A simulation approach to achieving more efficient production systems

Bronislav Chramcov, Petr Beran, Ladislav Daníček, Roman Jašek

***Abstract*—**The paper highlights the problem of the use of computer simulation for improving the effectives of operations in production systems. The main idea of this paper is to outline the possibilities afforded by the Witness simulation environment for the construction of models and the subsequent simulation of concrete manufacturing systems. The possibilities of making use of the Witness are herein presented in the form of two simulation studies that were performed within the framework of cooperative ventures between our workplace and industrial partners. The aim of these studies is to suggest and simulate experiments designed to increase productivity and to find bottlenecks in the system. Simulation experiments are proposed on the basis of the predefined requirements of the users. Results of the paper show, that computer simulation (especially Witness simulation environment) is possible to use not only for suggestions designed to increase the effectivity of existing production system, but also in the initial creation and design of production system.

***Keywords*—**Computer simulation, discrete event systems, manufacturing systems, modeling, Witness.

I. Introduction

Predictive technologies and methodologies are drawing ever greater attention from experts in a wide variety of fields. Computer simulation is an essential component of every larger-scale production process as thus is also an auxiliary tool for improving the effectives of operations in manufacturing systems.

The ever more rapid evolution of new technologies and manufacturing processes and procedures place an ever greater demand upon the pre-implementation phase of the implementation of these aspects into real-life conditions. Equally, the growing pressures from the competitive environment have an ever more significant share of the ever-more strict tracking of manufacturing costs, their targeted reduction thereby requiring continuous change from manufacturing enterprises. In the complex environment of a manufacturing system, it is virtually impossible to achieve effective operation only through tracking and evaluating the subsidiary parameters of the production workshop floor. Their mutual interlinkage tends to be so complicated and complex, that there is a need to consider the whole manufacturing system from a global perspective and, in so doing, to look for ways of optimization them as a complex whole. This requires the application of a set of suitable methods and tools, which enable a complex approach to the manufacturing process as a whole – beginning right from the initial phase of its design and which also allow for experimentation with a series of a variety of solutions prior to the actual implementation of the manufacturing production system or the implementation of potential changes under consideration.

One form of computer simulation is the so-called "Discrete Event Simulation (DES)" [1]. DES is the modelling of systems in which the state variable only gauges a discrete set of points in time. The simulation models are analysed using numerical methods rather than by analytical ones. DES is an extremely valuable technique for investigating the behaviour of many business processes ranging from manufacturing layouts to the operation of modern contact centers, from the handling of patient influx in emergency departments to the processing of internet enquiries on a web-site. The high abstraction level of the concept of discrete event simulation renders its' application potential extremely wide-ranging. Some common application areas of discrete event simulation are service stations such as airports, call centers and supermarkets; road and rail traffic; industrial production lines and logistical operations such as warehousing and distribution. With a simulation model, the creator simply sets up the correct real world rules at each stage where a real-world decision is made. The model then plays the scenario forward - taking each of these decisions in turn. This gives great insight into the performance of the described system in terms of throughput, services levels, resource utilization, profitability, etc. With a discrete event simulation model, it is possible to conduct experiments which show the ranges of current and projected outcomes without the need for costly pilot schemes that disrupt the current process.

This experimentation is carried out at a number of levels. At one level, a user simply wishes to establish the variability of the current process, given certain input rates and profiles. Simulation can establish the projected variation using two similar, yet different, methods. To describe these, it is helpful to use a model example where a workplace (e.g. clinic, machine) admits a certain profile of parts (i.e. patients, products) every week. In this model, the number of parts admitted to the workplace is a set number arriving according to a variable time profile. At a second level, a user may wish to alter different parameters within the model to observe the

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different effects. Again, with this type of experimentation, the range of results might also be important - again accomplished through elongated or repeated experiments. At a third level, a user may wish to compare one model with another. For example, in manufacturing there may be two investment options – production layout A and production layout B. These may indeed be the only options, although often within each solution, there may also be parameter choices (e.g. buffer storage level options). In addition, once again, there is the optional value of establishing the range of results. A wide variety of experimental designs can be used for all these levels of experimentation. For different models for instance, the model itself can simply be considered a different type of parameter. In the DES field, a whole range of application and academic works have come into existence; for instance [5], where the author pointed out the significance of simulation in management and control systems in support of the decision-making process. The inclusion and exploitation of these simulation models enables online decision-taking in systems where is not possible to precisely calculate the consequences of such decisions. A further example can be the work [3], which resolves the problems and issues associated with the modelling of resolving customer orders in a flexible manufacturing system in line with the suggested control algorithms. Equations of State are used to describe this system and its ever-changing structure. It is possible to use a wide range software environment for DES. University in Naples has conducted simulation using software Arena. These simulation study solve analysis of passenger flow in the terminal airport, from entrance to boarding [6] or optimize cooking center [7].

The aim of this paper is to outline the possibilities afforded by the Witness simulation environment for the construction of models and the subsequent simulation of concrete manufacturing systems. Witness is used for achieving more efficient operation in manufacturing, logistic and queuing systems in a whole range of simulation studies. Process analysis using Witness has been conducted, for instance, in the lens manufacturing process flow of the firm in order to identify improvement prone areas and improvement alternative solutions were proposed [8]. The other work illustrates the use of computer simulation by Witness to design the production of a manufacturing company that produces snow melting modules. The analysis presented here describes the production design process and compares the performance of new design with the existing system performances [9]. The Witness environment was to used also for simulation of the ophthalmology service of Regional Military and University Hospital of Oran in Algeria[10] or for analysis the best layout for an industrial plant [11]. In our workplace for instance, we have used this environment to verify the functionality of suggested designs for the production lines of the company: Continental Automotive Systems Czech Republic s.r.o. [2]; or in the course of designing solutions designed to increase productivity and the discovery of bottlenecks in the short-barrel (pistol) production line [4] in the Zbrojovka a.s. company.

II. Software for Modelling and Simulating Manufacturing Processes

Currently, there is a wide range of commercial products on the market intended for the Windows and UNIX platforms, which offer an extremely wide spectrum of possibilities for the modelling and simulation of manufacturing, logistical and other queuing systems [12], [13]. These environments can be broken down into three main classes.

The first includes general simulation languages like Simula, C++SIM, GPSS/H, AweSim, Simscript, BaseSim, CSIM 19, JavaSIM and others. In essence, these are specific programming languages, whose inputs and outputs are in the form of textual data. In order for a user to be able to exploit all of the characteristics of a specific application to its limits, they must not only have experience with modelling – but also, they need to be a relatively gifted programmer. Among the chief advantages of these simulation languages is above all their great degree of flexibility in resolving the most varied of tasks and roles. As regards their demands on time, it goes without saying that one has to emphasise the relatively lengthy preparation of such models in the careful writing of source code. SIMSCRIPT, for example, is an open environment, and permits functions and routines written in other languages like C, C++ or Java to be invoked with simple commands. You get a quick and easy way to interface with specialized libraries, databases and packages. JavaSim is a set of Java packages for building discrete event process-based simulation, similar to that in Simula and C++SIM (from which JavaSim is derived). The current version is free for research and education.

The second class of environments relates especially to software packages which used graphic interfaces between the simulation language being used and the user. This category includes for instance, MapleSim 4, AutoMod, Quest, and Arena. In this case, it is possible to create a model either in a graphical form, or with the assistance of source codes. This also ensures a certain degree of flexibility. Equally, the output(s) can also be depicted graphically; today, most frequently through the assistance of visualisations of the modelled problem. From the time perspective, we can safely say that the period needed for the creation of the model is shortened, since one can use the much-favoured "Drag & Drop" method. For example, MapleSim - from MapleSoft, the creators of Maple, is a drag-and-drop physical modelling tool that applies symbolic computation techniques to produce simulation models of multi-domain systems. You can construct plant models using causal connections between the components to represent their physical relationships, and then combine your plant models with signal flow-based control systems. MapleSim generates the representative system equations, reduces them to an optimal form while maintaining model fidelity, and runs a dynamic simulation of the resulting system, complete with a 3-D visual representation.

The third such class is that of the generation of simulators which have appeared on the market over the past ten years or so thanks to the marked expansion and sophistication of computer graphics. For these types of environment, there is practically no need to programme anything at all or only in exceptional cases. Representatives of this class include for instance, Renque, ProModel, Tailor II, FACTOR/AIM – and, the often mentioned WITNESS [15]. The characteristic index of these environments is their fully-graphical interface; thus, even a user with a relatively average knowledge of programming can easily create and fine-tune models. Among the advantages of such a conceived system is the possibility of visualising the modelling of manufacturing, most frequently in the form of 3D animations or the VRML virtual reality format. Today, it is not exceptional to find the possibility of interlinking these with databases and tabular calculators. The only limitation of these environments is their reduced flexibility. Renque [14] is a software tool developed to create and operate discrete event simulation models. A discrete event is something that happens in an instant of time, with zero duration. Although gradual system transitions can be represented in a Renque model, the program was designed primarily to deal with instantaneous changes.

Apart from software environments, in today´s everyday working practice, hardware instrumentaria are also used These are above all, built up from assemblable components of a technical character which enable one to assemble reduced (miniaturised) functional models of the widest variety of machinery and equipment. Well-known manufacturers of such assembly kits are, for instance, the German companies like FischerTechnik or Staudinger EST GmbH – who use these components to assemble working models. In many cases, these models are then used for the design of production or control systems.

A. Simulation studies of manufacturing processes in the Witness environment

Our workplace is equipped with a Witness environment, in which we have, in close cooperation with industrial partners, conducted a number of simulation studies that have led – at least in part, to the optimisation of manufacturing, queuing and logistical systems. The Witness simulation environment is the product of the British Lanner Group company [15], and is one of the most successful world class environment for the simulation of manufacturing, queuing and logistics systems. It is used in support of the decision-making process of senior management when resolving organisational, technical and operational problems associated especially with the restructuralisation and upgrading of an enterprise´s processes. WITNESS helps to limit risk in the course of implementing changes within an organisation by enabling management to create an interactive version of visually understandable simulation models of complex enterprise processes, and to analyse and optimize them. WITNESS also enables one to test various variants of changes to a system as well as to evaluate their eventual impact on the behaviour of the processes. It is possible to identify bottlenecks in the production process, and to evaluate the costs and benefits of potential changes prior to even purchasing the requisite plant and equipment, or to increase the performance of an organisation without the need to expand resources and so on. The models in the WITNESS environment programme depict the movement of materials or customers within the system, the states of individual elements, the operations performed, as well as the actual use of resources. At the same time, records are made of all of the events that have occurred/occur in the system. Thereby, the user can track the dynamics of the process and also has at their disposition the requisite data to be able to evaluate the effective performance of a given system on the basis of selected criteria. It is also possible to perform "what-if" analyses. The simulation run can be stopped whenever one wants to, or changes made to the parameters of the system – for instance, the size of resource “buffers”, number of employees on a shift, or the directional flows of materials, and then to quite simply continue with the simulation. Thereby, one can immediately track the consequences of any such changes.

The core of the WITNESS environment system is complemented by the WITNESS Optimizer modules for the optimisation of processes, depicted in a virtual reality environment, for the ease of mutual exchanges of information between the environment of the WITNESS and Microsoft VISIO environments, linked to CAD/CAM systems, the documentation of models and the acquisition of knowledge and information from an extensive set of data. The WITNESS simulation package is capable of modelling a variety of discrete (e.g., part-based) and continuous (e.g., fluids and high-volume fast-moving goods) elements. Depending on the type of element, each can be in any of a number of “states”. These states can be idle (waiting), busy (processing), blocked, in-setup, broken down, and waiting labor (cycle/setup/repair). Witness models are based on template elements. These may be customised and combined into module elements and templates for reuse. The most basic discrete modelling elements are Parts, Buffers, Machines, and Conveyors. Other discrete modelling elements include multiple types of tracks and vehicles, labor, carriers, shifts, variables and part attributes. The behavior of each element is described on a tabbed detail form in the Witness user interface. Parts are simply objects that travel from one location to another. They may be pulled passively into the model by the simulation, pushed into the system by an active part arrival schedule, arrive from a part file, be created via a “production” machine, or any combination of the above. Buffers are simply passive storage areas of finite capacity. Buffers can be configured as “delay” buffers, where parts must stay in for a minimum amount of time. They can be configured as “dwell” buffers, where they cannot stay in the buffer any longer than a specific time. A part can be optionally ejected from a buffer if it violates any of these conditions. Combinations of First-In-First-Out / Last-In-First-Out sequencing are possible, as well as the ability to have parts pushed to and pulled from locations in the buffer other than the front and rear. Machines are the workhorses of WITNESS. The standard machine elements can be single, batch, production, assembly, multistation or multicycle. Machines can be defined with Setup and Breakdown parameters, useful for modelling real-life failures, retooling, preventive maintenance, etc.

The possibilities of making use of the Witness simulation environment are herein presented in the form of two simulation studies that were performed within the framework of cooperative ventures between our workplace and industrial partners.

III. Simulation Study for the Design of Production Line for the Manufacture of Electronic Control Units for Automobile Motors

Continental Automotive Systems Czech Republic s.r.o., prepared the installation and getting it up and running of a production line for one of its customers with a division located in Frenštát pod Radhošt, which was intended for the mass-production manufacture of electronic control units of diesel fuel-injection units. The aim of this simulation study is to design a number of variants for the spatial location of operators on this production line.

A. Description of the production line

The scheme for the design of the production line is circular – or, to be more exact, ellipsoidal arrangement. The finished product leaves the production line at the same place where it enters it. The production line represents a certain complex whole of logically arranged individual machines, on which the assembly of the finished product takes place. The individual working operations are linked onto one another in a logical manner, upon completion of each individual sub-operation the product progresses to the next work-place, where another subsidiary part of the assembly process takes place. This approach thereby creates a certain logical flow of the product in a circular arrangement between the individual work-stations and machines in the assembly production line. The individual operators who work on the production line only work in a pre-determined section of the production line (and only work with a finite number of machines). The whole production assembly line is composed of 15 machines, 5 belt conveyors, 2 vehicles for the transfer of products in a certain state of semi-completion between two work-stations and 2 individual workplaces of labours that have no machinery. An indivisible element of the production assembly line is its service – i.e. the production workers, representing human resources just as those working on the technical maintenance of the production line. The scheme of the design of the production line is depicted in Fig. 1. Here, three machines are highlighted in red - with which it is planned to expand the production line in the future with the possibility of adapting the assembly process with minor modifications to sub-assembly products. These are ignored in the further creation of our models, but it was important to include them in the initial phases of the scheme since their location on the assembly plant shop floor will to a certain extent influence the flows of the manufacturing process of the finished product whose assembly on this assembly line was the subject of our simulation study. A more detailed description of the individual machines mounted on the assembly line and the manufacturing operations associated with each can be found in this work [2].

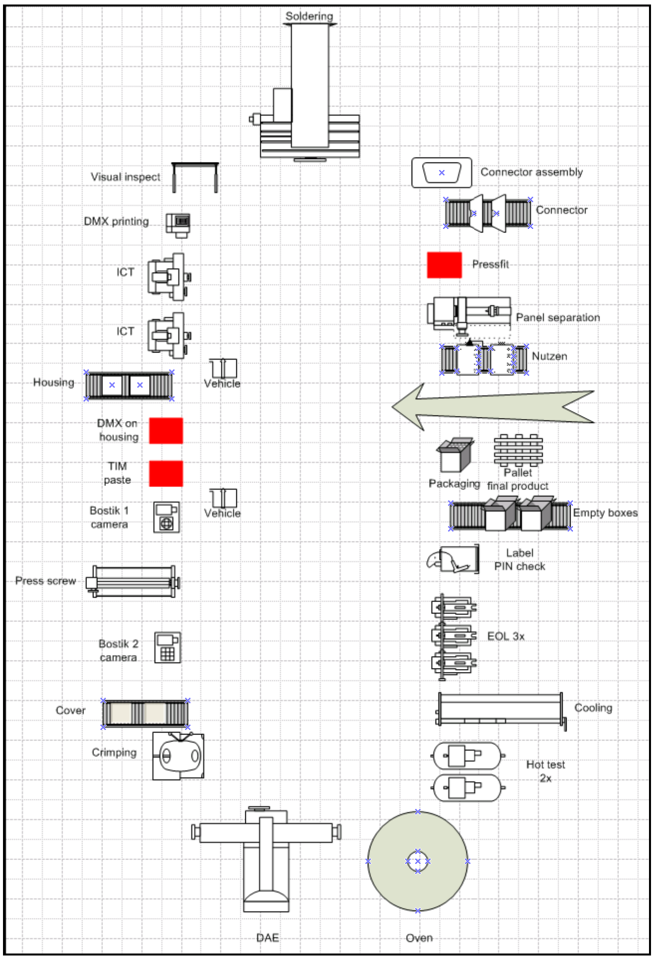

Fig. 1: Scheme of the production line

B. Construction of the model in the Witness environment

All of the machines in a production assembly line work on a similar principle. The operator approaches the machine, positions the incomplete product in its initial starting position, performs the requisite essential steps associated with the individual operations, and instructs the machine to begin operations. The machine begins to perform the production process; operator meanwhile removes the "completed" product from its initial position (the production operation having been completed in the previous phase by the machine) and carries it to the next production machine to continue the production process, where the prescribed operations on this machine are completed. Every production machine in an assembly line thus has an input and output position, where the machine-operator either places it in its initial position or removes it from its final position. The action of removing the work-in-progress does not occur immediately upon completion of the machine´s operations – the semi-finished product remains in its initial position for a certain amount of time before being removed by the operator and transferred further along in the manufacturing production process. This phenomenon can be modelled by means of container receptacles – i.e. buffers, into which the completed semi-finished product from each machine is placed upon completion of its operations. The transfer of product between the individual operator´s positions is assured by the operator who places the product into its initial input position on the appropriate machine. The time needed to move the product between the individual operator positions is included in the operating time of the operator – thus, the actual movement of the product between individual positions is not actually modelled any further. The time measurement unit for the model was in seconds, to meet the requirements in compliance with the provided outputs. The simulation period chosen was two working days (i.e. three-shift operations).

In order to achieve the unskewed outputs and the correct, observable outcomes, it is necessary to consider the initial part of the installation and running-in of the production assembly line right up to the time of its supply of all requisite inputs and until it is fully up and running smoothly. Warm-up was used for modelling this phase and we also chose a sufficient time lag after "kitting out" the assembly line, this was set as one working day (i.e. 86400 seconds). Once this time-lag expired, this allowed the initialisation of the ancillary variables. In the model, it is necessary to differentiate out the operator time and the cycle time of machine. The sum of the individual times for the transfer of the semi-finished product between the individual positions, fixation of the semi-finished product in its input position, removal of the completed semi-finished product from its output position or completion of further intermediary or subsidiary operations (e.g. placing of other sub-assembly components as inputs for the particular partial production operation) represents the operator´s time, and in the model of the assembly line, is modelled as Setup Time. The machine time represents the actual time that each individual machine needs to complete its production operation as this is modelled for each individual machine as Cycle time. Experimental measurements were made during the installation and running-in phase of the production line to discover the machine/operator times required for individual operations. The operator time is inputted into the model, modified by a randomising factor based upon a Gauss Curve with a 20 % spread factor for operator time. The individual work-stations of the production assembly line are modelled individually, in the main as an element: Machine, type: Single. Further, we also used elements like Buffer, Vehicle, or, respectively: Tracks. The model also includes an element type: Carousel. This element models the machining time of the work-station - Oven, where tests are performed of the product´s resistance to, and resilience against increased temperatures. For these purpose, the control unit is heated for a period of 45 minutes to a temperature of 90° C, which simulates the extremes of the conditions of the planned upon localisation of the production in the engine space of a private car.

C. *Simulation experiments and results and outcomes*

The aim of the first simulation experiments we conducted was to determine the workload of individual operators in the existing design of the production assembly line and further, to suggest further possible scenarios for the spatial disposition of operators within the spaces of the assembly line and, at the same time, to track their workload and the overall impact on the daily production / tempo of the assembly line. The task of other experiments was to design further possible scenarios for the spatial disposition of operators in order to increase the throughput of the production line overall with the presumption that the space within the production line could be served by up to six operators at a time. While designing these simulation experiments, it was necessary to respect other restrictions made by the customer:

- It would not be possible to increase the number of machines in the schemata.
- Operators serve machine requirements in a logical way, linked to production process flows.
- Operators could be allocated to machines in certain spatial units (either machines directly linked in series in a production flow or which were grouped closely together).
- The operator with the least workload would move the vehicles between work-stations

In order to achieve the set goals, it is necessary to correctly evaluate the individual experiments and to draw the corresponding correct conclusions from them. For these reasons, there was a need to establish and set the corresponding target functions to be able to track the relevant parameters. In the course of realising the simulation experiments, the workload of individual operators, the overall daily production of the assembly line, the tempo (pauses in seconds between individual products leaving the assembly line) and the difference between maximum and minimum determination of workloads for individual operators were all tracked. Since this system under investigation works non-stop, it is appropriate to always evaluate the output data upon the full completion of a batch run on the production assembly line. The value of 86400 seconds was chosen for the production line cycle - which corresponds to the period of one day and thereby sets the time when the tracking of the variables and indices can be reset to zero. This timeframe provides sufficient space and reserves for the production line. The overall timeframe of the simulation for all of the simulation experiments performed was 2 days (1 day set-up, 1 day test period). Overall, apart from the simulation of the existing state of the assembly line, a further 11 simulation experiments with a variety of results were performed. The results of the best simulation experiments and their comparison with the results of the simulation of the existing state-of-affairs are described in the herein below and result report of these experiments is shown in the Table 1.. Since, at the time of the creation of the simulation study, the assembly line was already in the design and initial set-up phase, it was impossible to precisely verify the suggested model against

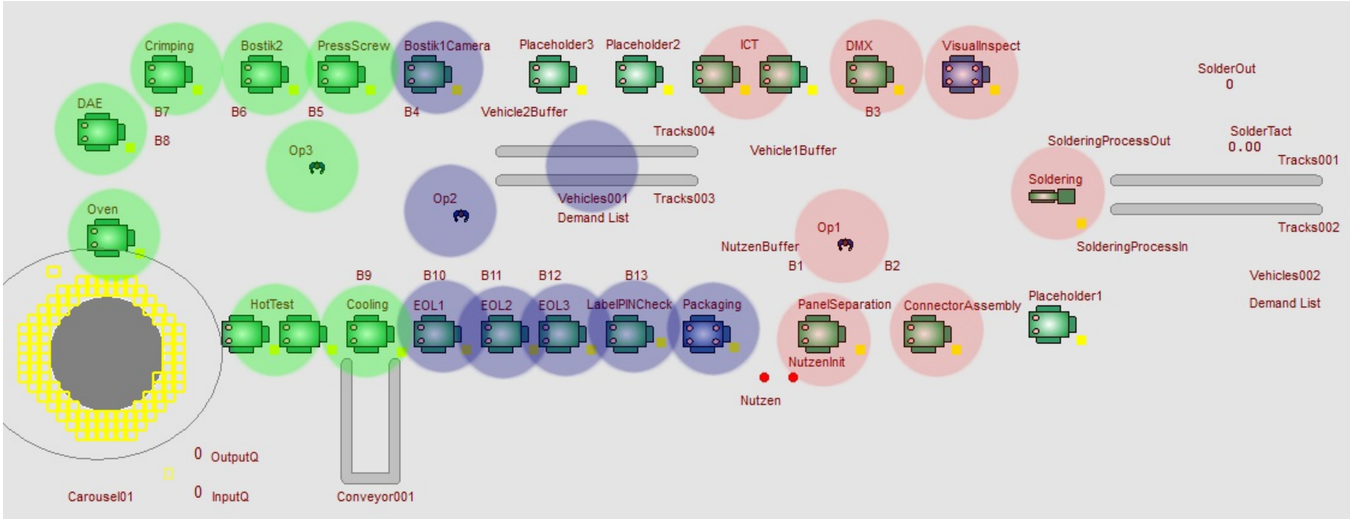

Fig. 2: Model of the existing design of the production line

reality. The model thus was based upon the input data provided as the best estimate as well as that of the experimental operation of the assembly line “dry runs”. This basic model – see the Fig.2., is used for the subsequent simulation experiments. The coloured profiles in the visual schema identify the fields of operation of individual operators and the allocation of their services to concrete machines. The results of the simulation of the existing design for the production line are clearly set out in the second row of the Table 1. From these results of the simulated design model it is clear that the distribution of operators around the workplace is not completely well-balanced. The 100% load upon operator 1 causes insufficient supplies of semi-products to the production line in the first section of the production line and may thereby lead to the insufficient workloading of other production line operators, who are waiting for the delivery of products from work-stations further back down the line.

Table 1: Evaluation of the best simulation experiments for the different location of operators on the production line

	Existing state	Experiment No. 4	Experiment No. 7	Experiment No. 9
	Workload			
1. Operator in Station 1	100%	78%	62%	81%
2. Operator in Station 1	-	-	86%	70%
Operator in Station 2	78%	79%	65%	72%
Operator in Station 3	81%	91%	97%	91%
	Other monitored target functions			
Production line tempo	44.93 s/pces	47.99 s/pces	37.61 s/pces	37.91 s/pces
Overall daily production	1923 ks	1800 ks	2297 ks	2284 ks
Difference in workload	22%	13%	35%	21%

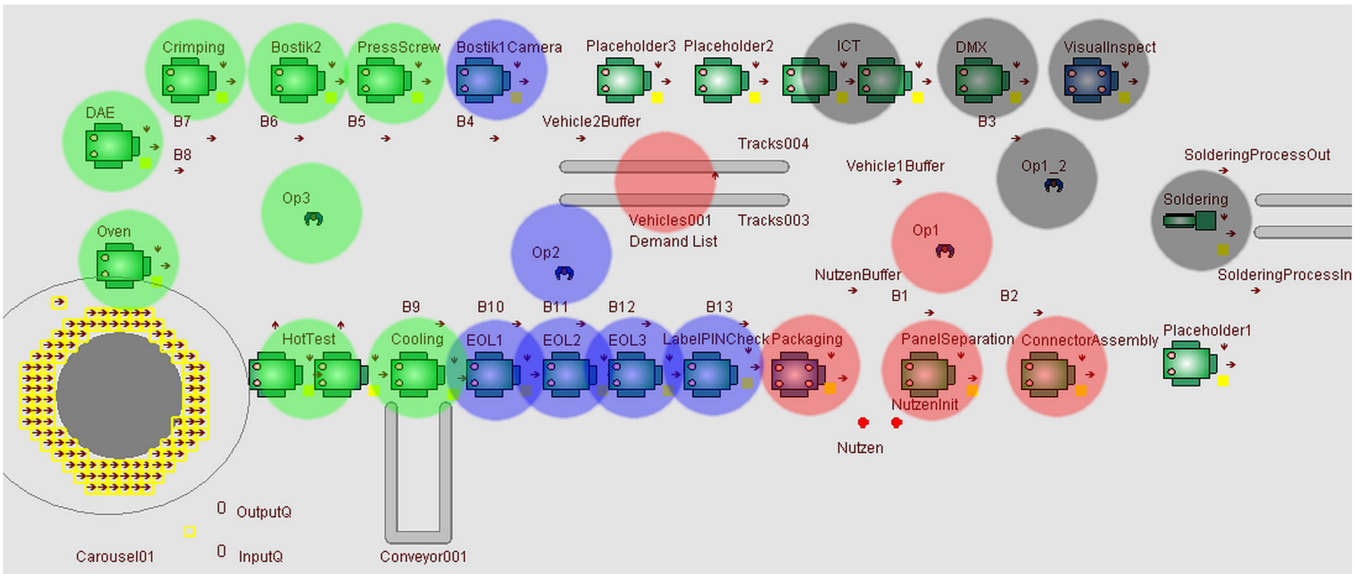

Fig. 3: Model of simulation experiment No.7.

The best results were obtained when experimenting with four operators. The experiments were based upon the fact that increasing the number of operators in Station 1 and the subsequent subdivision of this section into two independent units. The best results were achieved in experiments No. 7 and No. 9. Simulation experiment No.7 – as against the original state of affairs, reallocated the L02-Packaging machine into Station 1. (see the Fig. 3).The allocation of an extra operator into Station 1 brings a visible improvement in the reduction of the tempo of the production line, thereby increasing the overall daily production rate (see the Table 1). In experiment No.9, in addition, there is a change to the worker allocations for the M13-Cooling and M03-Soldering machines. Simulation experiment No. 9 provided the best results out of all of the simulation experiments with four operators from the point-of-view of the balancing out of workloads between individual operators with a slight impact on the throughput and tempo of the production line as compared to simulation experiment No.7. This fact indicates the last column of the Table 1.

D. *Analysis of the simulation experiments and recommendations*

The performance of these simulation experiments indicated that the best possible solution not only from the perspective of the overall daily production rate, but also from the perspective of the balanced loading of individual operators was achieved by the production line model with four operators. The highest throughput of the production line was offered by simulation experiment No. 7 – however, at the price of a median imbalance between the distributions of workloads between the individual operators.

The most well-balanced distribution of workloads is achieved in simulation experiment No. 9, with the minimum difference in the number of output products, (4 pces / shift). In view of this minimal difference in the throughput of the production line and the conditions set at the outset by the customer, it is recommended that one uses the most uniformly distribution of workloads between individual operators on the production line and to use the schema of simulation experiment No. 9. If the priority for the customer is throughput to meet supplier conditions, then the optimal solution is to use the schema for the redistribution of operators on the production line – as per simulation experiment No. 7 (the difference in monthly production figures combined with non-stop production amounts to some 374 units). Here, there is a need to point out the fact that expansion of the production process by the allocation of one extra worker in a non-stop, three-shift production schedule means the additional wages and salaries of the three additional people. The benefit to the production line through the implementation of three workers means 374 units per day. In the case of the addition to the production line of three operators in a non-stop operation, then the benefit accrued from one operator per shift is 214 products. The addition of one extra worker into the production per shift however, only means a further 125 products. Since we were unable to acquire concrete data for evaluation from an economical/financial perspective, the customer must therefore weigh up whether this increase in capacity will be financially viable; that is to say, whether the income from deliveries of such additional finished product, will cover the increased costs entailed by the operators´ wages and salaries.

Should it not prove economically viable to add a fourth operator to the production line, then there also exists the possibility of using three operators - according to simulation experiment No. 4 - which achieved the optimal distribution of workloads between individual operators (see the Table 1). In order to achieve the highest possible throughput for the production line from the experiment on the simulation of the existing state of affairs, there is a need during the course of the shift to change the positioning of operators to ensure optimal coverage of other sections of the production assembly line.

The model with five operators in the production line only brings an increase of a mere 18 units per shift as compared to the model with four operators, i.e. the benefit is merely 8.5% - in comparison to the production per operator when allocating three operators. The benefit accruing from such changes is not significantly different, and in addition, the workload of the operators is not sufficiently effective (workloads under 50%). The same also holds true for the model with six operators in the production line. These variants therefore, cannot be recommended.

IV. Simulation Study of the Short Barrel of the Gun Manufacture

In this case is Witness environment used for the determination of the optimal number of machines for individual work-stations or respectively, to establish the optimal number of production shifts for these workplaces in the production line of short-barrels for pistols in the Zbrojovka a.s (gun-makers) company. The production process is described in detail in [4] and schematic drawing is in Fig. 4. The machines used in the manufacture serve for machining the products in various production phases. These are, in particular, lathes, grinding and drilling machines. All these machines are machining only one product at a given moment. Thus, only one part enters the machine and a specific operation is carried out on it, and also only one part leaves the machine. Individual machines are arranged into groups. Each group forms a workplace to perform a certain operation. Every machine (except for one machine) is operated by one operator. For this reason, labour does not have to be considered in the model. Table 2 shows quantities of machines in individual workplaces which are used in the system for machining the products, together with the number of shifts during which the workplace is in operation. Each workplace performs a certain operation. The product comes through some workplaces repeatedly, therefore one workplace carries out a few different operations. The values of time of individual operations were provided by the operator of the plant from its planning system where the data for all machines are stored. The data collection

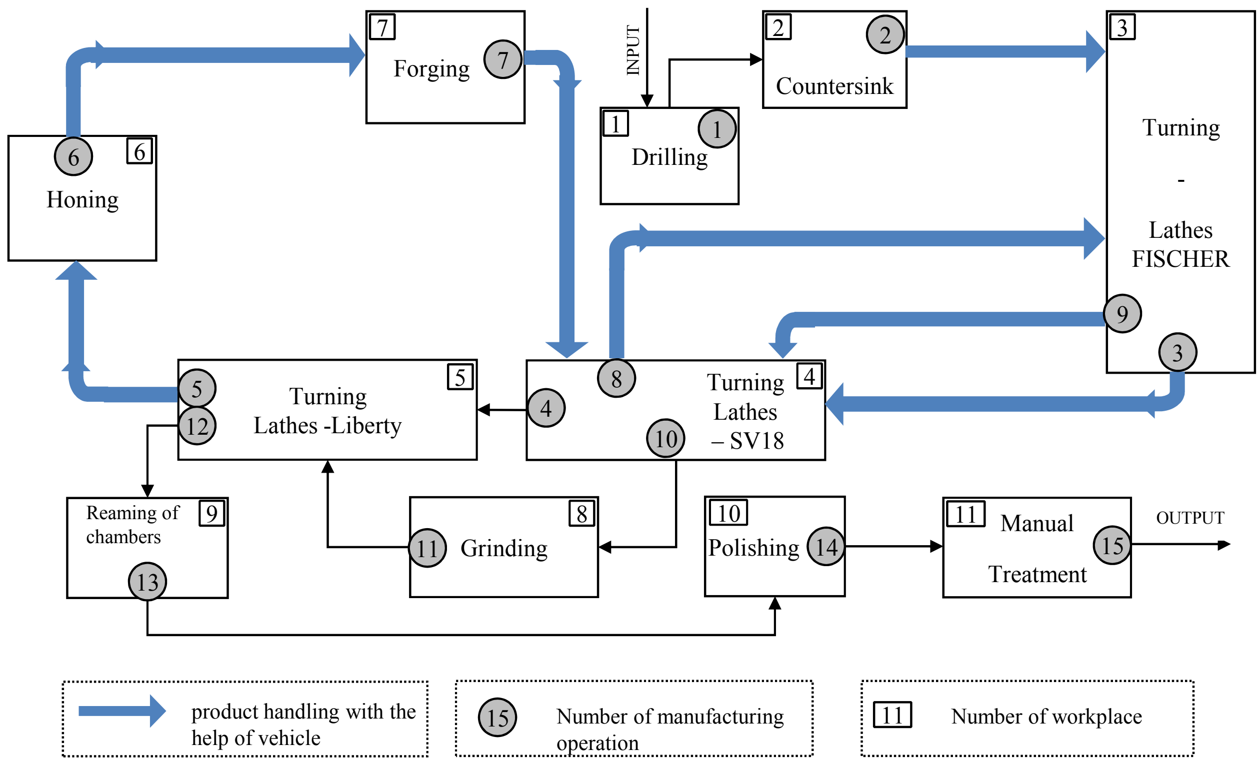

Fig. 4: Simplified scheme of the operation of the production plant

was carried out in that workplace for a long time, hence we can consider this data to be very correct. So any further measurement directly in operation would be just waste of time. Products' handling in the production is made with the help of vehicles. Material handling is not controlled in real manufacture; this is done in case of emptying individual buffers. Time of material handling from one machine to another is minimal, as the distance is very short. Therefore we can say that the time of material handling is negligible.

Table 2: Number of machines in individual workplaces and number of shifts

Workplace No.	Description of workplace	Number of machines	Number of shifts
1	Drilling of the short barrel of the gun	3	2
2	Drilling –countersinking	1	2
3	Turning-Lathe – Fischer	3	2
4	Turning-Lathe - SV 18	7	2
5	Turning-Lathe - Liberty	6	2
6	Honing	5	2
7	Forging	2	3
8	Grinding	6	2
9	Turning-Lathe – chambers	3	2
10	Polishing - chambers	2	2
11	Manual treatment	9	1

The manufacturing plant works in three-shift operation. Most workplaces are in two-shift operation (see the Table 2). In operation, maintenance of the machine is done on a regular basis. Thanks to this maintenance, faults occur on individual machines only exceptionally. Time of maintenance together with elimination of faults will take 3 % of machine time.

A. Model of production process in Witness

Every operating workplace of the manufacturing line is modelled in the Witness environment with help of the element Machine of Single type. Parameters of each element are set by means of tabbed detail form. Quantity of machines in the particular workplace and cycle time are set up according to Table 2 and data provided by the operator. If a workplace carries out a few operations with a different cycle time, this parameter is considered as a variable. The value of this variable is then set up in the output rule of the buffer in front of the workplace concerned. Products' handling in the manufacture is performed by vehicles. These are modelled with help of the element Vehicle. These vehicles move along the predefined tracks (modelled by means of the element Track). In the simulation model, the handling is carried out at the moment when quantity of products in the buffer has decreased under a value of 3. Capacity of each buffer is 5000. As mentioned above, time of material handling from one machine to another is minimal. For creating the model of process of maintenance and fault in individual workplaces, an auxiliary element of Machine type is used, which takes care of fault generation (maintenance on individual machines of the particular workplace). Thus, each workplace has its fault generator. This solution is given by the fact that it is not possible to set up a fault only on one machine of the particular workplace which is just modelled by the only element. A fault (or maintenance, respectively) is generated by means of a new part (element of Part type), which at the input into the particular fault generator will cause a fault on the corresponding machine of that workplace. Time of fault (maintenance) is set up by means of the parameter Cycle Time of the fault generator. For generating a fault (maintenance), normal distribution is used. The parameters are chosen so that a fault (maintenance) occurs on each machine at least once a day. In the model, working shifts are made with help of the element Shift. For purposes of the simulation, three one-week shifts were created. The shifts were then assigned to the individual workplaces as per the number of shifts in which the particular workplace is in operation every day.

B. Simulation experiments and results

After building up the model of the manufacturing line, the proposed model must be first verified. The verified model will be subsequently used for simulation experiments. As the system in view works in continuous operation, the model would have to be first filled with products in order to verify the model with the real system. This can be made in the Witness environment due to the parameter WarmUp Period. The value of this parameter determines the time when the followed-up statistics and variables are zeroized. The value WarmUp Period is set up to 172800 seconds, which corresponds to the time of 2 days. This time is sufficient for filling the whole model with products. Total time of simulation is 2 weeks (that means 2 days Warm Up, 12 days testing period). The Tables given below show the results of simulation of current manufacturing line and the best simulation experiments. Only informal and static techniques [1] were used for verification, validation and testing. During the verification, especially percentage capacity utilization of individual workplaces and total production of the manufacturing line were monitored (see Table 3). The values of monitored characteristics are comparable to those of the real system. The Table 3 shows ineffective operation of this manufacturing system. More than half of workplaces are blocked. It is caused due to filling the buffers between individual workplaces (capacity of buffers is 5000). Busy time of most workplaces is less than 50%. Workplace of Honing is the critical point of system (busy time practically 100%, 3% maintenance).

The simulation experiments were suggested on the basis of the predefined requirements of the user:

- It is possible to reduce the number of machines in individual workplaces
- It is not possible to increase the number of machines in a workplace
- It is possible to change the number of working shifts of individual workplaces

The task was thus to determine an adequate number of machines in individual workplaces, or possibly, to set up an appropriate number of working shifts of the operation of these workplaces.

Table 3: Report on results of current manufacturing line

Workplace No.	Description of workplace	Number of machines	Number of shifts	Busy Time [%]	Blocked Time [%]
1	Drilling	3	2	35.10	61.87
2	Countersinking	1	2	46.73	50.13
3	Turning-Lathe – Fischer	3	2	34.94	60.39
4	Turning-Lathe - SV 18	7	2	43.58	53.43
5	Turning-Lathe - Liberty	6	2	30.15	57.14
6	Honing	2	2	96.95	0.00
7	Forging	2	3	66.38	16.74
8	Grinding	6	2	23.00	0.00
9	Turning-Lathe – chambers	3	2	47.49	0.00
10	Polishing - chambers	2	2	22.02	0.00
11	Manual treatment	9	1	0.54	0.00
TOTAL		44	22	40.63	27.25
Number of necessary labour per day				81	
Total production of manufacture [pieces]				6230	

Numbers of modifications were gradually proposed for the present status of the manufacturing line. All the proposed experiments were simulated. Description and results of the best experiments are presented below and result report for these experiments is shown in the Table 4. Proposed changes are highlighted. Original values are stated in the brackets.

From result of simulation of current manufacturing line it is obvious that workplace Honing is the bottleneck of this production process. Due to high manufacturing capacity of machines before workplace Honing and inadequate capacity of Honing many workplaces became blocked. Experiment No.1 eliminates the significant bottleneck of current manufacturing system by means of increasing the number of working shifts. Operation time of workplace Honing was set to three shift operation. Blocked Time of these workplaces can be reduced with cut in manufacturing capacity of workplaces Drilling and Countersinking. Further the unsuitable number of working place of Manual treatment is reduced. More than double Total production increase and labour cuts (11 labourers) are reached in this experiment. Disadvantage of this experiment consists in partial blocking the Turning-Lathes - Fischer resulting from maximum busy time of Turning-Lathes - SV18. The experiment No.2 solves this problem. More than treble Total production increase at the practically identical labour (80 labourers) is reached in this experiment. Blockage

Table 4: Report on Results of simulation experiments

Workplace No.	Description of workplace	Number of machines				Number of shifts				Busy Time [%]				Blocked Time [%]			
		Experiment No.				Experiment No.				Experiment No.				Experiment No.			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Drilling	2 (3)	2 (3)	2 (3)	2 (3)	1 (2)	1 (2)	1 (2)	1 (2)	96.99	96.99	96.99	96.99	0.00	0.00	0.00	0,00
2	Countersinking	1	1	1	1	1 (2)	1 (2)	1 (2)	1 (2)	86.95	86.95	86.95	86.95	0.00	0.00	0.00	0,00
3	Turning-Lathe – Fischer	3	3	3	2 (3)	2	2	2	2	60.04	67.55	66.83	97.00	18.41	0.00	0.00	0,00
4	Turning-Lathe - SV 18	7	7	7	7	2	3 (2)	3 (2)	3 (2)	97.01	93.07	90.89	89.38	0.00	0.00	0.00	0,00
5	Turning-Lathe - Liberty	6	6	5 (6)	5 (6)	2	2	2	2	59.03	84.60	95.20	95.87	0.00	0.00	0.00	0,00
6	Honing	2	2	2	2	3 (2)	3 (2)	3 (2)	3 (2)	73.17	76.17	75.93	79.18	0.00	0.00	0.00	0,00
7	Forging	2	2	2	2	3	3	3	3	90.85	93.40	91.80	95.87	0.00	0.00	0.00	0,00
8	Grinding	6	6	5 (6)	5 (6)	2	2	2	2	56.69	84.99	95.54	95.61	0.00	0.00	0.00	0,00
9	Turning-Lathe – chambers	3	3	3	3	2	3 (2)	3 (2)	3 (2)	97.03	94.49	94.51	95.05	0.00	0.00	0.00	0,00
10	Polishing - chambers	2	2	1 (2)	2	2	2	3 (2)	2	45.01	64.66	87.61	65.05	0.00	0.00	0.00	0,00
11	Manual treatment	1 (9)	1 (9)	1 (9)	1 (9)	1	1	1	1	10.95	15.73	15.74	15.83	0.00	0.00	0.00	0,00
TOTAL / AVERAGE		35 (44)	35 (44)	32 (44)	32 (44)	21 (22)	23 (22)	24 (22)	23 (22)	70.34 (40.63)	78.05 (40.63)	81.64 (40.63)	82.98 (40.63)	1.67 (27.25)	0.00 (27.25)	0.00 (27.25)	0.00 (27.25)

	Experiment No.1	Experiment No.2	Experiment No.3	Experiment No.4
Number of necessary labour per day	70 (81)	80 (81)	75 (81)	74 (81)
Total production of manufacture [pieces]	14019 (6230)	20140 (6230)	20146 (6230)	20263 (6230)

of the machine almost never occurs. Imperceptible blocking of the Turning-Lathes-Liberty comes about after one month simulation.

Experiment No.3 solves lower workload of Turning-Lathes – Liberty, workplace of grinding and workplace of Polishing-chambers. The number of Turning-Lathes-Liberty and grinding machines is decreased. The workplace of polishing-chambers is set in three-shift operation but the number of machines is reduced. Five labour positions are saved compared to the previous experiment. Value of Total production is practically unchanged. Imperceptible blocking of the Turning-Lathe-Liberty comes about after two month simulation.

Experiment No.4 corresponds practically to experiment No.3. This experiment corrects the lower workload of Turning-Lathes – Fischer. The number of machines in this workplace is reduced. Total production increase (cca 120 pieces) and labour cut (1 labourer) are achieved compared to experiment No.3. However Turning-Lathes-SV18 are blocked soon (after 3 weeks). It is resulted from maximum busy (3% maintenance) time of Turning-Lathes-Fischer. On the basis of the results of executed experiments, we can say that Experiment No.4 is the best. Total production of manufacture is the highest and labour cuts (7 labourers) are achieved.

However this experiment has a weak point which comes out after longer simulation time. Turning-Lathes-SV18 are blocked after 3 weeks. It is resulted from maximum busy time of Turning-Lathes-Fischer. From this point of view it is better Experiment No.3. Blockage of the machines almost never occurs. Imperceptible blocking of the Turning-Lathe-Liberty comes about not until after two month simulation time. Six labour positions are saved compared to the current manufacturing line. Value of Total production is practically comparable to Experiment No.4.

V. Conclusion

This paper presents the possibilities afforded by using dynamic simulation for the design, optimisation and identification of reserves in manufacturing systems. Using concrete examples, it has been demonstrated that the use of the Witness simulation environment – not only for suggestions designed to increase the effectivity of existing production runs, but also in the initial creation and design of production lines themselves is valid and effective. In the first example, on the basis of a large number of simulation experiments, bottlenecks in the original production assembly line for short-barrels for pistols were identified and nullified in the gun-making company. The solution rested upon the elimination of the number of machines in selected work-stations. In other work-stations, it was suggested that they reduce - or as the case may be, increase the number of operational shifts. All of these suggestions and designs led not only to increases in productivity (in our case, of up to 1,000 units per day) but also to savings in the workplace and in energy. In the second example, the series of measures suggested and subsequently tested using the Witness simulation environment uncovered production opportunities in the initial design of the production assembly line for the manufacture of electronic control units for diesel motors in the Continental Automotive Systems Czech Republic s.r.o. company. Equally, the performance of these simulation experiments identified further alternatives relating to the allocation of production-line operators, whether with regard to the expansion of production capacity itself and the more effective allocation of working duties among the individual operators themselves. At the same time, we managed to determine the borderline capacity limits of the production line as currently designed and to determine its bottlenecks which prevented further reductions in the tempo and thereby increasing its throughput.

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