PRODUCTION PROCESS MODELING AND PLANNING WIH SIMULATION METHOD, MOUNTING PROCESS OPTIMISATION

János, Jósvai[(a)]

[(a)] Széchenyi István University, Professorship for Material Sciences and Automobile Production

[(a)]josvai@sze.hu

ABSTRACT

The paper focuses on the establishment of the production program using simulation technology in a structure, where several products and high amount of variants per product are produced. The topic of the paper addresses the discrete event simulation technology which is used to model the material flow and the manufacturing processes in the production area. This paper would like to show and describe the modelling steps of a complex production system with a lot of products and three different line parts, which are connected with buffers.

Keywords: discrete event simulation, production planning, scheduling, genetic algorithm.

1. INTRODUCTION

Today the production tasks have got a very complex planning process. This is caused by the high amount of variants of one product. We can speak here about a vehicle or engine production. Most of the production structures are established as lines and have the task to produce several product types and several variants of the products. This means a very difficult planning and execution of production. The establishment of the production program is complicated, the times of work tasks are different, and the material delivery on the line and the inventory has to be taken into consideration, too.

The production planning has several goals, some of them are:

- the scheduling of the tasks to ensure delivery accuracy,
- to determine the lot size of product batches,
- to ensure smoothed workloads at the workplaces,
- to determine the buffer sizes in the production line,
- to handle the lead times – depending on the complexities of the products,
- to determine and handle the bottlenecks – can change with the system dynamic behaviour, etc.

Mostly the production system is not configured as a whole integrated line. To plan a system, which is separated by buffers between two or perhaps three main lines, has a lot of influential parameters. The main question is either to plan these part lines together, or to plan the production on the lines separately because of some reasons. For example if the mean cycle time is different on the lines then this could be a reason to make the planning separately.

These properties show the complexity of this field. The influence parameters are not only a large number, but the combination of these parameters causes a lot of option and problems to solve. In practice there is not enough time to fulfil the mathematical analysis manually, even if the right behaviour functions are ready to use.

There is another possible method which is useful to plan such complex systems. The modelling and dynamic simulation are able to answer most of the questions, and show the time dependent behaviour of the concerned production system. This modelling technique is the time discrete event controlled simulation.

This paper would like to show and describe the modelling steps of a complex production system with a lot of products and three different line parts, which are connected with buffers.

2. PROBLEM DEFINITION

The considered production system was an engine production line with three separated line parts. These were connected by buffers. The simulation model and study had to investigate, how the line output, usage statistics changes with the different production sequences.

The product mix changes time to time, this had many influences and plus tasks while the planning of the model. We will see how it works when a product has to be changed in the model. This could mean for instance the end of production of one product type, or new type has to be launched on the line. This data handling procedure and the amount of handled data causes a great model size.

The modelling had to consider, that a lot of flexible parameters were needed to ensure enough planning roam. Lot size determination had to be fixed, that the actual pre-planned production program could be changed and set on new levels by the simulation.

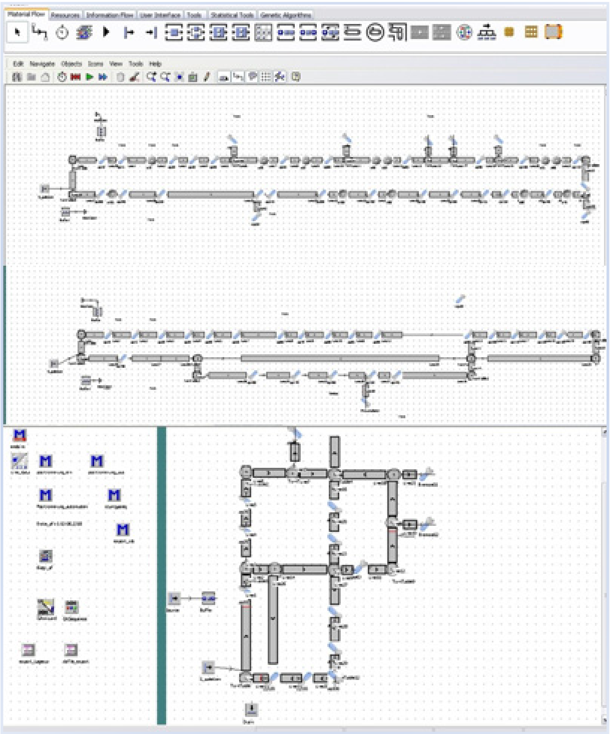

Figure 1: Simulation models of the line parts

Another main goal was to determine the computational achievable "right" production sequence. The hand-made production program should be optimized by the simulation. A genetic evolution algorithm was used to solve this difficult problem with a large search area.

For planning the line balancing there was needed an option, to ensure handling functionality, when workload change has to be planned. The mounting tasks can be assigned to various places in the line. This means that the variation of workloads at the stations in the line has a large number. The line balancing has the goal to put the tasks in the right order after each other and approximately hold the average cycle time at one station. In case of production changes - product type, produced volume, technological, and production base time – there was a need to pre-calculate the changed line behaviour. There are different changes in the task load of the stations, we make such influences which determine the throughput, working portion of the stations and gives different optimal sequence combination of products.

3. SIMULATION AND SCHEDULING

There are similarities and differences as well between general research- and simulation case studies. Simulation case studies are typically focused on finding answers to questions through simulation-based experiments. In the social science arena, experimentation is considered to be a distinct research method separate from the case study. Social science case study researchers use observation, data collection, and analysis to try to develop theories that explain social phenomena and behaviours. Simulation analysts use observation and data collection to develop "as-is" models of manufacturing systems, facilities, and organizations. The analysts test their theories and modifications to those models through simulation experiments using collected data as inputs. Data sets may be used to exercise both "as-is" and "to-be" simulation models. Data sets may also be fabricated to represent possible future "to-be" conditions, e.g., forecast workloads for a factory. (McLean 2003.).

In (Standridge 2000.), teaching simulation through the use of manufacturing case studies is discussed. He organizes case studies into four modules:

- Basic manufacturing systems organizations, such as work stations, production lines, and job shops.
- System operating strategies including pull (just-in-time) versus push operations, flexible manufacturing, cellular manufacturing, and complete automation.
- Material handling mechanisms such as conveyors, automated guided vehicle systems, and automated storage/retrieval systems.
- Supply chain management including automated inventory management, logistics, and multiple locations for inventory.

Simulation case study problem formulations and objectives define the reasons for performing the simulation. Some examples of study objectives might be to evaluate the best site for a new plant, create a better layout for an existing facility, determine the impact of a proposed new machine on shop production capacity, or evaluate alternative scheduling algorithms. (McLean 2003.)

Simulation textbooks typically recommend that a ten to twelve step process be followed in the development of simulation case studies. The recommended approach usually involves the following steps: (1) problem formulation, (2) setting of objectives and overall project plan, (3) model conceptualization, (4) data collection, (5) model translation into computerized format, (6) code verification, (7) model validation, (8) design of experiments to be run, (9) production runs and analysis, (10) documentation and reporting, and (11) implementation (Banks et al. 1998).

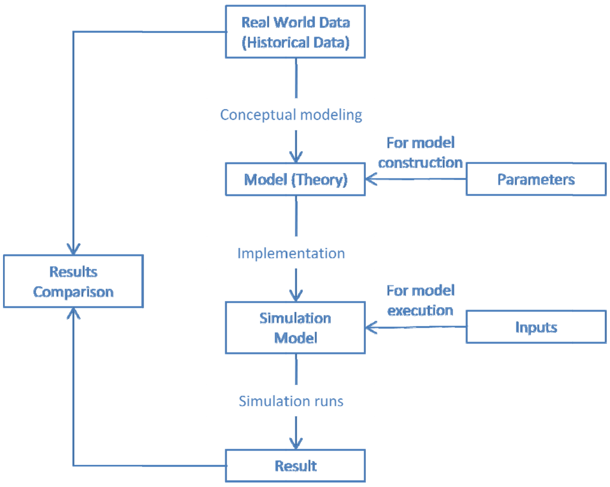

Figure 2: Simulation modelling and executing steps (Shao 2008.)

What is manufacturing simulation? In The Handbook of Simulation, Jerry Banks defines simulation as:

"…the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operational characteristics of the real system that is represented. Simulation is an indispensable problem-solving methodology for the solution of many real-world problems. Simulation is used to describe and analyze the behaviour of a system, ask what-if questions about the real system, and aid in the design of real systems. Both existing and conceptual systems can be modelled with simulation." (Banks 1998.)

Manufacturing simulation focuses on modelling the behaviour of manufacturing organizations, processes, and systems. Organizations, processes and systems include supply chains, as well as people, machines, tools, and information systems. For example, manufacturing simulation can be used to:

- Model "as-is" and "to-be" manufacturing and support operations from the supply chain level down to the shop floor
- Evaluate the manufacturability of new product designs
- Support the development and validation of process data for new products
- Assist in the engineering of new production systems and processes
- Evaluate their impact on overall business performance
- Evaluate resource allocation and scheduling alternatives
- Analyze layouts and flow of materials within production areas, lines, and workstations
- Perform capacity planning analyses
- Determine production and material handling resource requirements
- Train production and support staff on systems and processes
- Develop metrics to allow the comparison of predicted performance against "best in class" benchmarks to support continuous improvement of manufacturing operations (McLean 2002.)

3.1. Genetic Algorithms

An implementation of a genetic algorithm begins with a population of (typically random) chromosomes. One then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes which represent a better solution to the target problem are given more chances to reproduce than those chromosomes which are poorer solutions.

The goodness of a solution is typically defined with respect to the current population. This particular description of a genetic algorithm is intentionally abstract because in some sense, the term genetic algorithm has two meanings. In a strict interpretation, the genetic algorithm refers to a model introduced and investigated by John Holland (1975) and by students of Holland (e.g., DeJong, 1975). It is still the case that most of the existing theory for genetic algorithms applies either solely or primarily to the model introduced by Holland, as well as variations on what will be referred to in this paper as the canonical genetic algorithm. Recent theoretical advances in modelling genetic algorithms also apply primarily to the canonical genetic algorithm (Vose, 1993).

In a broader usage of the term, a genetic algorithm is any population-based model that uses selection and recombination operators to generate new sample points in a search space. Many genetic algorithm models have been introduced by researchers largely working from an experimental perspective. Many of these researchers are application oriented and are typically interested in genetic algorithms as optimization tools. (Whitley 1995)

The use of genetic algorithms requires five components:

1. A way of encoding solutions to the problem - fixed length string of symbols.
2. An evaluation function that returns a rating for each solution.
3. A way of initializing the population of solutions.
4. Operators that may be applied to parents when they reproduce to alter their genetic composition such as crossover (i.e. exchanging a randomly selected segment between parents), mutation (i.e. gene modification), and other domain specific operators.
5. Parameter setting for the algorithm, the operators, and so forth. (Jones 1996)

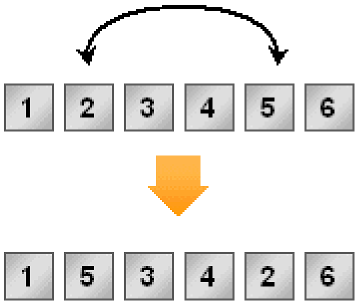

Figure 3: Mutation for a sequential task (Tecnomatix 2008)

The simulation model uses the genetic algorithm for a sequential task. The logic to produce a new population is shown on Figure 3. Several test runs were made in order to identify the right settings of the algorithm. The statistical operators were configured after real life data test runs, to make the algorithm converge faster. The runs showed at last, that the population size has to be set to 10 and the simulated generations' numbers were 20. This was a main question among others, because the simulation running time was limited up to one and half an hour.

3.2. Scheduling

Scheduling has been defined as the art of assigning resources to tasks in order to insure the termination of these tasks in a reasonable amount of time. The general problem is to find a sequence, in which the jobs (e.g., a basic task) pass between the resources (e.g., machines), which is a feasible schedule, and optimal with respect to some performance criterion. A functional classification scheme categorizes problems using the following dimensions:

1. Requirement generation,
2. Processing complexity,
3. Scheduling criteria,
4. Parameter variability,
5. Scheduling environment.

Based on requirements generation, a manufacturing shop can be classified as an open shop or a closed shop. An open shop is "build to order", and no inventory is stocked. In a closed shop the orders are filled from existing inventory.

Processing complexity refers to the number of processing steps and workstations associated with the production process. This dimension can be decomposed further as follows:

1. One stage, one processor
2. One stage, multiple processors,
3. Multistage, flow shop,
4. Multistage, job shop.

The one stage, one processor and one stage, multiple processors problems require one processing step that must be performed on a single resource or multiple resources respectively.

In the multistage, flow shop problem each job consists of several tasks, which require processing by distinct resources; but there is a common route for all jobs.

Finally, in the multistage, job shop situation, alternative resource sets and routes can be chosen, possibly for the same job, allowing the production of different part types.

The third dimension, scheduling criteria, states the desired objectives to be met. They are numerous, complex, and often conflicting. Some commonly used scheduling criteria include the following:

1. Minimize total tardiness,
2. Minimize the number of late jobs,
3. Maximize system/resource utilization,
4. Minimize in-process inventory,
5. Balance resource usage,
6. Maximize production rate.

The fourth dimension, parameters variability, indicates the degree of uncertainty of the various parameters of the scheduling problem. If the degree of uncertainty is insignificant, the scheduling problem could be called deterministic. For example, the expected processing time is six hours, and the variance is one minute. Otherwise, the scheduling problem could be called stochastic.

The last dimension, scheduling environment, defined the scheduling problem as static or dynamic. Scheduling problems in which the number of jobs to be considered and their ready times are available are called static. On the other hand, scheduling problems in which the number of jobs and related characteristics change over time are called dynamic. (Jones 1998)

According to the previous classification the modelled system can be classified as:

- Open shop
- Multistage, flow shop
- The processing times are treated as deterministic
- Job characteristic is dynamic

4. MODELING AND SIMULATION RUNS

This model is a planning tool which is able to answer several questions of the complex production planning. The creation of the model followed the physical parameters of the real system. The iteration process of the modelling was difficult because it had to handle the product mounting time. The mounting times were gained from the real production system, but the collection and filtering was made inside the simulation model, to prepare the data ready for production inside the simulation.

4.1. Model building

Plant Simulation provides a number of predefined objects for simulating the material flow and logic in a manufacturing environment. There are five types of main object groups from Plant Simulation:

- **Material flow objects**: Objects used to represent stationary processes and resources that process moving objects.
- **Moving objects**: Objects used to represent mobile material, people and vehicles in the simulation model and that are processed by material flow objects. Moving objects are more commonly referred to as MUs.
- **Information flow objects**: Objects used to record information and distribute information among objects in the model.
- **Control objects**: Objects inherently necessary for controlling the logic and functionality of the simulation model.
- **Display and User interface objects**: Objects used to display and communicate information to the user and to prompt the user to provide inputs at any time during a simulation run.

SimTalk is the programming language of Plant Simulation; it was specifically developed for application in Plant Simulation models. The Method objects are used to dynamically control and manipulate models. SimTalk programs are written inside method objects and executed every time the method is called during a simulation run.

The logical structure of the model was created on basis of Plant Simulation provided level structure. So it was a “simple” planning step to divide the model into specified functional levels. Different folders and frames are used in order to implement the line structure, the data handling for manufacturing programs and the basic data for the manufactured products. However, the scheduling of the production program has its own separate level.

The data input and output of the model work with the Excel Interface of Plant Simulation. Users can manipulate the parameter settings and see the results of the simulation runs on this easy way independently from Plant Simulation – no special simulation knowledge is asked.

User interface has been implemented for the model in order to handle the simulation model and the several built-in functions, which are to test the simulated line behaviour. This handling tool, which is shown on Figure 4, helps the manufacturing engineer to plan tasks and solve rescheduling problems on the line.

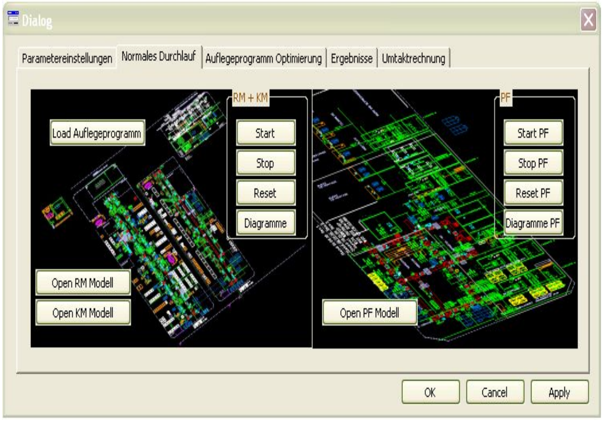

Figure 4: Simulation models of the line parts

4.2. Model validation and verification

Validation and verification of the model is formulated as follows:

Model validation: process of demonstrating that a model and its behaviour are suitable representations of the real system and its behaviour w.r.t. intended purpose of model application.

Model verification: process of demonstrating that a model is correctly represented and was transformed correctly from one representation form into another, w.r.t. transformation and representation rules, requirements, and constraints. (Rabe 2008)

There are many techniques to validate and verify the model. The physical environment has high influence on the method which is adaptable to verify and validate the model. In this particular case together with experts from the enterprise a structured walkthrough was possible to use for this system model. For special throughput data of the line it was possible to make historical data validation.

4.3. Simulation runs and results

The regular use of the simulation was secured with the several setting function, among them the line speed, the different value setting of the palettes on the separated lines, lot size limitations, and daily production program definition function.

With the simulation model it is possible to gain information about the system elements, for example how they are working in time, their occupation and empty time – waiting, etc. (Figure 5). Not only the elements can be obtained, but also the different working scenarios of the planned system load are about to be tested.

The simulation test runs with manufacturing data brought the following most important results:

- The simulation model is capable for everyday usage.
- To bring more efficiency 2-3 days are to be handled with the rescheduling algorithm.
- It is able to reduce lead time with 1-10%, this depends on product mixtures.

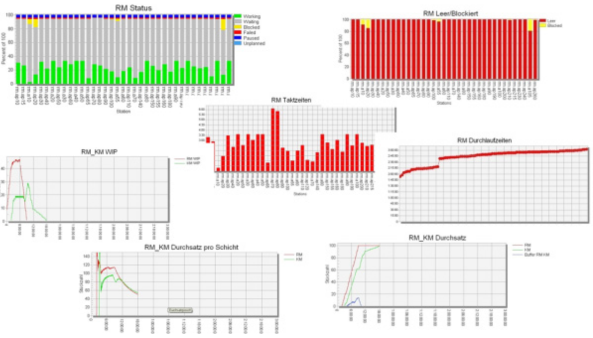

Figure 5: Evaluation diagrams of the modelled production system

The simulation model building and the test runs at the enterprise show that the simulation technique is suitable for the manufacturing planning. The model and the line connection mean in this case that the real data application could be made much better. This depends on both sides; the model structure has to be modified if the physical system is able to give over real time data. In this matter the rescheduling and the simulation tool could be not only the planning tool, but also it would be the production control tool.

5. CONCLUSIONS

The paper focuses on the applicability of simulation technology in production schedule of a production oriented firm and on the possibilities of planning and controlling the manufacturing process with simulation method in the automotive industry. A simulation model for manufacturing line planning and its establishment process is presented.

The paper discusses the questions of simulation and scheduling problems, these questions help to classify the physical system and the simulated problem.

Model validation and verification are taken into consideration after the presentation of the implemented genetic algorithm for production sequence optimization.

The most important benefits were highlighted based on the results of simulation runs.

REFERENCES

Edited by: Jerry Banks, 1998. *Handbook of simulation, Principles, Methodology, Advances, Application and Practice*. Atlanta:JohnWiley & Sons Inc.

Gudehus T., 1999. *Logistik Grundlagen Strategien Anwendungen*. Berlin : Springer.

Hopp, W. J., Spearman, M.L., 2008. *Factory Physics*. Boston : McGraw-Hill.

Jones, A., Riddick, F., Rabelo, L., 1996. *Development of a Predictive-Reactive Scheduler Using Genetic Algorithms and Simulation-based Scheduling Software*. National Institute of Standards and Technology, Ohio University. Available from: http://www.nist.gov [accessed 18 May 2009]

Jones, A., Rabelo, L., 1998. *Survey of Job Shop Scheduling Techniques*, National Institute of Standards and Technology, California Polytechnic State University. Available from: http://www.nist.gov [accessed 18 May 2009]

Kuhn A., Tempelmeier H., Arnold D., Isermann H., 2002. *Handbuch Logistik*. Berlin : Springer.

Rabe, M., Spieckermann, S., Wenzel, S., 2008. *Verifikation und Validierung für die Simulation in Produktion und Logistik*, Berlin:Springer.

McLean, C., Leong, S., 2002. *The Role of Simulation in Strategic Manufacturing*. Manufacturing Simulation and Modeling Group National Institute of Standards and Technology. Available from: http://www.nist.gov [accessed 18 May 2009]

McLean, C., Shao, G., 2003. *Generic Case Studies for Manufacturing Simulation Applications*. National Institute of Standards and Technology. Available from: http://www.nist.gov [accessed 18 May 2009]

Pfeiffer, A., 2007. *Novel Methods for Decision Support in Production Planning and Control*. Thesis (PhD). Budapest University of Technology and Economics.

Schönsleben, P., 2007. *Integrales Logistikmanagement, Operations and Supply Chain Management in umfassenden Wertschöpfungsnetzwerken*. Berlin : Springer.

Shao, G., McLean, C., Brodsky, A., Amman, P., 2008. *Parameter Validation Using Constraint Optimization for Modeling and Simulation*. Manufacturing Simulation and Modeling Group, National Institute of Standards and Technology. Available from: http://www.nist.gov [accessed 18 May 2009]

Standridge, C., 2000. Teaching Simulation Using Case Studies. *Proceedings of the 32nd on Winter Simulation Conference*, pp. 1630-1634. December 10-13, Orlando, (Florida, USA).

Tecnomatix Technologies Ltd., 2006. *Tecnomatix Plant Simulation Help*.

Vollmann, T.E., Berry, W. L., Whybark, D.C., Jacobs, F.R., 2005. *Manufacturing Planning and Control Systems for Supply Chain Management*. New York : McGraw-Hill.

Whitley, D., 1995. A Genetic Algorithm Tutorial. *Statistics and Computing* Vol. 4:65-85.

AUTHORS BIOGRAPHY

János Jósvai is working at the Széchenyi István University, Győr, Hungary. He is a PhD candidate, his field is manufacturing planning and simulation methods. He has several year experiences in material flow simulation of manufacturing systems and in production process planning. In the field of research and development he spent significant time aboard with international cooperation in matter of digital factory.