# Hybrid Methods Aiding Organisational and Technological Production Preparation Using Simulation Models of Nonlinear Production Systems

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**Abstract.** Various problem solving techniques are used in organisational and technological production preparation in combinations assuring the overarching goals to be achieved in an optimum manner. The paper presents current progress in planning a facility manufacturing cabinet furniture. In order to determine output level and match a production process, expert knowledge, theoretical computations (Schmigalla method of triangles) and data aggregation were used. The entire project was then verified using adequate simulation models.

**Keywords:** Production preparation, modelling, simulation, hybridity.

## 1 Introduction

The all-important issue in planning a new production facility – in this case intended to manufacture cabinet furniture – is to determine the output level and pair it with an adequate production process. The output level is determined based on available expert and theoretical knowledge. It lays foundations for further work and computations ultimately verified using computer simulation by means of a simulation model combining discrete and continuous simulation.

The success of a simulation project is dependent on simulation and project management tools, but also on acquisition of appropriate information, scattered usually across different enterprise departments [3], [7], [11], into account should be also taken kind of structure of the production system. The structure of the system, which determines the relation between the state of reliability of the system and the state of reliability of its objects. The analysis of the reliability structure of a system should be preceded by dividing the system into individual components – the system decomposition, which should reflect the logical connections in the system [2], [4].

Set out were the following fundamental tasks:

- adjust the technological process to the ten-fold higher sales plan,
- select means of production,
- determine layout of workstations,

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- identify of the structure of production system,
- verify the project using adequate simulation models.

A system, which employs in excess of one problem solving technique, can be classified as a hybrid system. Among fundamental problem solving techniques are: data aggregation, fuzzy logic, genetic algorithms, expert systems, simulation methods, neural networks and other.

## 2 Characteristics of Production Processes

The enterprise had already put some effort into development aimed at expanding the range of products with cabinet furniture finished with natural wood veneer. The process was initiated by designing a collection of furniture and mocking up prototypes using available means of production.

The collection of furniture produced, are high quality cabinet furniture finished with natural beech-wood veneer, intended for dining rooms, lounges, offices and living rooms. The collection features approx. 50 pieces coming in different sizes. High variability of products without a shadow of a doubt hinders building a simulation model.

A system producing a selection of furniture, characterises with a set of features giving evidence of its non-rhythmicity (non-pipelined [1], [5]). There is no pre-determined production program, which would regulate time-wise the course of operations against a schedule. Production management requires from managers and production foremen knowledge, experience and intuition. Subsequently, both the irregularity of the production plan and application of different type random variables, proved particularly challenging to constructors of the simulation model.

Furniture is manufactured - up to the operation of dyeing - by a push system: completed pieces are stored at work in process storage. Further processing continues upon and in line with client orders. Starting from there, furniture is manufactured by a pull system.

The process can be divided into three main stages: chipboard and fibreboard processing, plywood processing and lumber processing. The process includes the following machining operations: cutting, milling, drilling, grinding and refining i.e. dyeing and varnishing, subsequently gluing and assembling.

In-process quality control takes place after each operation – machine operators are obliged to self-control. In-process transport uses industrial transport trolleys and pallets, both of which were adapted to the furniture production process.

## 3 Forecasted Sales Volumes

Sales volumes of new collection of cabinet furniture – i.e. production volume of finished products – were forecasted using two basic research methods:

- a quantitative method of similarity – imitation,
- a qualitative method.

The former forecasts aggregate sales volumes of products newly or lately launched to the market, based on sales figures for similar products launched earlier (qualitative method of similarity – imitation).

The later uses expert knowledge to evaluate expected sales (qualitative method), based on opinions and plans envisaged by company owners and marketing staff.

Precise future order figures remain unknown for individual pieces of furniture, thus computations were carried out for an arithmetic mean of material consumption across the entire batch of products, for a single piece. The data illustrates total material used in production, including: furniture body, drawers, solid wood doors, wooden strip doors and used auxiliary fixings: handles, guides, hinges, pegs etc. Based on the production process, opinions and experiences of the production manager, all machines and equipment required to manufacture cabinet furniture were established.

Due to ever-increasing labour costs and company's strive to assure high quality, the majority of technological operations should be automated using high-end production equipment. Such machines guarantee high: repeatability, precision, tolerances, processing speed. Moreover, they require less professional supervision, and can be operated by less qualified employees.

## 4 Production and Organisational Parameters

Due to technology-related imperfections, material defects, and finger trouble, defective pieces are being manufactured over the course of production, which could neither be sold nor repaired. Production plan should compensate for and accommodate rejects, so it could satisfy expected market pull. Those needs are included in the corrected production program [1], formulated as:

$$N = N_e(1 + b) \tag{1}$$

where: N – corrected production program, $N_e$ – forecasted sales volumes, b – target level of rejects.

The b coefficient, here 0.5%, was empirically derived based on previous production runs of furniture and pieces finished with veneer. Having substituted into the equation forecasted sales, it produced 5000 pieces from the collection of cabinet furniture. Derived results play a marginal role in the increase of material consumption. Such insignificant increase is caused by low level of rejects. It stems from high-precision machining, highly qualified staff and raw materials enabling repair of possible rejects.

The factor critical to efficiency and costs of production is the minimum batch size. "A batch is a group of homogeneous pieces manufactured by a workstation at a constant set-up time, uninterrupted for manufacturing other work pieces …" [6]. The aim of estimating that parameter is to avoid having to frequently changeover equipment and to maintain flexible and multivariate production. The method of changeover share [1] is one of the methods for computing that parameter, where the minimum batch size is produced using the formula:

$$S_{ek} = \frac{t_{pz}}{q \times t_j} \quad (2)$$

where: $t_{pz}$ – set-up time, q – empirically derived changeover loss factor, $t_j$ – time per unit.

Taken into account were technological operations characterised by the highest set-up time to time per unit ratio. The q parameter was attributed the 0.15 value for complicated, expensive parts, which contributed a large share of finished product costs. At $t_{pz}$ = 0,5 h and $t_j$ = 0,05 h the minimum batch size was 67 pieces.

The available working time per employee Fr enables determining actual, planned employee utilisation for production, factoring in downtimes [1].

$$F_r = F_{nr} \times \eta_{pr} \quad (3)$$

where: $F_{nr}$ – nominal working time per employee – h/year, $\eta_{pr}$ – coefficient factoring in employee downtimes.

## 5 Layout Planning

Distribution of workstation within workcells is crucial to organisation and efficiency of work. A random sequence of workstations increases the length of transportation routes and causes transportation flows to cross. Those problems intensify when blue collar workers are delegated to transport the pieces.

The Schmigalla method of triangles was selected to distribute the workstations [8], [9], [10]. The salient criterion behind this method was its high accuracy coupled with computing speed. However, its drawback is inability to include real distances between workstations: distances between neighbouring equipment are fixed and equal to the grid module – figure 1.

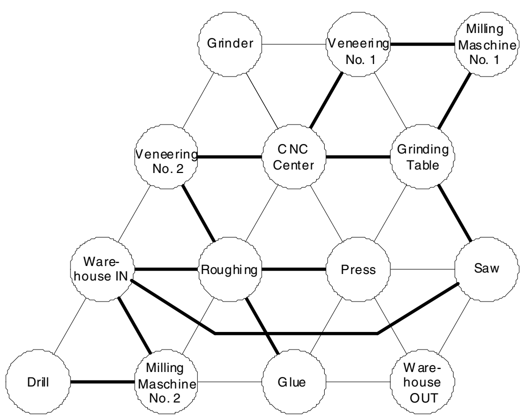


**Fig. 1.** General solution produced by the Schmigalla method of triangles – factory floor 1

The most important criterion is to minimise the distances between machine tools with the most frequent material flows.

Interdependencies and links between workstations and machines in the production process are illustrated by the modified depiction of the production process. Individual operations were allocated with machine tools and workstations.

## 6 Determining the Required Number of Machine Tools

Meeting monthly production plans would not be possible without adequate means of productions, which were determined in previous subsections. The extent, to which the plan was met, is also influenced by the number of machines, equipment and workstations. Workstation utilisation can serve as the starting parameter for determining analytically the number of required machine tools [1]. It informs about the time the machine takes to complete a production task. Global workstation utilisation $T_{gk}$ is produced by adding preparation time and lead time, which is time-specific:

$$T_{gk} = T_{pzk} + T_{jk} \tag{4}$$

where: $T_{gk}$ – global workstation utilisation k – of those workstations, $T_{pzk}$ – $t_{pz}$-related workstation utilisation, $T_{jk}$ – $t_j$-related workstation utilisation.

Bearing in mind that workstation utilisation is dictated by the production plan and batch size, that relation is illustrated with the following formula:

$$T_{gk} = \sum_k \left( n_i \times t_{pzij} + N_i \times t_{ij} \right) \tag{5}$$

where: $n_i$ – the number of homogenous piece batches, $t_{pzij}$ – „ij-th" operation's set-up time , $N_i$ – production program for the i-th product $t_{ji}$ – i-th operation's time per unit, k – type of homogenous workstations.

$$n_i = \frac{N_i}{S_i} \tag{6}$$

where: $S_i$ – batch size. Thus the required number of workstations per cell is:

$$L^o_{mk} = \frac{T_{gk}}{F_{jk}} \tag{7}$$

where: $L^o_{mk}$ – analytical number of workstations, $F_{jk}$ – available working time per given type of equipment.

## 7 Building a Simulation Model of the Planned Production System

Simulating the facility producing cabinet furniture is intended to help achieving the following goals:

- verify the feasibility of the production plan,
- verify the analytical number of machines and workplaces,

- determine the minimum number of pallets and industrial transport trolleys,
- verify and optimise planned supply and inventory of raw materials, semi-finished products and fixings,
- target bottlenecks in the production process and machines as well as workstations of highest utilisation.

In order to achieve the above-mentioned goals, actions have to be taken to build an adequate model of the process producing cabinet furniture. Because the time from system input to output is mostly influenced by the material flows and machining times at each workstation, and on the back of an ABC analysis a decision was reached, that the entire furniture collection would be represented by a small chest of drawers and a glass panel. They were selected based on the fact, that production of each requires almost all materials and semi-finished products.

Building a simulation model entails defining workstations, produced pieces, transportation routes and manufacturing resources. Then, modelled are production processes, deliveries, stoppage and shifts in the production system. Then, defined are variables, macros, arrays, sub-processes, distributions, attributes etc. Their combination should help to best represent the complex reality. A model combining features of discrete and continuous simulation achieved the desired result. The simulation model built in that manner was subject to simulation analysis. Subsequently, it was verified and validated as well.

## 8 The Experiment

Dry runs of the simulation experiment were being carried out since early stages of the model building, to find errors and verify it against reality on a regular basis. Figure 2 illustrates a part of described simulation model.

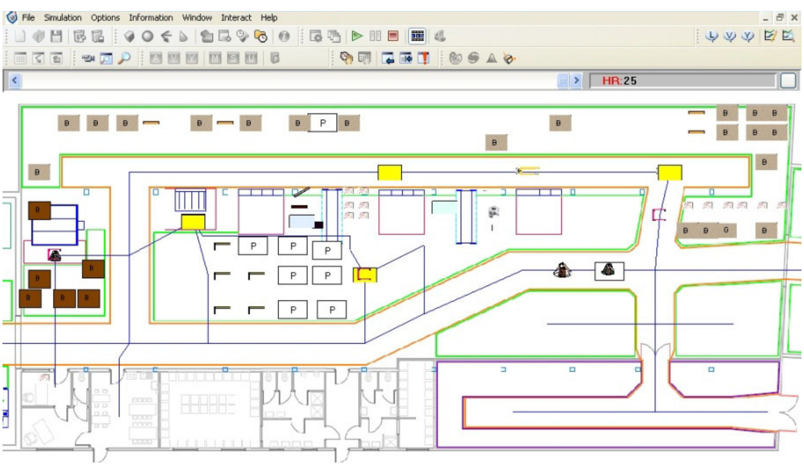


**Fig. 2.** A part of the model simulating the process producing cabinet furniture

The optimum number of workers was determined over two stages. At the first stage, workers were organised into groups by three factory floors and varnishers. Each worker had an assigned workstation, and could complete one's tasks within the designated work zone. Obtained data on utilisation of workstations and particular groups of workers allowed targeting utilisation hotspots. Bottlenecks – i.a. format effector, CNC machining centre, veneering machines for narrow pieces, painting line, floodbar – were all assigned with individual workers. That modification brought higher productivity and shortened the time required to produce planned selection of furniture.

At that stage the simulation was run iteratively. Additionally, after each simulation run results were analysed. Hence a desirable solution could be found, which was in line with experiment goals. The simulation time was defined as 2 working months (353 h) in order to obtained more repeatable results.

## 9 Analysis of the Results

Having configured the simulation model as discussed, the production plan was met in 99%. The first experiment goal i.e. "verify the feasibility of the production plan", was considered achieved.

The second goal i.e. "verify the analytical number of machines and workplaces", was achieved as well. The number of machines and workstations guarantees the production program to be met. After the results were analysed, there was no need to modify neither the number of workstations nor machines.

Based on curried out simulation, studied results and the experience in producing furniture, the number of blue collar workers came under scrutiny.

The proposed level of employment guarantees the facility to hit its target efficiency, and to keep employment-related costs low. The minimum number of industrial transport trolleys and pallets was approached similarly. Excessively low number of means of transport would jeopardise efficiency, by causing queues at workstations and by blocking machines, whereas their excess would generate additional costs and create the need for storing areas for redundant units. Based on the simulation model it was deduced, that assembly workstations show the highest utilisation percentage, caused by pieces awaiting other components. The time computed in that manner did not match the analytical working time.

Drawing on results, it can be concluded that there are production capacity reserves at factory floor number 1, which are currently constrained by the production program aligned with planned facility efficiency. Production efficiency at factory floor number 2 is constrained by the flow of semi-finished products from factory floor number 3 – furniture hold the assembly workstation long, waiting for components. Bottleneck at the factory floor number 3 is the printing line, which essentially constrains efficiency of the entire facility.

Further improvements of the simulation model could entail introduction of prioritised batches most needed at a specific point in time. Such solution would bring the model ever closer to an actual production system controlled by a production manager.

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