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Semi-automatic simulation model generation of virtual dynamic networks for production flow planning

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Abstract. Computer modelling, simulation and visualization of production flow allowing to increase the efficiency of production planning process in dynamic manufacturing networks. The use of the semi-automatic model generation concept based on parametric approach supporting processes of production planning is presented. The presented approach allows the use of simulation and visualization for verification of production plans and alternative topologies of manufacturing network configurations as well as with automatic generation of a series of production flow scenarios. Computational examples with the application of Enterprise Dynamics simulation software comprising the steps of production planning and control for manufacturing network have been also presented.

1. Introduction
In the area of organizational production preparation the modules of MRP I, MRP II and scheduling systems are mainly used. Unfortunately, in most cases, modules supporting the processes of production flow planning do not include all constrains of the production system, for instance constrains related to internal and external logistics. In order to fully verify prepared production plans, the following must be analysed: available quantities and capacity of transport means, possible risks of collisions, storage location and capacity (inter-operational, input, output) and their impact on the opportunities to meet the planned production norms. It is necessary to search for computer aided decision-making tools and implement them in planning process. One such area of computer support witch allow to increase the efficiency of production planning process is computer modelling, simulation and visualization of production flow [1,2]. Conducted research were oriented towards growth the efficiency of production planning and control systems through their integration with computer discrete event modelling, simulation and visualization systems for multi-assortment manufacturing systems [1,2,3,4,5,6,7,8].

Possibilities of using the methodology of semi-automatic model generation based on parametric approach for supporting processes of production planning is presented. Simulation models are generated based on simulation atoms (building blocks) stored in simulation libraries along with a fixed production routes (static data), and sequencing control of processes flow data for manufacturing resources (dynamic data). Proposed approach allows to eliminate the problems related to the preparation of simulation model in the traditional way, i.e. labour-intensive and time-consuming. The research on methodology of semi-automatic models generation presented in this paper includes issues related to the area of Virtual Enterprises (VE), Virtual Manufacturing Network (VMN) and Dynamic
Manufacturing Network (DMN) concepts development \cite{5,9,10,11,12}. The results obtained from simulation experiments allowing determination of Virtual Dynamics Networks routes parameters those that ensure execution of orders on time with an acceptable level of production and transportation cost. These problems are particularly important due to the fact that the results of their solutions would benefit both in the large as well as small and medium-sized enterprises. The proposed approach also supports one of the key importance in development of the concept of VE solution to the problems in exchange of information between IT systems supporting production management at various levels (from ERP systems, through MRP I, MRP II, PPC until MES).

2. Production planning in virtual and dynamic manufacturing networks

Today’s organizations operate in a very dynamic and complex environment, related among others to the globalization of the market, constant changes of customer requirements, fierce competition and changeable environments. These factors force manufacturers to adapt quickly to new circumstances. One of the responses to these demands are manufacturing concepts based on the cooperation networks. In this area VMN and DMN concepts are the most developed. Introducing new complex products to the market, companies are sharing the production (e.g. several parts provided by different manufacturers) enabling reduction of production time and costs, and increase quality and flexibility \cite{9,10}. Members of these networks constitute a permanent or temporal coalition comprising production systems of geographically dispersed SMEs that collaborate in a shared value-chain. At this level, the main objective is to create a collaborative platform to implement and support creation of a DMN. The platform encompasses globally distributed partners, suppliers and manufacturing plants who offer their resources \cite{9,10}.

Partners in the platform need access to some information from individual companies to support the choice of the best options depending on several criteria \cite{10} and they can provide data on available production capacity and production costs, which are necessary for the selection of a temporary coalition of manufacturers for the realization of a specific production order. At this stage, it is essential to efficiently perform the planning of the production flow, which consists of resources selection (from available) for carry out the steps of production process. A key challenge is related with different manners of production process planning and control, since each enterprise has its own set of manufacturing resources and uses its own planning systems and database management systems. The production flow planning process for DMN is much more complicated and more risky due to their dynamics and geographical dispersion, because operation of coalition partners may change very often in a not predictable way. The uncertainty associated with the production and transportation costs and time arise directly from dynamic nature of the manufacturing networks. Conventional planning methods do not include any restrictions related to manufacturers network topology, their dispersion and its degree of complexity \cite{9,10,13}. Conventional methods, such as approaches based on MRP II/ERP principles and concepts, require large amounts of data and is becoming extremely difficult to manage \cite{10,14,15}.

To increase the efficiency of planning and reduce the probability of failure, which increases with the number of network members, it is desirable to verify prepared production plans, taking into account transport means available quantities and capacity, possible risks of delays, location and storage capacity (inter-operational, input, output). One of the methods that can contribute to solve these problems is the use of discrete-event simulation system as a tool for verification, analysis and optimization of processes flow plans \cite{1,2,4,6}. Execution of calculations for each production flow variant may be successfully supported by the use of discrete-event simulation models for dynamic production networks. It gives the ability to provide that the manufacturing network could operate more efficiently for different composition and under different conditions. In the next sections of the paper the concept of simulation model semi-automatic generator for virtual manufacturing networks production flow planning will be presented. A practical example of the use of models supported by simulation in the Enterprise Dynamics simulation system is shown.
3. Semi-automatic simulation model generator

The concept of semi-automatic or automatic model generation is defined as a method of creating simulation models from external data sources using interfaces of the simulation system and algorithms for creating the model by users without any programming skills (or with minimal level of that skills) [4,16,17,18,19]. The simulation model is not created manually using the simulation software features and tools. This means that the planners/engineers using interface of the simulation system interface should be able to prepare simulation models and carry out experiments either by changing or by indication of input data which automatically updates the simulation model. The goal of such approach is set to generate simulation models directly from the available data sources using algorithm for configuring the simulation model.

Semi-automatic model generation can be classified into three main categories[16,17]:

- Parametric approaches: Models are generated based on existing simulation building blocks (atoms) stored in simulation systems libraries, which are selected and configured based on parameters,
- Structural approaches: model generation is based on data describing the structure of a system (typically in the form of factory layout data),
- Hybrid-knowledge-based approaches: combine AI methods (expert systems, neuronal nets) with two of the above presented.

Similarly, the concept of (parameter-based) automatic and semi-automatic model generation is given in [18] as general/generic models or model based on template. In this case that specific model instances can be created through parameter configuration. The division into automated and semi-automated generations is associated with the “level of automatism” [16] - model which has a completeness of 80% (“semi”-automatic model generation) in which it is required to add certain model details, schedule, experimentation parameters, technical data etc. by the simulation expert/planner. An example of such solution, automatic simulation model generator, is proposed by Son and Wysk [3]. The generator has been implemented using the Arena simulation system language and the models are built on the basis of data on a static model of resources and planning data on the production flow.

A semi-automatic concept for model generation based on parameter-based approach, in combination with concept of manufacturing network is elaborated by authors of this paper and is presented in figure 1.

![Figure 1. Concept for model generation.](image)

The main difference of the proposed parameter-based simulation model of manufacturing network in comparison to a conventional production flow is that these organizations could be geographically
dispersed. The choice of the appropriate structure for the simulation objects relating to appropriate allocation of resources, means of transport, etc., and the possibility of their parameterization is very important. Another important factor is the functioning of manufacturing resources in the network, as a temporary and changeable structure.

The presented concept of simulation model generation method in most can only be used with a dedicated computer simulation systems, or allow the generation of simulation models for a specific (similar) structures associated with production processes flow in the system. Practical implementation of the presented concept was performed in the Enterprise Dynamics simulation system.

3.1. Simulation Model

Enterprise Dynamics (ED) simulation system was chosen to prepare a parametric-based simulation model for dynamic manufacturing networks production flow. ED is a computer simulation and visualization system developed by InControl Simulation Solutions company. ED is an object-oriented simulation platform, that uses event-oriented approach in the implementation of the simulation process and offers a fully configurable and scalable simulation environment. During the simulation model construction a wide range of comprehensive, branch-specific simulation objects are available to the user. It was assumed that the structure of a created model consists of resources allocated to each of manufacturing network members separately:

- manufacturing system resources layer - resources that comprise the manufacturing system, i.e.: machines, inter-operational buffers, warehouses, input and output buffers,
- transportation system layer – creation means of transport simulation objects, connecting all the possible combinations between manufacturers,
- parameters of the system resources layer (information resources layer) - data objects that contain parameter values for previously defined resources, i.e.: tables containing data about the setup and cycle times of operations on production resources, data on processes routes, available alternative routes for each production process, capacity of transport means.

Model could be parameterized by data on the production system and the production flow. Prepared model is shown in figure 2.

![Simulation model](image-url)

**Figure 2.** Simulation model.
Layer of information resources (data tables) has been prepared in such a way that for prepared model the data for ten different variants of production can be entered at once. The model contains the following data tables:

- **prod_j** – in each row of the table information about production route is entered – IDs of next simulation object for subsequent operations for j-th manufacturer, and (last row) IDs of next manufacturer, where the production process is continued (or storage ID if the production process is finished). Each 10 row in the table corresponds to the variants of production process,
- **times** - in each row (corresponding to production flow variants) information about processing times is entered,
- **cost_p** - in each row (corresponding to production flow variants) information on unit production costs on resources is entered,
- **res_cost_p** – contains the results for each simulated variant about the summary of production costs for each product,
- **variant** – the currently simulated variant production flow.

The current version of simulation model is prepared to simulate manufacturing network consisting of three members, with a simultaneous implementation of two independent manufacturing processes, however, simply by copying the prepared sets of objects, their number may be increased. The data parameterization to the model may be entered manually by the planner, or generated directly from a database of external planning system (MRP/ERP). Exemplary data of production routes for the manufacturer are shown in figure 3.

![Exemplary data](image)

**Figure 3.** Exemplary data.

### 3.2. Practical example

Prepared simulation model was parameterized by data on the virtual manufacturing network which consists of three manufacturers. Manufacturers share their production resources (M₁, M₂ and M₃) to perform production order. Each manufacturers offers they own resources which can be used for the production order completion. The production order consists of processes P₁ and P₂. Processing times and unit production costs for each technological operation for the chosen variant are showed in table 1 (Mᵢ is an i-th resource of ε-th manufacturers).
Table 1. Processing time and unit production costs of the P₁ and P₂ processes for chosen variant.

| Process | Route | Processing time (unit cost) |
|---------|-------|----------------------------|
| P₁      | M₁    | 10 (3)                     |
|         | M₂    | 30 (2)                     |
|         | M₃    | 10 (2)                     |
| P₂      | M₃    | 40 (2)                     |
|         | M₄    | 30 (4)                     |
|         | M₃    | 30 (5)                     |

The results of simulation experiments (figure 4) are reporting and contain information about the coefficient of production resources utilization, time of production cycle and lead times for each product, transportation and production cost for all processes and all manufacturers. Visualization of production flow also allows to verify the correct functioning of the production system and checking of sufficient capacity of buffers and transportation means. Saving of routes and resources (belonging to individual manufacturers) used in the production as a parameter of the model allows for the verification of alternative topologies of manufacturing network configurations as well as automatic generation of a series of scenarios. Presented in this paper the simulation model can be downloaded from http://imns.home.pl/rapid_sim/modtech2016.mod.

Figure 4. Simulation experiment.

4. Conclusions
In the paper a concept of semi-automatic model generation method based on parametric approach has been presented. The approach enable verification of alternative topologies of dynamic manufacturing network configurations as well as automatic generation of a series of scenarios of production and transportation cost, routes and batches. It allows to answer the question if the manufacturing network is capable to effectively respond on market demands. Presented method can be successfully used with most computer simulation systems, which are characterized by object-oriented method of simulation model creating and offers configurable and scalable simulation environment. As further works authors foreseen to extend of the method for the further functionalities related to automatic data extraction.
from a collaborative platform and enterprise systems supporting the creation of a manufacturing networks.

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