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Conceptual Modelling of Complex Production Systems

Nenad Perši *nenad.persi@foi.hr*
University of Zagreb
Faculty of Organization and Informatics, Varaždin

Abstract

Complex system dynamics, structure and behaviour performances call for a wide range of methods, algorithms and tools to reach a model capable of finding optimal performing parameters. In the modelling process, it is up to the analyst to select the appropriate combination of methods, algorithms and tools to express significant system performances. Such a methodology for designing complex systems should be based upon conceptual modelling to perform a sensitive analysis of different system levels and views, allowing system representations for developing computer models.

Complex systems, such as business systems with a continuous-discrete production process, require a well organised supply chain highly reactive to production assortment changes. Aligning two different production components distinctive in their behavior is especially delicate at the production parameters transition point. Such system performances require distinctive designing methods that can follow the double nature of the production process behavior in accordance with their entities dynamics caused by assortment changes. Consequently, such systems need different conceptual presentations for their purpose to be realized from different views and aspects.

Keywords: conceptual modelling, complex system, production, methods, system models

1. Introduction

Conceptual models can be used to represent systems at different levels. They offer system representation appropriate for system behaviour and structure required for eliciting the most important specifics and entities dependencies. Using mathematical, statistical and algorithmic presentations computer models can be developed. In this way, conceptual modelling becomes a powerful tool for experimenting with systems states, aligning parameters and choosing the most appropriate production mode.

According to modelling levels, a combination of process approach conceptual modelling also allows the development of meta-models using different classes of abstraction. With concrete processes parameterisation such classes of models can become a real world process model.

Using conceptual modelling for systems with such performances we can reach an overall system model covering all entities of both production types and present their dynamics. To achieve that purpose we should have a wide knowledge of appropriate methods, algorithms, principles and techniques – a whole toolbox, not only a single tool – at our disposal.

2. Business processes

Business processes should also be considered through a system's strategic and operative goals. Strategic goals explain the purpose of the existence of business processes and reasons why they are performed in a particular way. These goals are reflected in the rules and procedures determining the way in which processes are managed, whereas the results are manifested through process definitions. Operative goals refer to results to be achieved within a particular instance of a process by using resources: material resources, human resources and organization [7].

In addition, there is an evident need for modelling at the conceptual level for two different business system instances, which means that the appropriateness of the modelling approach needs to be reflected not only in the accomplishment of goals but also in the features of resources employed in their realization.

Therefore, the key aspect according to which one modelling approach is different from another is the way of representing the development of process instances through time, that is, process dynamics. Figure 1 [11] shows a possible way of system modelling, in which various business system instances as well as conditions for occurrence of interactions among them and interaction states can be recognized.

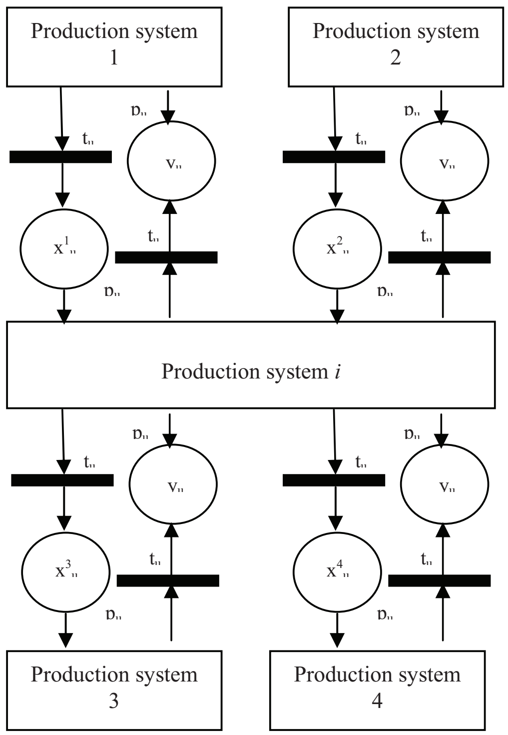

Figure 1. Conceptual model of production system

In that respect, the following should be distinguished [1]:

- entry/exit flows;
- workflows;
- active resources (agents) flow overviews and
- state flows.

Entry/exit flows describe the objects consumed, produced or modified by the process during the performance of related activities. Workflow presentations are focused on performance of activities through time and the results of performance of those activities. Flow overviews concerning active resources (agents) present the way in which agents perform their tasks. State flows are used to describe changes occurring in a part of a real system related to a particular project instance [5].

Taking into consideration characteristics of business processes, they can be classified according to the following criteria:

1. Objects' physical level and passive mobility: by means of this level the mobility of objects within a process is determined. They can be most appropriately represented by using workflow and state flow presentation
2. Level of agents' specialization and their mobility degree: staff and equipment needed for activities to be performed;

   - According to their level of specialization, agents can vary from narrowly specialized to universal agents. If a large number of narrowly specialized agents are involved, for representation of their activity a work flow restricted to particular agents' activity domain is most appropriate. For universal agents' activity, a classic workflow presentation is more appropriate.
   - When process agents' mobility is concerned, it is necessary to represent the ease and speed at which they pass through particular process instances. In terms of mobility, agents can vary from totally immobile agents to almost completely mobile ones. Depending on passive agents' mobility degree, both workflow overviews dealing with particular agents and overviews of entry/exit flows of objects upon which activities are performed by active agents are appropriate.

3. Level of determination of operative goals correlating with the nature of the activity to be performed for the results of the process to be achieved. The more determined an operative goal, the easier it wil be to determine the activities leading to the realization of that goal. Representations focusing on displaying states provide an opportunity for defining operative goals by restriction to final states only;
4. Autonomy and characteristics of the environment in which processes are performed: the dynamics of autonomous (mainly internal) processes can be well described by workflows. Processes involving external influences do not depend only on the system's internal logic, but also on rules governing the behaviour of external factors. In that respect, it is important to consider whether the processes are executed in a friendly and collaborative environment or a highly competitive one. In a competitive environment special attention needs to be paid to agents controlling processes within the system from the outside. Such business processes, whose states can be triggered by changes in the environment, can be well described by state flows;
5. Nature of the activity: (exact) activities, defined by the method of execution and their object and (non-exact) activities, defined by results arising from their activity upon the object. Exact activities can be described in terms of time and other resources required for their execution. They can be well described by 'what-if' analysis and system simulation, provided certain parameters are modified. Therefore they can be well described by workflow description. Parameters describing non-exact activities can be described only randomly, and not in a universal manner, which is why the choice of tools and ways to describe each particular activity varies from case to case;
6. Order of activities: determining whether process activities strictly follow a pre-defined order or it is possible to establish a provisional or partially defined order. In case of a pre-defined order of activities, workflow diagrams are appropriate. However, non-autonomous processes performed in a competitive environment with functionally defined goals and non-exactly defined activities have a fairly low level of determination of activity order execution. They can be most appropriately presented by means of state flow diagrams;

The level of maturity of a process within an organization and professionalism of human resources participating in the process are characteristics of the environment in which the process is performed, and should by no means be neglected. If an organization is not mature enough, it has to learn to recognize the processes, and diagrams presenting an organization's functional structure as well as entry/exit flows provide useful reference points for analyzing those processes. In mature organizations with a highly developed organizational culture and well-defined processes, responsibilities and competencies, it is more appropriate to employ representations of flows oriented toward agents and activities they perform. In that respect it is particularly important to determine the points of collaboration and communication between individual processes or their parts.

3. Business process modelling

Processes yielding physical results can be investigated, and their results measured, in real time. This approach is not applicable to most processes of intellectual kind. Defining their dynamics depends on highly-developed professional knowledge of human resources involved in a process. Depending on the character of that knowledge, different approaches to process description can be taken.

Reasons for using models in a business environment include the following:

- improving the level of process maturity;
- building the basis for process analysis and reengineering;
- building the basis for the computing support system development.

Purposeful application of models in business systems is achieved through the selection of an appropriate conceptual model for the description of specific segments of business processes (by using computer simulation, individual models can be integrated into a comprehensive business system model), showing system dynamics and business environment influences.

Developing a conceptual model is the first stage in simulation modelling. The conceptual model's primary function is to enable problem structuring and, consequently, better understanding of the problem. The relevance of this model type is in its ability to:

- identify the most important characteristics of the system;
- describe the system elements and their interaction;
- facilitate the communication between the development team and model users;
- assist the development of the computer-based model [6].

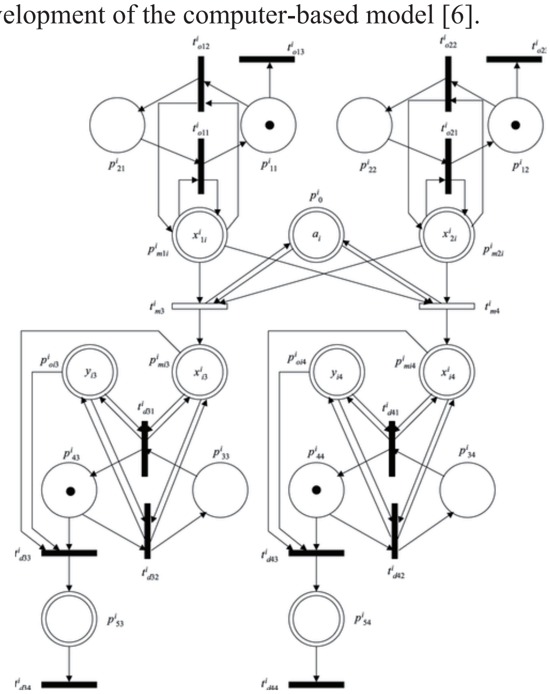

Figure 2. Production system model with a high level Petri net

Conceptual models contain a rough description of the system, further elaborated into particular modules. In them, the idea of how to solve a problem is combined with strictly – in formal terms – defined computer models for system behaviour simulation. According to Wang [11] (Figure. 2), certain imprecision and inconsistency in representing a real system by means of conceptual modelling still exists, to be explained by the impossibility to precisely determine the dynamic behaviour of a system through time, as well as the possibility of occurrence of certain parallel activities in the system.

The conceptual model is therefore a partially general model, but can nevertheless be considered as a dynamic system in which model objects can also work and interact in parallel. The modularity principle is observed in conceptual model development primarily owing to its similarity with human reasoning. Since a conceptual model is a result of reflecting on interactions among objects within a real system, it is natural for a problem to be broken down into smaller meaningful units.

Thus a conceptual model of a real system will be expressed by means of closed modules. Each of them represents only a particular part of a real system. (To solve a described problem, different concepts are implemented: Petri Net, Activity Cycle Diagram, Causal Loop Diagram, Flow Chart Diagram, Transition Diagram). By integrating the modules, a complete model is obtained. A quality conceptual model is supposed to:

- provide a simple, natural, easily understandable and unambiguous presentation of system elements
- possess a great expressive potential in terms of modelling
- show a modular and adaptable approach enabling simple and safe model modifications [9].

The ability to adapt efficiently to newly-arisen changes in the environment requires business systems to introduce and implement new methods and technologies, so as to ensure that rapid modification is effectuated duly, with a minimum error rate, while reducing the costs incurred during modification and time needed for selecting and developing a new business model. Using appropriate conceptual modelling methods and techniques will enable the automation of business process modelling. In other words, it will provide a possibility of using patterns of behaviour with a view to improving the quality of finding a new business model while speeding up the process itself. This kind of automation relies on a combination of planning techniques from the artificial intelligence domain, dynamic and descriptive features of conceptual modelling methods as well as data-processing ability of contemporary ICT. The role of conceptual models in such an approach is primarily based on defining the control function which plays an important part in ensuring that the subsequent (automated) part of system modelling is proceeded with correctly. In other words, in production systems, conceptual models can also be used in monitoring business processes and their management.

4. Business systems management models

When production systems are concerned, the description of a system, relationships between its structural elements and its behaviour as well as monitoring its business processes are by definition connected to several types of machines, tools, and materials. Production features values are expressed in quantitative terms, regardless of whether discrete or continuous values are used. In practice, these values tend to be intertwined and therefore need to be optimized [13].

Using typical non-linear multidimensional models is not always appropriate for solving optimization problems in production systems, owing to an increased model complexity resulting from the increased complexity of the system itself. By combining appropriate descriptions, contemporary conceptual modelling methods, such as Petri nets, different types of useful formalization are defined for different stages of a system's lifecycle, and each of them connected with appropriate business operations and processes [10].

Describing the dynamics of execution of business processes and introduction of the time component contributes to solving problems arising in complex and mutually dependent business processes (especially those related to sharing common resources – complex decision making problems) which can lead to system deadlock.

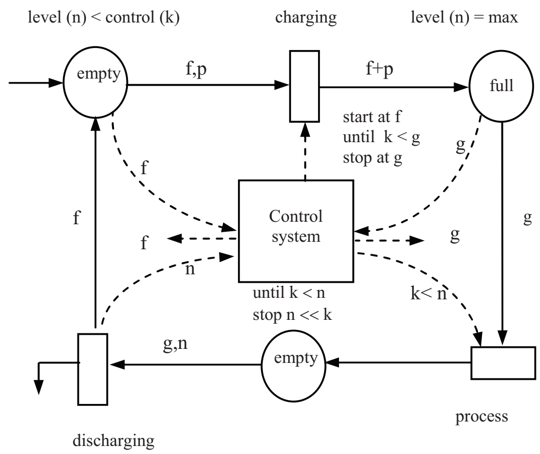

Figure 3. Coloured Petri net

On the other hand, in production systems, there are certain complex higher-level functions primarily concerned with monitoring the execution of business processes and related to the system's control mechanisms.

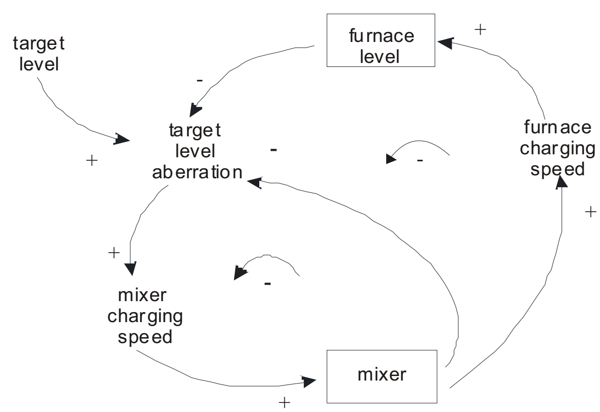

Figure 4. Casual loop

For modelling such processes it is necessary to employ more complex multiple models to be applied through various methods within conceptual modelling. Complex control functions are usually divided into two parts. The more complex part, in charge of coordinating the subsystems with key controls, is described by higher-level models (for example, a High Level Petri Net – Well-Formed (Coloured) Nets – Figure. 3), whereas the less complex part, the scheduling decision system, is described by lover-level complexity models (example: an Expert System, Activity Cycle Diagram, Casual Loop – Figure. 4) [12].

Hence it can be said that for every problem or situation arising within production systems an appropriate conceptual modelling type, or a combination of several types, can be found, so as to precisely address a particular system and representatively describe the observed system.

5. Conclusion

Business systems with a transitive production processes behaviour sensitive to assortment changes are a complex systems class requiring a consistent methodology. That methodology should allow production process modelling according to its component specifics in behaviour, structure and dynamics, but without losing component specifics and environmental influence. Such a methodology ought to represent the overall production process dynamics, enabling different system states investigation while searching for the optimal process parameterisation. Finally, it is also important to develop a model's valuation, verification and approval regarding its structuring, functionality, reality, reliability and predictability.

Conceptual modelling includes a range of different modelling methods and tools according to system components behaviour, structure and dynamics. In addition, it should enable:

- entities transition from state to state followed by metrology alignment,
- different behavior presentation according to subsystems' components characteristics,
- process parameterization and formalization appropriate for using information technology to improve the reengineering process.

According to modelling levels, a combination of process approach and conceptual modelling also enables the development of a wide range of meta-models. With concrete process parameterisation, such models can become a representation of a real world process model, appropriate for investigating optimal parameter values.

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