VERIFICATION AND VALIDATION OF THE PRODUCTION PROCESS MODEL

Sebastjan Zorzut, Vladimir Jovan

"Jožef Stefan" Institute, Ljubljana, Slovenia
E-mail: sebastjan.zorzut@ijs.si, vladimir.jovan@ijs.si

Abstract: This paper considers validation of a model of batch process for the production of polymer emulsions. The modelled process is complex with many sub-processes and activities. The key to effective modelling was clear definition of model purpose and consecutive simplification of the modelled process. Agreement of developed model with production process has been evaluated with the validation process. The emphasis was placed on time duration of production phases and on conformity of model behaviour with acquired knowledge about the production process properties.

Keywords: production process model, verification, validation.

1. INTRODUCTION

In the last few decades production enterprises have evolved in dynamic and complex systems which are usually producing broad assortment of products on different locations. Beside this the production has changed from planned production to order driven one. This brought new demands related to flexible production, increased production efficiency, fast respond to customer needs, and high and uniform quality of products and services. All these required the development of a new concept for enterprise management, which relies on an on-line estimation of the current state, more efficient decision-making and appropriate execution of decisions. One way of solving such problems is use of decision support systems for the production management that are based on production process model and simulation.

Production model is a computational representation of the structure, activities, processes, information, resources, people, behaviour, goals and constraints of production process. All modelled aspects of production have to be linked together in the way that represents the model as a whole (Dangelmaier *et al.*, 2005). With increasing size and complexity of the model its performance is decreasing, investments in model construction and efficient graphical user interface are increasing. To avoid these problems only important aspects of production should be modelled and the definition of the main goals of general production model is a step in this way. The main goals of production model are:

- Representation of production dynamics,
- Representation of the state of production process during simulation run,
- Production planning (number and quantity of product) and execution of scheduled jobs,
- Possibility to change manipulated (input) variables and production parameters (production rate, equipment failure, availability and quality of raw materials, etc.),
- Representation of cross correlations between manipulated and controlled model variables.

From the presented production model goals it can be seen that model is only a reproduction of reality because reasonable simplifications are necessary.

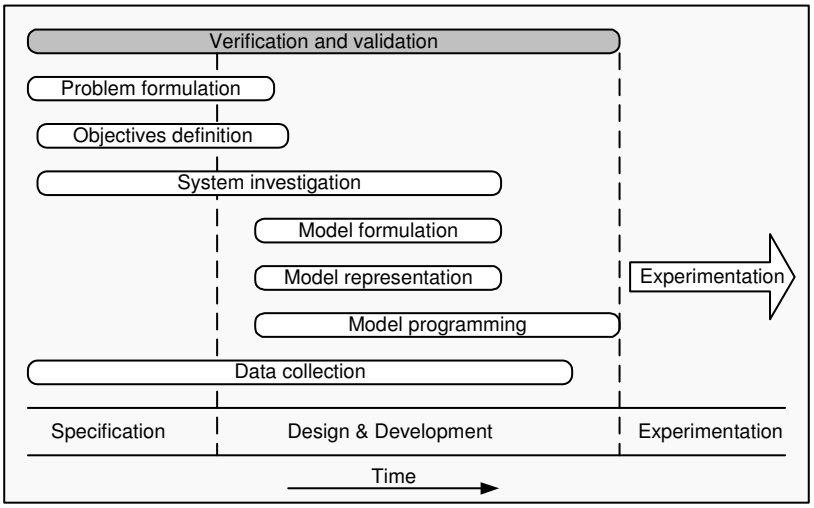

Fig. 1: Key stages of the model building process (Robertson, 2002).

Figure 1 represents key stages of the model building process. If we follow simple 'Garbage In, Garbage Out' theory than the 'Data collection' process is first crucial stage in model building process (Robertson, 2002). On the other hand the 'Verification and validation' process is of great importance because it gives us assurance that the model works reasonably. Verification concerns the consistency and accuracy of simulation programs compared with the associated mathematical models, while model validation concerns the level of agreement between mathematical descriptions and the real process under investigation (Hvala *et al.*, 2005; Murray-Smith, 1998). Validation of industrial process models is normally reduced to checking the agreement between outputs of the model and those of the real system. The reason for such reduction is in process complexity, insufficient knowledge about the process and a lack of proper data. When designing a model for engineering purpose the main issue in the design process is to design a model that is good for intended use.

Quality of the model can be judged with respect to model usefulness, model falseness and model plausibility. Usefulness tells whether a model satisfies its purpose, model falseness define agreement with measurements (data) and model plausibility expresses the conformity of the model with a priori knowledge about the process.

2. PRODUCTION PROCESS FOR POLYMERISATION

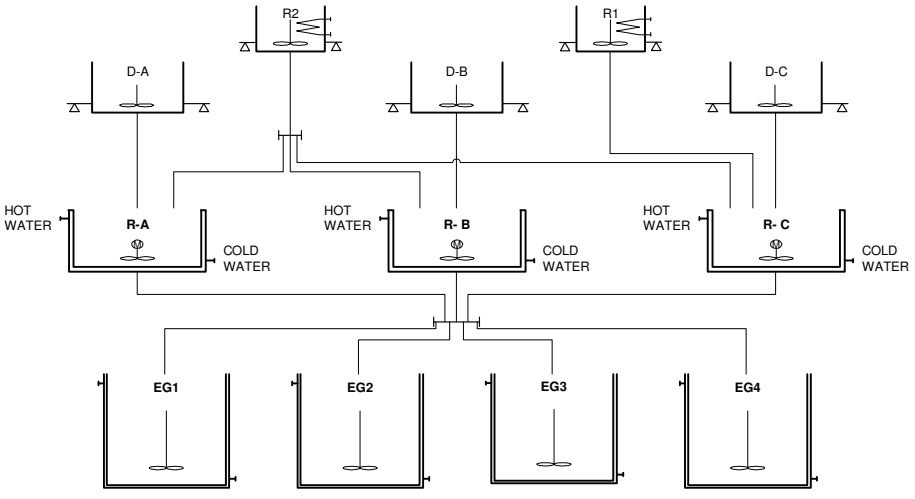

Fig. 2. Technological scheme of the production process for polymerisation.

Figure 2 represents the scheme of the production process for polymerisation. The main characteristic of the case study batch process is the production of products in several successive stages on different equipment where on each stage intermediate product appear and have to be used in successive stage in limited time period. In each step some physical action (heating, blending) or chemical reaction is taking place and has great influence on the final product's quality.

The construction of production process model was based on one-year data set for the main reactor R-A and assistant reactors R1 and R2. These data were not complete and insufficient for in detail process modelling. Additional knowledge about the production process has been obtained by interviewing the production manager and technologists. The behaviour patterns for production process are listed below.

With increased production rate, some of the phases are shortened what is indicated in slightly increased productivity, increased production costs and decreased product quality and also, vice versa, with decreased production rate, some of the phases are longer what is indicated in slightly decreased productivity, decreased production costs and increased product quality. Raw materials of higher quality are more expensive and the products that are made with such materials have better quality and are more expensive. If the quality of raw material is bad or the production process is interrupted (electricity loss, bad regulation) than the quality parameters of the product may not reach prescribed boundary and the product have to be recycled in next batches or eliminated.

The production process model was designed in the Matlab, Simulink and Stateflow simulation environment. The production process data, gathered during simulation run, is stored in the MS Access Database. This simulation environment was chosen because of its openness and because it involves statistical toolboxes that can be used for later production data analyses and for the presentation of results.

3. VALIDATION OF THE POLYMERISATION PRODUCTION MODEL

Before the construction of the production process model began modelling goals were defined and are listed below:

- Possibility of main production jobs scheduling and their automatic execution (preparation of raw materials, recipe execution, reactor cleaning, equalization of batches, etc.)
- Presentation of main phases in the process of polymerization (time phases, temperature profile, mass flow)
- Construction of sub-model for product quality estimation
- Evaluation of production process costs.
- Automatic production data storage in database that is available for on-line and off-line analyses

2.1 Validation of temperature profile and duration of time phases

Upper graph on figure 3 represents temperature profile for one batch execution in the main reactor and lower graph represents simulated temperature profile. Production process model does not contain exact mathematical model of the chemical reaction of polymerization because polymerization is complex process and construction of exact mathematical model would exceed the main production model goals. By observing temperature profile the main phases in the batch process can be defined (Figure 4).

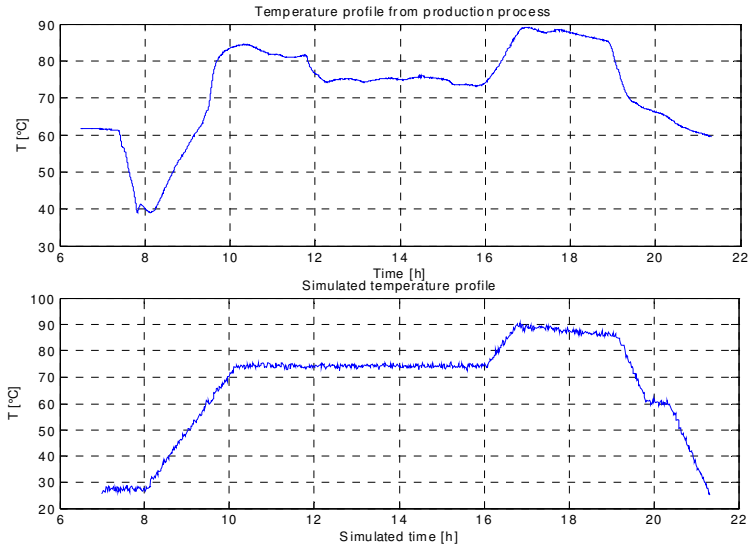

Fig. 3. Validation of the temperature profile for the production of polymer emulsion in reactor.

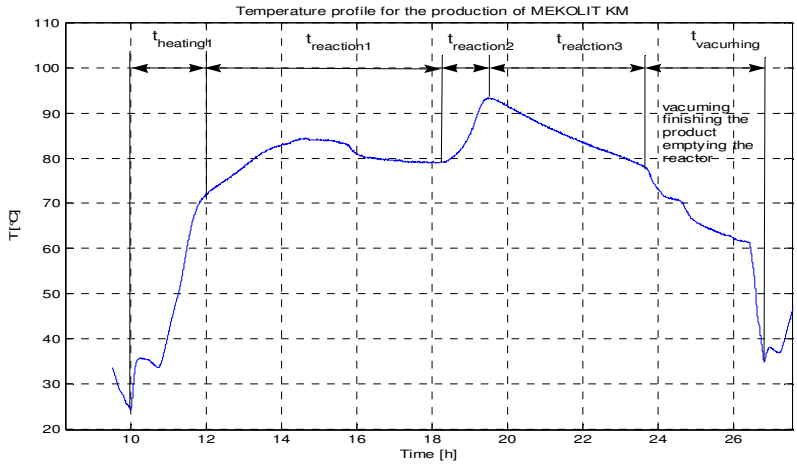

Fig. 4. Definition of main batch phases.

Table 1 represents estimated times for the batch phases which were obtained from the production process data. The results of simulation are listed below. The comparison of results shows that simulated batch size is on average for one hour shorter than the batch size we obtained from the production data. The results show that some corrections of model are needed.

Table 1. Estimated duration of batch and batch phases for three different types of products for production and simulated data.

Product	Sample/ All data	$T_{heating}$	$T_{reaction1}$	$T_{reaction2}$	$T_{reaction3}$	$T_{vacuming}$	T_{batch}
			Production data				
Mekolit KM	12/122	1.6 ± 0.4	6.7 ± 0.2	1.3 ± 0.25	1.3 ± 1	3.7 ± 0.6	14.6 ± 1
Mekolit H45	10/64	1.9 ± 0.3	6.8 ± 0.8	0.9 ± 0.2	2 ± 0.7	4.8 ± 1.6	15.7 ± 2.3
Mekolit HB	8/94	1.9 ± 0.4	6.3 ± 0.5	1 ± 0.3	2 ± 1.3	5.8 ± 3.7	14.4 ± 1.5
			Simulation results				
Mekolit KM	24						13.6 ± 0.6
Mekolit H45	24						13.4 ± 0.6
Mekolit HB	24						13.5 ± 0.5

1.1 Quality of the final products

The quality factor of the product is estimated from:

- The quality of the raw material,
- The number of stops during production process,
- The quality of temperature regulation in the reaction phase,
- Number of finished batches from last reactor cleaning,
- The production rate.

All these quality aspects are comprised in one normalised quality factor for each finished batch. Figure 5 represents dependence of product quality upon the quality of the raw materials. The results are in agreement with obtained knowledge about the process. Figure 6 represents temperature profile with significant temperature oscillations during the phase of reaction. Oscillations in temperature profile are appearing as a consequence of bad manual regulation of reaction temperature. The final quality of product is measured at the end of the equalization phase where two or three batches of the same product are mixed together in equalizer (bigger vessel) to obtain more uniform properties of the product. The batch with the temperature profile depicted on figure 6 was mixed with another one and the viscosity of the mixed product was 27500 mPas. Good product has viscosity in the range from 26000 to 34000 mPas, normally around 32000 mPas. Because of the lack of the data about the process more in detail investigation and validation was not performed. Described phenomenon is incorporated in the sub-model for assessment of the final product quality.

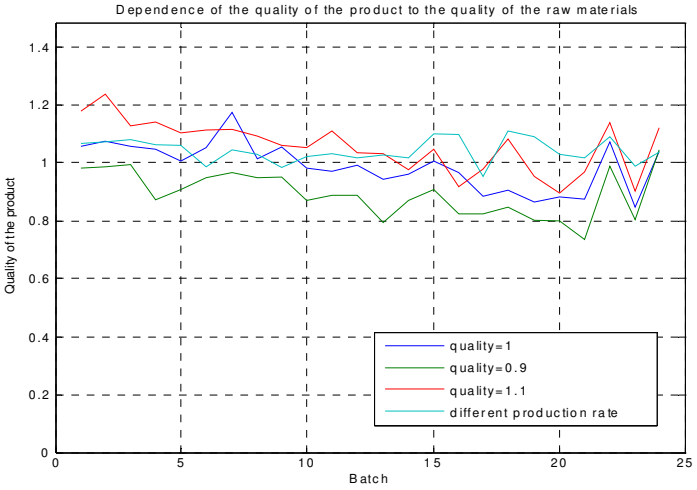

Fig. 5. Dependence of the quality of the product on the quality of raw materials.

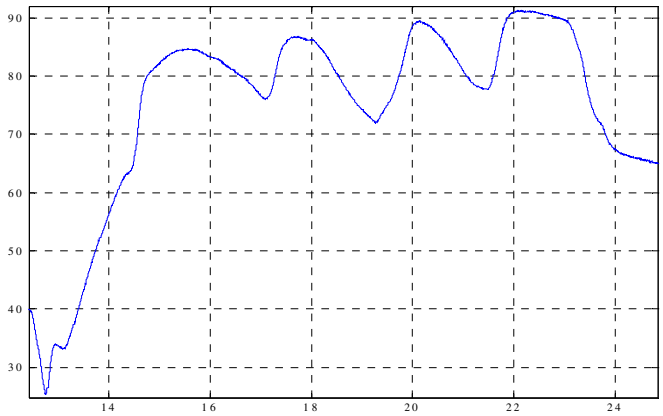

Fig. 6. Temperature profile with significant oscillations of temperature during the phase of reaction (from 16 to 22 hours).

CONCLUSIONS

This paper discusses why the production process modelling is useful for the production process managers and what the main goals of the production process models are. Beside the collection of good production process data the rigorous model verification and validation has to be performed to obtain useful production process model. There are three main validation features that are used for judging the quality of the model: model usefulness, model falseness and model plausibility. In this work the validation procedure was mostly based on the confirmation of the usefulness of the model and on the model plausibility; this is the conformity of the model with a priori knowledge about the process.
Designed model represents modelled production process aspects quite well, but some additional research should be done to improve it. The main reason lies in insufficient set of production process data that has to be increased.

REFERENCES

Dangelmaier, W., M. Fischer, J. Gausemeier, M. Grafe, C. Matysczok and B. Mueck (2005). Virtual and augmented reality support for discrete manufacturing system simulation. *Computers in Industry*, v**ol. 56**, pp. 371-383.

Gien, D. and S. Jacqmart (2005). Design and simulation of manufacturing systems facing imperfectly defined information. *Simulation modelling, Practice and Theory.* **vol.13**, pp. 465-485.

Hvala, N., S. Strčnik, D. Šel and B. Banko (2005). Influenceof model validation on proper selection of propcess models – an industrial case study, *Computers &Chemical Engineering*, **vol. 29**, pp. 1507-1522.

Karba, R. (1999). *Modeliranje procesov.* University of Ljubljana, Ljubljana.

Murray-Smith, D. J. (1998). Methods for the external validation of continuous system simulation models; A review. *Mathematical and Computer Modelling of Dynamical Systems,* **vol 4**, pp. 5-31.

Robertson, N. and T. Perera (2002). Automated data collection for simulation?. *Simulation Practice and Theory*, **vol. 9**, pp 349-364.

Turban, E. and J. E. Aronson (2001). *Decision support systems and intelligent systems*, 6th ed. Prentice- Hall, Inc., Upper Saddle River, New Jersey.