OPTIMIZATION OF PAINT SHOP DEPARTMENT USING DISCRETE EVENT SIMULATION

Pavel Raska[(a)], Zdenek Ulrych[(b)]

[(a)] Department of Industrial Engineering - Faculty of Mechanical Engineering, University of West Bohemia, Univerzitni 22, 306 14 Pilsen
[(b)] Department of Industrial Engineering - Faculty of Mechanical Engineering, University of West Bohemia, Univerzitni 22, 306 14 Pilsen

[(a)]praska@kpv.zcu.cz, [(b)] ulrychz@kpv.zcu.cz,

ABSTRACT
The paper deals with a realistic simulation case study focused on the optimization of the production processes of products staining. The simulation study is focused on the validation of various options for increasing the total production quantity of the production system. The goal of the simulation study is to validate the planned investment and also verify other possible measures leading to an overall increase of the production of the paint shop department.

Keywords: optimization, paint shop, discrete event simulation, simulation model

1. INTRODUCTION

Using simulation in the optimization of the production processes is well known (Boysen, Scholl, and Wopperer, 2012; Frank, Laroque, and Uhlig, 2013; Gopalakrishnan, Skoogh, and Laroque, 2014; Jahangirian, Eldabi, Naseer, Stergioulas, and Young, 2010; Longo, Massei, and Nicoletti, 2012; Rabbani, Ahmad, Baladi, and Khan, 2013; Scholl, Laroque, and Weigert, 2014; Su, Fu, Tan, and Hu, 2010). It is possible to achieve various levels of performance of the whole system by choosing various configurations of the production systems (Ulrych, Votava, Raska, and Horejsi, 2013). Simulation can verify which measures should be implemented in a given company with a given structure and production volume.
The paper deals with the modelling and simulation of a paint shop. Designing a paint shop is usually difficult, if we need to ensure its maximum throughput. Using simulation models to describe paint shop optimization problems is covered in many papers, e.g. (Arinez, Biller, and Meerkov, 2010; Cheng and Park, 2010; Lemessi, Schulze, and Rehbein, 2011; Lemessi, Rehbein, and Rehn, WSC 2012, 2012; Li, Blumenfeld, and Marin, 2007).
The Department of Industrial Engineering and Management at the University of West Bohemia has been dealing with discrete event simulation and optimization of production processes for several years. Various results of simulation studies have been published e.g. (Horejsi, Horejsi, Latif, and Ulrych, 2011; Raska and Ulrych, EMSS 2014, 2014; Votava, Ulrych, Edl, Korecky, and Trkovsky, 2008).
The second area of interest we are intensively engaged in, is the use of various algorithms applicable to optimization of the discrete simulation, e.g. (Raska and Ulrych, 2015).

2. SIMULATION MODEL DESCRIPTION

This paper deals with the optimization of a paint shop department where various types of products of different materials are dyed. The products range in size from tens of centimetres to approximately four meters long.
The modelled production system consists of a series of workplaces. Transportation between workplaces is performed by chains strung on defined paths. The chains designed for towing a girder are approximately two kilometres long. Chains are used for conveying the hanging girder, which carries the products. Each type of product passes through different workplaces of the paint shop department according to its painting program. There are dozens of painting programs.

2.1. Workplaces in the Paint shop Department

Basic modelled painting workplaces are:

- Hanging on girder - the products are hung on the girder. Number of hung products depends on the size of the product and product type. Selecting a painting program determines the product path, sequence of workplaces and processing times. Furthermore, the chemical preparation program has to be selected
- Sandblasting – this workplace is only used for some of the painting programs. Sandblasting time depends mainly on the size and number of parts
- Chemical preparation - products pass through several successive chemical preparation chambers. The processing times in different chambers depend on the selected chemical preparations program (some of products just pass through the chamber)

- Drying furnace - drying time depends on the selected painting program. All the products hung on more girders are dried according to the maximum capacity of the drying furnace
- Paint booths – there are several paint booths at the workplace. Each paint booth applies a specific powder coating (base coat, second and another layer, or colour variants). It is possible to ensure partial interchangeability of the individual paint booths.
- Kiln - firing time depends on the selected painting program. All the products hung on more girders are fired according to the maximum capacity of the kiln. Girders in the kiln cannot overtake each other.
- Cooling – there must be some time for cooling the products after the firing phase. The container for this purpose is located behind the kiln.
- Removing - The last workplace in the circuit is where the product is removed. Products are removed from the girder and the girder is sent back to the container, which is located in front of the workplace where products are hung on the girder.

The basic scheme of material flow of the paint shop workplaces is shown in Figure 1. Green arrows represent input/output of material to/from the paint shop department workplaces. Before each workplace is a buffer defined by its maximum capacity.

Depending on the painting program, the girder can pass through some workplaces several times.

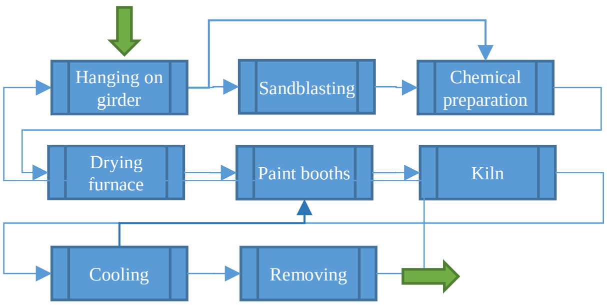

Figure 1: Material Flow of the Paint Shop Workplaces

3. BUILT SIMULATION MODEL

The simulation model was built by Plant Simulation software version 12.1. It was created hierarchically using the principles of object-oriented programming. The following figure shows an example of a class of sandblasting workplace where there are two sandblasting chambers - Figure 2. Thus it is possible to sandblast the two girders at once. This sample class is used in the model several times depending on the required number of this workplace in the system that is being modelled.

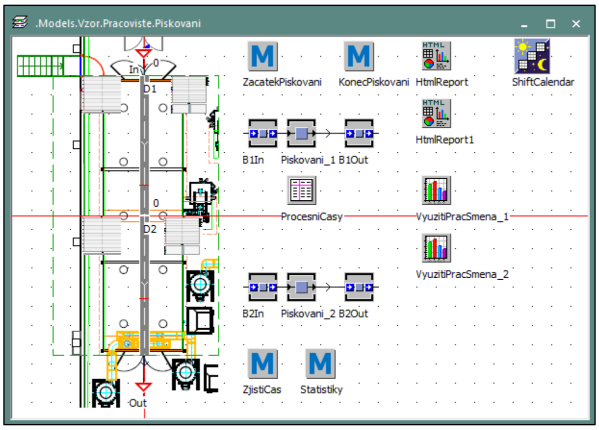

Figure 2: Sandblasting Workplace Class

The most difficult class model used in this model is a class representing a section of the path of girder - Figure 3. This sample class path is inherited from the "Track" class that is used for modelling a path for e.g. forklifts or Automated Guided Vehicles. We can see only a small part of the defined user attributes and the programming method, which assures the behaviour of the girder in the circuit according to the set attributes of the selected path and according to the selected painting program of the girder. Built-in user-defined methods can provide:

- Stopper control - whether the girder stops e.g. when reaching the maximum capacity of the next section; whether a girder can start moving - free capacity of the next section; defined rules of the crossroad (FIFO, according to priority, etc.); the time needed to hook a girder on a hook located on a chain
- Girder rotation – girder can keep going longitudinally or transversely (usually in the magazine)
- Collecting statistics - especially statistics on blocking path
- Controlling of intersections - which way a girder will go
- etc.

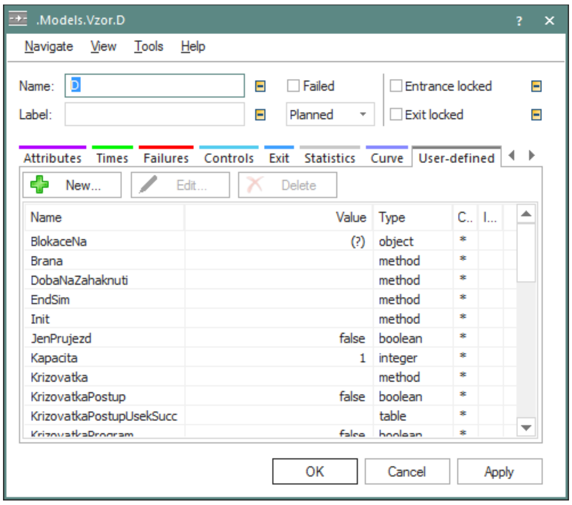

Figure 3: Class for Modelling Path

The following figure shows only a small part of the simulated system, including the defined animations - Figure 4. The animation shows the following attributes:

- The girder - which type of product is hung on the girder (colour); the size of hung products (size of coloured rectangle)
- Stopper on the path - the chart containing the percentage of blocking on the girder (girder cannot continue moving on defined path);
- Buffers - histogram of buffer occupation
- Checkboxes - used for setting a combination of simulated variants

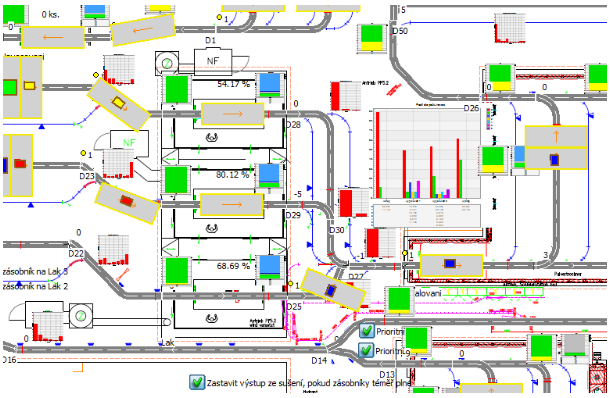

Figure 4: Animation of Simulated System

A detailed description of the simulation model and the values of the input parameters cannot be given due to the legal restrictions of the contract.

4. SIMULATION OF PRODUCTION OPTIMIZATION

The goal of this study was to find the appropriate measures to increase the production flow in the paint shop. Measures to be simulated can be defined as follows:

- Resize selected buffers before workplace (estimated investment)
- Possible changes to the path (planned investment)
- Logic of intersection control (path priority)
- Logic of possible path change according to current occupancy lanes on the path
- Change the logic of defining the path according to the painting program
- Change the logic of selection of paint booths according to current buffers occupancy located before paint booth than the selection of paint booths specified in the painting program.

4.1. Modelled measures

The goal of this simulation study was to find ways to increase the flow of products through the paint shop department. We tested a number of possible measures, which could lead to an increased flow rate:

- Resize selected buffers before workplaces - identification of possible buffers where capacity can be increased, considering their area. These measures focus on changing the positions of the stoppers and the control software of the product path. The product path remains the same. Using these measures, it is possible to place more girders between the stoppers instead of one girder
- Possible changes to the path - the influence of planned investment in the creation of new transport paths connecting some workplaces. It is possible to shorten the length of the transport paths for some painting programmes
- Logic of intersection control (path priority) – testing the control system of selected intersections where multiple paths from the various workplaces are merged into one path. We tested the effects of the advantages of individual input paths. Tested variants were:
    - FIFO Method – right of way of first girder to arrive at an intersection
    - Priority path - each path received a priority for entry of the girder into an intersection
- Logic of possible path change according to current occupancy of lanes on the path - there were a number of duplicate workplaces with various transport paths. The painting programme clearly identifies the target workplace. We tested the control of sending the girder to a duplicate workplace if the buffer before the workplace specified by the painting programme is full (the buffer of the duplicate workplace cannot also be full)
- Change the logic of defining the path according to the painting programme – we tested the impact of a predefined path change on the painting programme. We mainly focused on an alternative workplace specified in the painting programme and the change of the selected path to this workplace
- Possible change of the logic of paint booth selection according to the fullness of the buffer located in front of a paint booth instead of definition in the painting programme – some paint booths have a partial interchangeability. We tested the impact on overall production of the selection of an alternative paint booth if the buffer in front of a paint booth is full (the buffer of an alternative paint booth is partially filled)

We tested other measures such as the impact of the shift model on individual workplaces, impact of the production structure of products on the overall production capacity, etc.

4.2. Conclusions from the Simulation Model

A simulation model was validated on the historical data from a company. We validated whether the model showed the same outputs as the already implemented production. We set the following parameters for validation of the model:

- The structure and the volume of products entering the workplace at a defined time according to the data from the information system
- Setting workplaces
  - The shift model
  - Times of operation
  - Number of duplicate workplaces
- The logic of control of transport paths

A pre-defined standardized HTML report of each simulated variant is automatically exported at the end of the simulation. This report contains settings and all relevant results from the simulation.
The following table shows the percentage change of performance of the modelled system according to the selected production program (different structure, number and size of products). Option 0 is the default state. The table shows that the proposed measures may lead to a 21% increase in production for a certain structure of products.

Table 1: Percentage Change of Performance of the Modelled System - First Part

Variant	0	1	2	3	4	5	6	7
Product structure 1	100	104.9	104.9	104.9	103.7	104.9	104.9	103.7
Product structure 2	100	100.5	100.7	100.9	101.3	99.8	99.9	100.0
Product structure 3	100	100.5	100.7	100.9	101.3	99.8	99.9	100.0
Product structure 4	100	107.1	106.8	106.9	107.4	108.0	108.7	108.0
Product structure 5	100	100.0	100.5	100.3	100.0	104.8	105.0	105.0
Average	100	102.6	102.7	102.8	102.7	103.4	103.7	103.4

Table 2: Percentage Change of Performance of the Modelled System - Second Part

Variant	8	9	10	11	12	13	14	15
Product structure 1	117.5	117.5	117.5	117.5	117.5	117.5	117.5	117.5
Product structure 2	119.9	119.7	120.4	120.9	121.0	121.3	121.0	121.3
Product structure 3	119.9	119.7	120.4	120.9	121.0	121.3	121.0	121.3
Product structure 4	111.9	112.0	112.5	115.1	114.7	114.4	114.7	114.4
Product structure 5	100.6	99.8	100.0	106.8	106.7	106.7	106.7	106.7
Average	114.0	113.8	114.2	116.2	116.2	116.3	116.2	116.3

5. CONCLUSION

The simulation study described here focuses on testing and design alternatives that lead to an increase in the overall production of a paint shop department. The simulation study supports the proposed investment in the production system and the possible expected effect of these investments. The second group of simulation options focuses on the possible effects associated with organizational measures (shifts setting - not described in this paper) and also on the measures related to the change of the control logic of the automated programs that control the movement of the girders through the entire system that is modelled.

Simulation experiments demonstrate that the correct setting of the control logic of the production system usually has the most fundamental effect on the overall production of the entire system.

The results of the simulations proved the possibility to increase production by 21%. The overall increase of production is very dependent on the structure of the product type, size and quantity of products hung on girders. Recommendations from the results of the simulation study were implemented in the paint shop department.

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AUTHORS' BIOGRAPHIES

Pavel Raska is Doctor at the Department of Industrial Engineering and Management at the University of West Bohemia in Pilsen (Czech Republic). He holds M.Sc., Ph.D. in Mechanical Engineering at the same university. His research interests are oriented towards discrete event simulation, simulation optimization, modelling and simulation tools (ARENA, Plant Simulation) and working on practical simulation projects for companies.

Zdenek Ulrych is Associate Professor at the Department of Industrial Engineering and Management at the University of West Bohemia in Plzen and he is also a research worker in the Regional Technological Institute at the University of West Bohemia in Pilsen (Czech Republic). He holds M.Sc., Ph.D. and doc. in Mechanical Engineering at the same university. His research interests are oriented towards discrete event simulation, optimization in the simulation, modelling and simulation tools (ARENA, Plant Simulation), design and development of software and working on practical simulation projects for companies.