 3\) processes (which are also executive activities of the higher level),
- \(j = 2\) working activities (in the lowest level – elementary activities),
- \(j = 1\) basic activities (only in the lowest level),
- \(j = 0\) administrative activities,
- \(j = 4\) allocated activities (allocated to organizational subsystems).

Thus the set of all functional activities may be subdivided into subsets of executive, working, structural, administrative, and allocated activities. The located resources, which separate functional activities in processes, are classified into analogous separable subsystems: \(RM = RMK \cup RML \cup RMH \cup RME \cup RMB\).

Functional activities, like functional subsystems, correspond to activity functional units, which are activity control units from the view point of lower layers. Activity control units are contained in corresponding system control units and – analogously to them – participate in system couplings of activity control units between the functional layers \((s, j, a, u, y, c) \in SJC \subset SJ \times SYC\) (Fig. 9). Moreover, \((s, j, a) \in SJA\) identify functional units, whereas control units are identified by \((u, y, c) \in SYC \subset SJA\).

The activity functional unit corresponding to the functional process is a common control unit for functional activities belonging to this process (Fig. 8). Thus relationships between functional activities \((s, j, a) \in SJA\) belonging to the functional process \((sn(s), 3, p) \in SJP\) and this process itself are special cases of couplings between activity control units \((s, j, a, sn(s), 3, p) \in SJAP \subset SJAC\) (Fig. 10).

![Fig. 9. Class diagram for functional activities.](image_url)
The functional process may be:
\[ j = 2 \] a working process (in the lowest level – an elementary process),
\[ j = 1 \] a basic process (only in the lowest level),
\[ j = 4 \] an allocated process or
\[ j = 3 \] an executive process.

It depends on the layer, to which the component activities of the process belong (Fig. 8, 10). However, in each case the functional process in a given organizational system is identified by the same control unit, which belongs to the coordination layer (\( j = 3 \)) in this system.

Information flow between coupled system control units relies on recording and reading data in system information places \( m \in \text{MS} \) and resource information places \( m \in \text{MR} \) (Fig. 7). Analogously, activity information clusters \( (m, a) \in \text{AM} \subset \text{MS} \times \text{A} \) and resource information clusters \( (m, r) \in \text{XRM} \subset \text{MR} \times \text{R} \) participate in couplings between activity control units (Fig. 8). In particular, it refers to couplings between the control unit of a process and its component functional activities. Moreover, between system places and functional subsystems, as well as between activity clusters and functional activities, there are mutually univocal dependencies. In the class diagrams (Fig. 5, 9) alternative primary keys are shown – \((s, j)\) \in SJ for the system place table MS and \((s, j, a)\) \in SJA for the activity cluster table AM – because they are more often used to searching in an EPC database for information.
Fig. 11. Class diagram for resource inputs and outputs of functional subsystems and activities.
The assumption of separating activities by resources is crucial for formal description of the process structure. Output resources of a given activity are input resources for other activities. In this way the order of activities in the functional process is defined by resource inputs and outputs of functional activities. They are formally determined by associations between functional activities and located resources, \(((s, j, a, (m, r))) \in SJJA \times RM\), which are recorded as the lives of numbers of organizational units, functional layers, activity kinds, resource information places and resource kinds: for inputs \((s, j, a, (m, r)) \in URSJA\), whereas for outputs \((s, j, a, (m, r)) \in YRSJA\) (Fig. 11). Tables of inputs and outputs of located resources to/from functional activities correspond to analogous specifications of resource inputs and outputs of activity kinds \(((a, r)) \in URA\), \(((a, r)) \in YRA\) (Fig. 11), resource inputs and outputs of functional subsystems \(((s, j, m)) \in USJ\), \(((s, j, m)) \in YSJ\) (Fig. 7, 11) and generic resource inputs and outputs of functional subsystems \(((s, j, m, r)) \in URSJ\), \(((s, j, m, r)) \in YRSJ\) (Fig. 11).

Information elements of resource inputs and outputs, which are recorded in presented above tables of USJ, URSJ, URSJA, YSJ, YRSJ, YRSJA, are distributed among resource information places \(m \in MR\), and more narrowly – among resource information clusters, identified by corresponding located resources \((m, r)) \in RM\). Analogous information concerning input and output couplings of system control units \(((s, j, m, u, y)) \in USJY \subset USJ \times SY\), \(((s, j, m, u, y)) \in YSJY \subset YSJ \times SY\) (through input and output resource information places of functional subsystems), as well as input and output couplings of activity control units \(((s, j, a, m, r, u, y, c)) \in URSJAC \subset URSJA \times SYC\), \(((s, j, a, m, r, u, y, c)) \in YRSJAC \subset YRSJA \times SYC\) (through input and output located resources of functional activities), is recorded in the same resource places and resource clusters (Fig. 11).

### Classification of activities and resources

Enterprise processes may be classified by their nature into:
- manufacturing processes, whose products are new material goods,
- service processes, whose outcome (product) is satisfaction of needs, that are other than the need of possessing material goods, and
- data processing processes, whose products are information items.

![Class diagram for classification of activity and resource kinds](image-url)
For functional processes classification by their role in the EPC systems is more important. Strictly speaking, the question concerns the role of processes in organizational systems of the higher level, where these processes are activities. In the EPC theory activity kinds are subdivided into:

- productive activities (of various nature),
- preparatory activities (tooling setups, repairs, overhauls and the like) and
- administrative activities (performed in administrative subsystems and initiated by those transition procedures of organizational systems that require additional time and resources).

This classification reminds the one from [23, 24], which specifies production, support and managerial processes, but it not exactly the same.

In the case of service processes and data processing processes the postulate of separating their component activities by resources may seem to be wrong. However, it is possible owing to properly wide definition of resources. In the EPC theory the classification of resource kinds includes (Fig. 12):

- reusable resources,
- consumable resources,
- financial resources,
- information resources,
- organizational resources and
- administrative resources.

It is important that the same resource specimen in different circumstances may be an element of different categories.

Information resources mean not only data processed for customers but also products of service activities, e.g. the messages of service activity terminations which, in turn, are used to the next activities of a given service process. The products of services are not material but information of these products really exists. One should notice that also in the case of manufacturing processes the systems of management and control have no disposal material goods, which are manufactured in these processes, but only information concerning these goods, just as in the case of service processes. Administrative resources are information elements, which are inputs or outputs of mentioned above administrative activities. Organizational resources are products of presented preparatory preparatory activities.

Aggregation of activities, resources, organizational units and information places

Different resource categories, activity groups and statistical groups of organization-
tivities \((s, j, a) \in SJA\) are called **readiness variants** [10] of functional subsystems \((s, j, g) \in SJG \subset S \times J \times GG\) (Fig. 12). Like organizational activity groups, which formally belong to the set of all activity kinds, the readiness variants belong to the set of functional activities, \(SJG \subset SJA\). Each organizational activity group has its main product, which is the family of main products of activities belonging to this group.

Among input resource kinds of a given organizational activity group one should distinguish the **organizational resource** kind \(ro(g) \in RO \subset R\), which corresponds to it. Its zero-one attribute is the **readiness state** of functional subsystems which can perform this activity group. It demonstrates readiness of a given functional subsystem \((s, j) \in SJ\) to perform activities belonging to corresponding readiness variant \((s, j, g) \in SJG\). The organizational resource, like reusable resources, is returned to its rest place (i.e. to the corresponding information place) after executing activities from a given group. On the other hand, the organizational resource is a main product of the **preparatory activity** \(a \in AO \subset A\), which prepares organizational units to corresponding readiness variant. The dependencies between organizational activity groups, organizational resource kinds and preparatory activity kinds are mutually univocal (Fig. 12).

If preparations refer to the change of production profile of an organizational system, then their “product” is readiness to the new overall activity group. If the preparatory activity is the repair after a break-down, then its “product” is the readiness state of repaired organizational unit, which in general is the same as before the break-down. It should be stressed that preparatory activities are performed with proper preparatory organizational units, not with the units which are their objects. Furthermore, one execution of the preparatory activity prepares the organizational unit to one or many executions of one or many kinds of productive activities. Thus the presented here model better reflects practical cases than commonly used simple operation description, in which the execution time is subdivided to the setup time and the run time.

Separation of preparatory activities, as well as introduction of organizational resources and organizational activity groups, facilitates unified description of internal structure of productive and preparatory organizational units. What is more, owing to this it is possible to work out a precise model of interaction between management systems for production and for preparations to production. In this model, obviously, production is planned with regard to constraints resulting from decisions concerning maintenance, overhauls and the like, but on the other hand it is possible to adapt these decisions (in the permissible scope) to the current production decisions.

**Conclusions**

The theory of Enterprise Process Control (the EPC theory) is structured by way of deduction. From more general notions, namely from the notions of organizational level, functional layer, organizational unit, activity kind, resource kind, information place, information kind, other basic notions of the EPC theory are deduced. Among them one should notice the notions of organizational system, functional subsystem, control unit, functional unit, transition unit, transition, functional activity, functional process, located resource, inputs and outputs of functional subsystems and functional activities, information cluster and the like. Successive notions are defined by way of presentation of their relationships with previously defined notions. Using diagrams of the UML language [5, 6] to describe these relationships assures precision of the definitions and, on the other hand, demonstrates that the framework EPC system may be used in practice.

From basic notions of the EPC theory one can deduce more detailed notions, such as transactions, orders, plans, reports, their parameters and the like. Among many new detailed notions there are also such as reengineering units, administrative resources, organizational resources, readiness variants of functional subsystems and the others, which are introduced to remove structural barriers on the way to precise modeling problems of reengineering organizational systems in all organizational levels, problems of data transfer between productive and administrative processes, problems of interaction between productive and preparatory process management systems etc.

The meaning of notions, presented herein and in the following publications on the EPC theory, is univocal, but their names may be an object of discussion. As a result of this discussion those names should be recommended, which properly associate with the sense of these notions for experts of four different special fields – management engineering, production engineering, software engineering and automation. In certain cases not only names, but also the sense of definitions may seem to be disputable. E.g. it refers to the definition of a business process, in which resources separating activities are mentioned, and the definition of a resource, which does not encompass organizational units. Resources are always
passive beings, whereas an organizational unit is an active being and in addition contains internal control units.

Deductive nature of the EPC theory facilitates verification of its consistence, that should induce to accept the thesis of its generality. This, in turn, justifies advisability of a research into the EPC theory usefulness to modeling practical problems of management and process control, as well as advisability of starting work on the prototype of the framework EPC system.

References

