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SIMULATION OF PRODUCTION LINES IN THE EDUCATION OF ENGINEERS: HOW TO CHOOSE THE RIGHT SOFTWARE?

Marta Rostkowska

Poznań University of Technology, Institute of Control and Information Engineering, Poland

Corresponding author:
Marta Rostkowska
Poznań University of Technology
Institute of Control and Information Engineering
Piotrowo 3A, 60-965 Poznań, Poland
phone: (+48) 609-623-065
e-mail: marta.a.rostkowska@doctorate.put.poznan.pl

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Abstract
The article discusses the problems of modeling and simulation in the design of production lines, mainly from an educator's perspective. Nowadays, there is a wide range of computer programs that can be used to design production lines and to simulate various aspects of their operation. However, the programs being available vary considerably as to their functionality, the approach to production system design, and the visualization tools. Therefore we demonstrate and evaluate in this paper four simulation programs, focusing on the easiness of system design, area of the possible applications in education of engineers, and the limitations imposed by versions dedicated for students. We evaluate three of programs for digital factory simulation on a common, simple assembly task, then demonstrate that these programs may be also used for more specialized simulations in various areas of production, and compare with a specialized program for simulation of robotised production lines and work cells.

Keywords
simulation, factory automation, production line, simulation approaches, simulation applications, 3D animation.

Introduction

In order to meet the demand for engineers educated in modern factory automation, universities provide the students with courses on flexible manufacturing and production automation. However, real production lines are often very complicated systems of classic and/or numerically controlled machine tools, assembly stations, various types of robots, conveyors, and other means of transportation. Designing properly such a system requires knowledge in several areas, and some experience, which is hard to obtain for a student outside of a real production plant.

The industry wants to improve flexibility, competitiveness and reduce costs by cutting down the need of producing prototypes and test series [1].

Production is planned in details with regard to the efficient management of resources. Planning process is implemented by designating short-term and long-term tasks. Simulation allows to check the behavior of the system after the implementation of the proposed solution and the removal of all existing errors. The use of 3D visualization allows to more accurately understand the process and explains the ambiguities. Computer simulation of production line enables testing of the designed solution without former physical implementation. Digital factory allows the integration of devices, people and machines that allows efficient use of factory resources and process lines [2, 3]. Simulations addressed the effective management of resources [4], including the following issues:

- determining the effect of changes in parameters and properties in the course of the simulation,
- flexibility and capacity of the system,
- bottlenecks,
- number of elements of the production system and the types of machines,
- the number of staff needed,

- performance of work,
- delays in delivery, quality problems, equipment failures,
- reduction of losses and downtime with maximum synchronization and coordination of all processes related to movement of materials and production processes.

The increasing usage of simulation in the process of modernization and planning of production lines in factories caused a change in the education in this field.

At the university, the students may gain this experience in two ways. One solution involves the use of scaled-down, small production lines mounted at teaching sites. Examples of such lines are those produced by Koester [5] and Micro [6]. Although appealing to the students, this solution is very expensive and allows testing of a limited number of configurations and component types. The other solution is to use software simulators. With the simulations, various configurations of the equipment on the production line can be tested easily, production statistics can be carried out (costs and benefits) and the solution optimal with respect to the structure and components of the considered production line can be chosen.

On the software market, a large number of commercial programs for simulation of various aspects of the operation of production plants and/or lines is available. However, it is unclear how to choose a right program for the students that want to gain the knowledge how to design production lines.

The level of popularity of simulation software in the industry has been presented in [7]. Although this comparison allows to familiarize with the basic features and capabilities of many programs, it does not cover the recent versions of the software, and does not take into account the educational aspects of simulations. An interesting method for choosing a production line simulation program by using analytical methods has been presented in [8]. The Analytic Hierarchy Process employed to select the most appropriate simulation program seems to be particularly useful for industrial users, that may have well defined priorities as to the aspects of the simulation that are most important in their domain. However, formulation of such weights for programs used for education is less obvious, as the students should familiarize with various aspects of the simulations.

There are some criteria for making the informed choice of a simulation program that stem from the experience of the educators:

- the program should allow to simulate various types of production lines: assembly lines, continuous production lines (e.g. in the food industry), robotized lines, lines involving human workers, etc.,
- the program should allow the user to set the spatial layout of the machines and other components,
- if possible, the program should simulate both the discrete-event systems and continuous-time dynamic systems,
- a library of pre-defined components (machines, robots, conveyors, etc.) has to be available, as well as a possibility to define custom components, including their logic programmed as a script an external function,
- comprehensive reports should be generated regarding production statistics, machine usage, defective products, etc.,
- 2D as well as 3D graphics should be available to demonstrate the layout of the designed system, if possible supported by animation,
- the program should be available to the individual students also for the homework, so there should be a free or educational version provided.

A broad comparison of the programs for simulation of various processes can be found in [9]. Unfortunately, this comparison does not include the recent versions of the software available on the market, and does not take into account the educational aspects, which are central to our study.

Simulation programs typically used in the robotics and automation education, e.g. the very popular Matlab/Simulink [10] do not fulfill these requirements, usually focusing on the simulation of dynamic systems. The software developed specifically to simulate industrial robots and their co-operating machinery shares some properties with the simulators of production lines, but usually focus on the simulation of physical interactions between the machines, and on off line programming of the robots (i.e. developing programs that can be transferred to real robots). Nevertheless, such programs may be useful for education in the design of robotised production lines, and should be considered as a supplement to the general purpose simulators.

Due to the limited space of this article, it was decided to focus on a case study of three programs that we consider representative for the current software market. While selecting these programs, mainly the possibility of using them in the academic training has been taken into consideration. The key factor influencing the choice was the availability of free student or trial versions, with the functionality as similar to the full version as possible, and an easy access to documentation and instructional materials. Another important factor was the intuitive and user-friendly interface. The most important functionality was the ability to design the logical schemes and the 3D simulation/animation in one program. We assumed, that

Table 1
Comparison of programs for simulation of industrial processes.

Program property	Program name			
	Production line simulation/Virtual factory			Robotics-specific simulation software
	Arena	FlexSim	Tecnomatix Plant Simulation	Robot Studio
Trial version	+	+	+	+
Student version	+	+	+	–
Materials for students	+	+	+	+
Restriction applied in the trial version	Model with only 20 elements	No limits on the model. Limited functionality of the program such as: – no data tree view – no command console – no optimalizer	Model with only 80 elements	30 days trial, full funcionality
Logical diagram	+	–	–	–
Simulation of manufacturing processes	+	+	+	+
Programming robots offline	–	–	–	+
Simulation of robot motion	+	+	+	+
Simulates people at work	+	+	+	–
2D Simulation/Animation	+	–	+	–
3D Simulation/Animation	Postprocesor	+	+	+
Access to the parameters of object	+	+	+	+
Import of CAD 3D models	+	+	+	+
Using custom 3D models	–	–	–	+
Script programming languages	C/C++	C++, FlexScript.	SimTalk	RAPID
Creation of custom libraries	+	+	+	+
Production statistics	+	+	+	–
Diagnostic tools (breakpoints, watch, etc.)	+	+	+	+
File format of the report	spreadsheet (csv), txt, pdf, html, xml	spreadsheet (csv), htm, html, png	html, htm, txt	–

the programs are MS Windows (XP/7) aplications, as this operational environment is most popular and commonly available to the students, also for the homework. Finally, the chosen programs are: Tecnomatix Plant Simulation (version 11.0.3), Arena Simulation Software (version 17.70.00000), and FlexSim (version 7.1.4). Additionally, the RobotStudio (version 5.61.01) simulation software is considered in this paper, to demonstrate both the similarities and the important differences between the programs developed for design and simulation of production plants, and the robotics-specific software.

A qualitative comparison of their key features is presented in Table 1.

Programs

Simulation is a method involving replacement of real objects by digital models to obtain the necessary information about how the system works at set parameters and how it reacts when input parameters change. Simulation overcomes the limitations of analytical modeling due to the huge computational power of modern computers. A detailed description of the designing methodology for the technological lines using simulation programs is presented in [11].

According to [9], the simulation process involves the following steps:

1. Analysis of description of the system, which should be designed and tested.
2. Collection and processing of information: the input data, model parameters, timing of individual components of the system and the efficiency of the machines.
3. Creation of a model in the simulation program.
4. Verification of the model.
5. Development of simulation experiments.

6. Conducting simulations to answer the questions posed in the analysis phase.
7. Performance tests and simulations by changing the parameters of machines and their properties.
8. Evaluation of experiments and final report.

In the remainder of this section we present the three plant and production line simulation software packages considered in our study, focusing on their usability for students (availability, user interface), and the functionality when designing and simulating the technological processes. We also briefly mention the limitations of the student/trial versions used in our experiments.

Tecnomatix Plant Simulation

Tecnomatix is a collection of programs for the optimization and design of technological lines, developed by Siemens [12]. Tecnomatix platform is composed of: Tecnomatix Jack, Intosite, Robcad and Plant Simulation. Plant Simulation is a tool for the simulation of discrete events, which allows creation of digital models of logistics, so that properties of technological lines can be examined and their performance can be optimized.

In this article, Plant Simulation details will be presented. It allows to model the production lines in 2D and 3D, space, optimize the material flow at all levels of planning, starting with creation of the factory, to the individual production lines. It also has advanced tool to analyze bottlenecks, generate various kinds of statistics, graphs and evaluations of different scenarios of production.

The platform is available on a proprietary license. However, student version can be used. Some limitations are applied – only 80 material flow objects can be put. Siemens allows using of full version for graduated work. In this case, the finished project should be forwarded to Siemens. The program has very good documentation, instructional videos and manual which significantly facilitates the start of work.

Arena Simulation Software

Another program which enables the design of production lines is the Arena from Rockwell Automation [13]. In this program, the user builds a model by placing modules on the scene, reflecting the processes.

With the combination of process simulation and optimization, Arena helps demonstrating, predicting and measuring the system performance.

The program allows simulations in 2D and 3D. Using the 2D mode, the logical model of the whole production process can be created. It is adapted to the duration and the speed of production. To move around the worksheet containing the model, the navigation-key, which will allow a full view of the selected element, can be used. 3D animations can be created inside Arena by the module called Arena Visual Designer. Creating the 3D models is inconvenient. If queuing, handling resources, stations or other functionalities are desired to be simulated, it is necessary to create objects in 2D scheme and then update their properties to 3D environment.

Three-dimensional animation shows the arrangement of machinery, production line workers and illustrates the whole process, starting with the delivery of materials and ending with taking away of finished products. For each carried simulation a report is generated.

The full version is not free. However, student version can be used. It has limitations that significantly hamper the work. Models composed of only 20 properties can be used. As a result, it is possible to design only a very simple process. After purchasing the academic license, training materials in the form of presentations and exercises with solutions that can be used when conducting classes with students are accessible. The program has a very good technical support. There are several books describing the program's features. On the manufacturer's website, instructional videos can be downloaded and watched. Also, the online support is available.

FlexSim

FlexSim is a program for creating discrete events simulations developed by FlexSim Software Products Inc [14]. Family of FlexSim programs currently consists of basic simulation software FlexSim and FlexSim Healthcare Simulation (FlexSim HC). The main program uses the OpenGL environment to render 3D images in real time. It is possible to simulate not only the work of machines and conveyors but also working men, robots or forklifts.

The software is proprietary but students can use trial version for free. Unfortunately, it has limitations. Certain features cannot be used, such as: the tree view, debugging test scripts. The program has a very good technical support. Several books describing the workflow in the program are available on the market [15].

One digital line and three simulation programs

In order to compare the properties of simulation programs, a model of technological process was designed using three programs: Tecnomatix Plant Simulation, Arena and FlexSim.

The chosen technological process is decorating by engraving a kit consisting of ornamented packaging and two components: a USB memory and a pen. A customer selects a model and defines a content of inscriptions and decorative logo to be placed on objects. The logic diagram is in Fig. 1. It was chosen because it is a simple process, which can be simulated with students versions of all the considered programs. Moreover, this process contains elements which are necessary in the simulation of production lines. In this simple process, we can demonstrate the potential and difference of all programs. In this task, logic diagram, statistics, identifying of bottleneck and capability of the production line will be presented. The bottleneck is a quality control of engraved pens and USB. The process is divided into steps:

- Every 1 minute: providing a new set into the production slot.
- Split a set pen and USB memory (30 seconds).
- Engraving: pen (3 seconds), USB memory (5 seconds). The engraving of both elements is simultaneous.
- Quality control (1 minute) – rejecting those items, that do not comply assumptions of quality, such as: incorrect engraving or hidden defects of the products. The amount of rejected pens is 3% of the entire batch, and 1%. for USB memories.
- Completing the kit and packing in the box (30 seconds).

The simulation of process was performed for 8 hours. The modeled process can be observed and affected by changing the sample's size, speed of engraving and the percentage of recoil. In all three programs, it is possible to change the speed and duration of the simulation. This process is implemented in a small company. The students involved in the course taught by the author had a realistic production process to simulate, and some of them had even the opportunity to check the solution on the actual production line. The decorating kit, which is a result of students' work, is shown in Fig. 2.

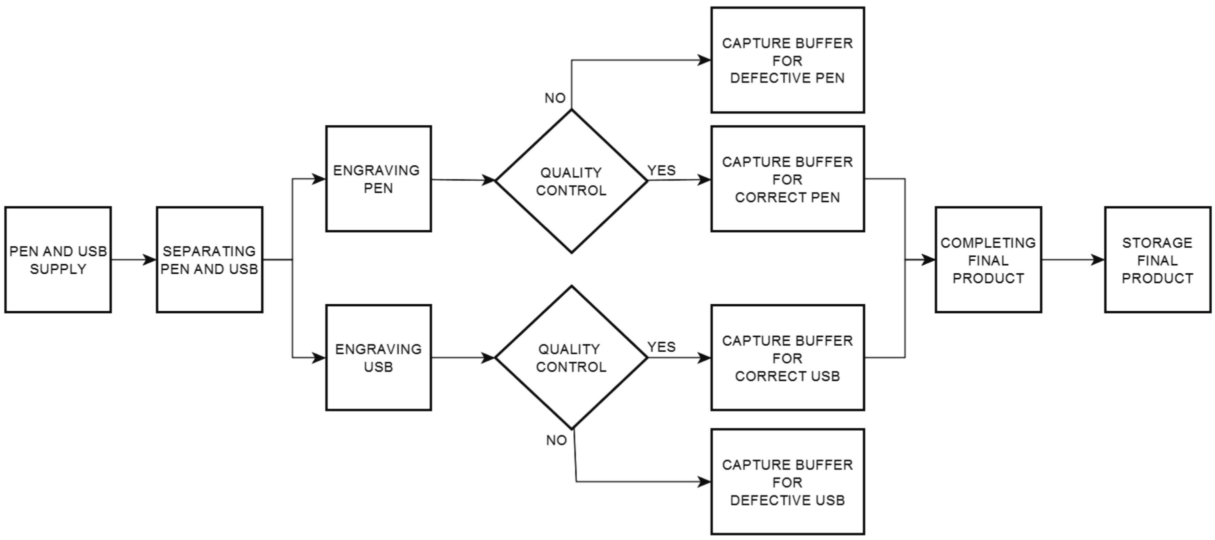

Fig. 1. Logic diagram of the decorating by engraving process.

Fig. 2. Example of a finished product.

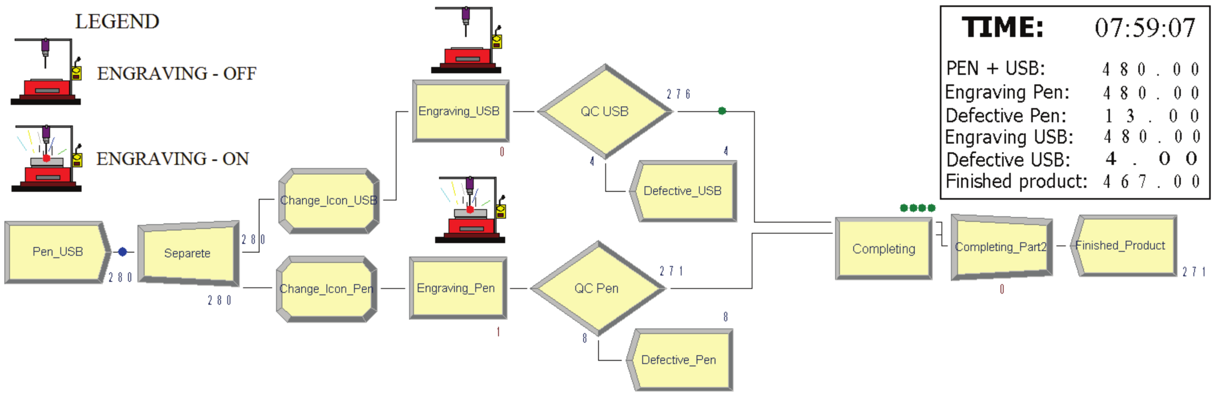

Fig. 3. Model and statistics of the decorating process realized in Arena.

Arena

Model and statistics realized using the Arena is presented in Fig. 3. All elements of the model are placed on the sheet by dragging and dropping the selected blocks. To insert again the same block, drag the object onto the sheet. A similar situation occurs when combining individual elements. After clicking on the icon Connect, only one pair of blocks can be connected. In order to connect the second pair, Connect function must be used again.

It is possible to simulate the operating conditions of the machine. Figure 3 presents two states: working and waiting for the product. There is also the possibility of changing the graphical representation of the object to be processed at different stages of production, e.g.: the whole set is marked with a blue sphere, but after the set is splitted, red sphere represents the pens and USBs are represented by green ball. The finished product was presented again as a blue ball. Unfortunately, the blocks simulating the process do not have the properties connected with efficiency. For this purpose, there are conditional blocks that accept the conditions as percentage or logical value. Decisive blocks cannot set the duration of this process. In order to simulate the duration of the quality control process, appropriate blocks should be used.

The program contains examples of models that shall facilitate the work. These models can be found in the Smart Files. They show how to solve common problems such as: animation of resources, logic of the decision, how to create a queue, how to work with external files or how to simulate the state of machines at work. In Arena there is no separate block used to carry out the process queuing and buffering. The queuing takes place using certain properties in some blocks e.g. the Process.

The effect of the simulation can be observed by the number of elements on the output of each module displayed on the model blocks. After each simulation, a report is generated. In addition, user can use the objects' Variable value to display the selected value anywhere. During the simulation, breakpoint and watch functions are available.

In Arena, creating a model of the process is very easy, but the user must keep in mind, that not all units have the ability to act in such time period as they should in reality. Blocks used to establish models are easy and simple to use. However, this simplicity implies their limited functionality.

Tecnomatix Plant Simulation

The model and statistics implemented using Plant Simulation are presented in Fig. 4 and machines' states distribution during the process are shown in Fig. 5. All the elements of the model are placed on the sheet using the "drag & drop" method. One of the drawbacks of the program is a method of connecting and inserting elements. After clicking the icon, only one element can be added. To insert the next element, the operation must be repeated. An analogous situation occurs during the process of combining elements of the model. The program allows to change and create own graphical visualizations, even at different stages of production.

Built-in models contain a lot of configuration parameters such as: time which the product spends in the machine, the number of products being processed, the conditions of entry and exit from the machine and its efficiency. The program allows to display any values that are the attributes of the block. In Fig. 4, it can be seen that not only the number of items leaving the individual blocks are shown, but also, in some cases, the number of input elements. Transporting elements such as conveyor belts or employees can also be simulated. The program has broad capabilities in terms of analysis: cost and ener-

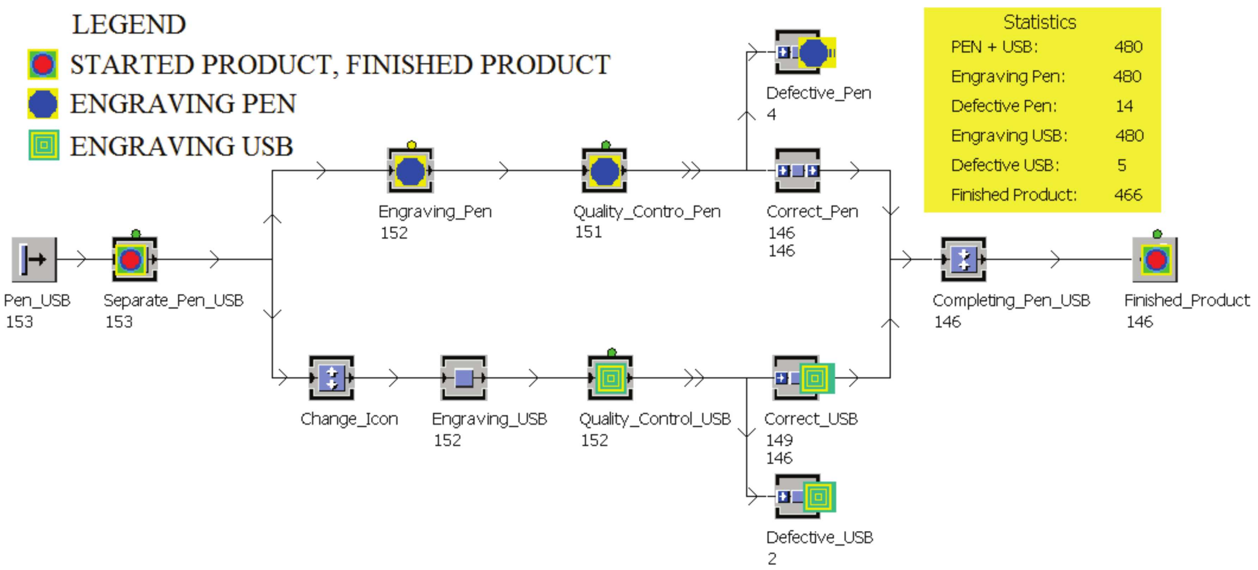

Fig. 4. Model and statistics of the decorating process realized in Plant Simulation.

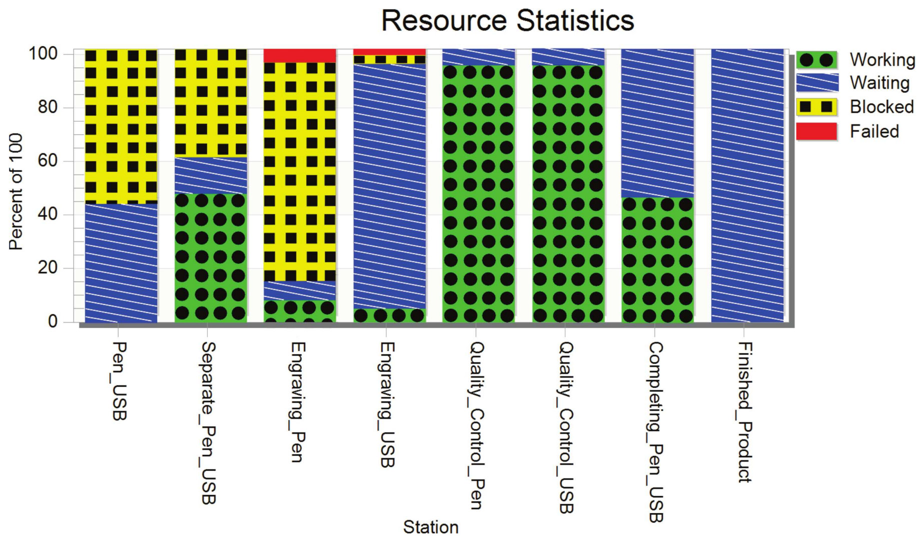

Fig. 5. Analyzing the machine states during the decorating process realized in Plant Simulation.

gy consumption, the percentage of working time and waiting time of machines. In addition, a workers schedule, charts and graph of states of the machine at every stage of the simulation can be created (Fig. 5). Based on this functionality, bottleneck and input-output relationship between machines can be identified. When built-in properties are not sufficient, custom functionality can be created by using blocks called methods.

Each object has a lot of properties and characteristics which significantly impedes the start of work. However, such number of features allows the simulation of very complex and sophisticated processes. In the exemplary process of engraving, efficiency of the machine was taken into account, but only in the process of quality control following the diagnosis correct and incorrect elements and their segregation to the respective blocks. However, the main drawback of the program is the lack of possibility to go back to the previous version of the project after saving the changes. Workaround is to make copies of the model, so that at any moment user could go back to the previous version. However, it is very annoying and significantly delays the progress of the work.

Each machine used in the program has an ability to assign to the model documentation and detailed information. The program has also models of hierarchy and inheritance, open architecture, genetic algorithm optimization and enables the simulation and analysis of energy consumption, automatic analysis of simulation and an ability to generate reports. The visualization allows to observe the product at various stages of production from different points of view.

FlexSim

The FlexSim can only simulate and visualize in 3D. The simulation and analysis is presented in Fig. 6.

Users can build a model by dragging and dropping predefined 3D objects from different classes. The parameters and functionality of the objects can be changed in the Properties tab or by using programming languages such as C++ or FlexScript. Using Tree View, the structure of the entire model including the characteristics of each element can be viewed, which helps in creating custom scripts.

The program allows to change graphical visualization elements at different stages of production, e.g.: in the examples process the whole kit is marked as a yellow square. After the engraving process, all the correct products are green and the incorrect are red. The student version cannot use the console and TreeView. The lack of this functionality makes it difficult to create custom methods. The program allows to generate a report in Excel format and analyze the output data using the table, graphs and by displaying the selected variables. Sample analysis is shown in the inset Fig. 6. Program allows to send messages between individual elements. For example: if the process did not end on one machine, a message can be sent from the other machine to stop the first one.

At the beginning of the creation of the program, a time unit in which the simulation will take place was defined. Unfortunately, the selected unit is very difficult to change during further work with the simulator. This application, as the only one, has the function of remembering which element was inserted into the worksheet and the function of remembering if the elements have been combined, which significantly simplifies and accelerates the process of creating the simulation. In this program, user can simulate the work of men, robots, machinery and transportation by conveyor belts, forklifts or workers. The processes during the simulation allow observation of the product at various stages of production and in different views.

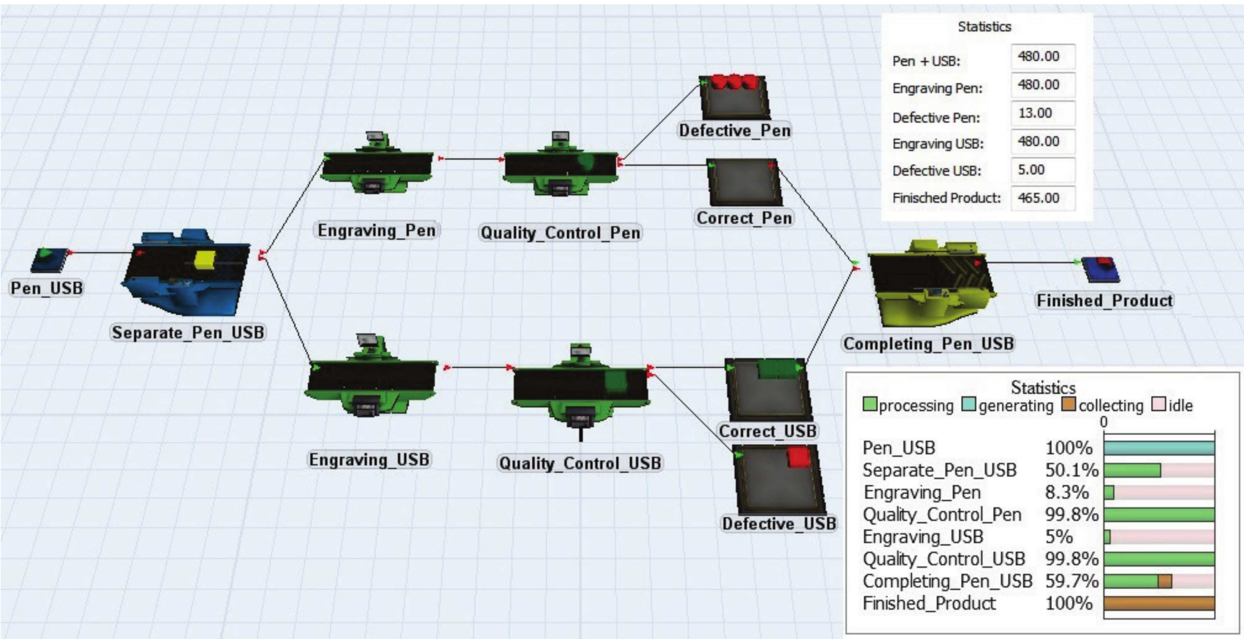

Fig. 6. Model and statistics of the decorating process realized in FlexSim.

Simulation of more complicated processes with 3D visualization

The production line layout and control logic visualized in 2D are enough to make assessment about the correctness of the design and the basic properties of the modeled process: bottlenecks and possible deadlocks, production statistics and efficiency of the machines. However, there are some aspects of production line modeling where the 3D visualization and even animations are much helpful. Among those aspects there are modeling and assessment of the physical interactions between machines (robots in particular), interactions between the machines and the human workers, and the ergonomics of work stands. In order to tell if the layout of a complicated production line is not only logically correct, but also if it leaves enough space to the workers, if the machines do not endanger the humans, etc. it is often necessary to see the whole design in 3D. Moreover, the 3D simulation and visualization may play crucial role when presenting the new design to the customers, who not necessarily are familiar with the symbols of the production line design and the specific simulation program. In addition, some programs can build the actual model of the operating environment using data from laser scanners. Such example is described in [16].

Therefore, in the second part of our analysis, we demonstrate how the considered simulation programs can deal with more complicated design problems and their 3D visualization. In this section, the RobotStudio has been included, although. this simulation software belongs to a different category than the other programs. It allows not only to simulate the operation of robots, but also to program them directly. On the other hand, RobotStudio does not allow to create an in-depth analysis of the simulated production process in terms of production statistics, percentage of defective products, etc.

This time the designs do not reflect actual production lines existing in some companies. As larger companies are quite reluctant to unveil details of their technology, we conceived some examples that span the spectrum of typical discrete production from packaging of pharmaceutics to the automotive industry. Although being only examples, the production lines are based on the description and/or CAD models of real components and machines that are freely available from catalogues and technical notes of various manufactures, and the general knowledge as to the respective technology. As these examples have been entirely designed by the author and the students working under her supervision they do not infringe any intellectual or commercial rights of real manufacturers, and thus may be used in education without any limitations.

Arena

In Arena, simulation of technological line is done using a separate tool: Arena Visual Designer. This tool utilizes information about objects used in the model. Unfortunately, this information is not used by the application to put elements into the environment. User puts all the necessary equipment and sets attributes. However, this process can be simplified using the information imported from the logical model. During the simulation, placement of the camera can be changed. There is also the possibility to share the visualization window to track the simulation from different angles of view. During the simulation, diagnostic and analytical tools can be used.

As an example simulation in 3D space, the line producing drugs in capsules has been used. Figure 7 presents the designed production line.

The production line consists of: the initial storage, encapsulating machine, conveyor belt, blister sealing machine and packaging machine. During the manufacturing process, five stages of production can be distinguished. First one is the transport of substrates from the warehouse that are needed for the next production stage – dispensing and encapsulating. In this step, workers bring materials using specially adapted carts. In the machine, capsules are opened, a suitable amount of powder is dispensed and the capsules are closed. Prepared capsules hit the conveyor. Every eighth capsule is subjected to quality control by inspection of weight. The third step is the delivery of the capsules to blister sealing machine. The machine uses rolls of foil delivered by workers. Next, the conveyor belt collects capsules. The next machine imprints lot number and expiry date. Each blister is checked for alignment of capsules within and if there are any holes that could be created during the sealing of the foil. All the work carried out by the machine is controlled by man. The fourth step is to pack blisters to cartons. The machine gets from the tray folded carton, leaflet and the right amount of blisters. Opens the carton and inserts blisters and leaflet, closing the carton and printing validity and batch number. Ready boxes hit the conveyor. The final step is packing boxes of drugs in cartons. Cartons are collected by staff and placed in a cardboard box. While doing so, the packaging is inspected. Closed boxes are placed on a pallet and transported to the warehouse, where they are handed forth to the customers.

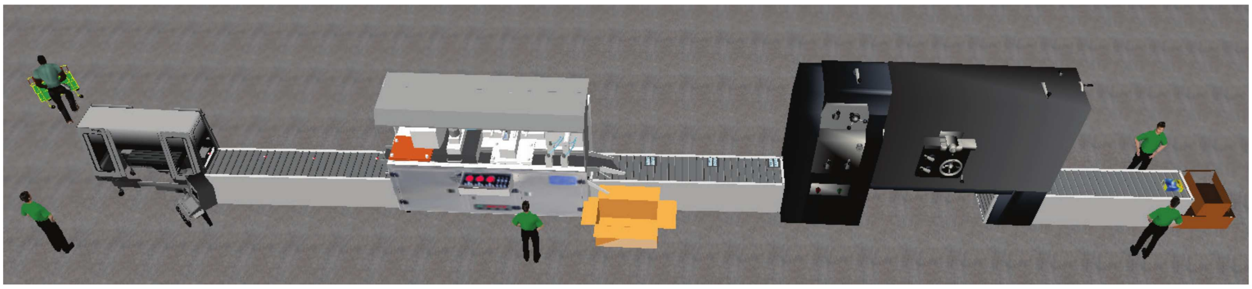

Fig. 7. 3D simulation of packed medicine technological process in Arena.

Tecnomatix Plant Simulation

Tecnomatix Plant Simulation designing in 3D space is achieved by changing the view of the display. 3D stage represents objects, that were used to create the logical model. User can design and load own graphical representation to the simulation. During the simulation, diagnostic and analytical tools can be used. The simulation of pouring beverage bottles and packaging of finished products into cartons (Fig. 8) was prepared in this program.

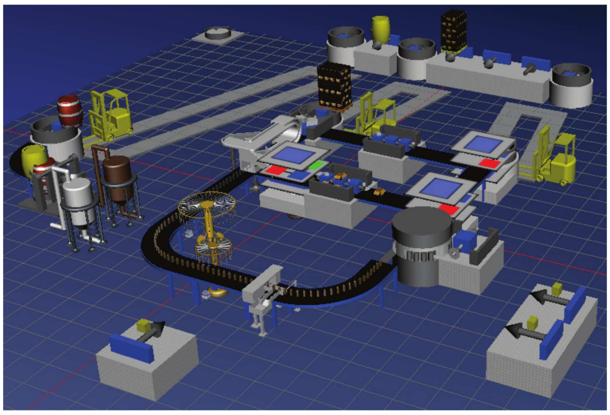

Fig. 8. 3D simulation of beverage technological process in Tecnomatix Plant Simulation.

The line consists of machines for unloading pallets, bottles unpacked from cartons, pouring, spiraling and packing nut. Employee brings palette from the storage and sets it to a designated place. What follows next, is sliding of layers of boxes from the pallet directly to the buffer standing in front of the machine. On the basis of the buffer fill level, the employee determines the frequency of delivery of pallets. After unloading all cartons, empty pallet is transferred to a separate conveyor belt leading to a buffer in front of the machine stacking cartons on pallets of ready products. Empty boxes will be used again during the packaging of filled bottles. Due to that, they are deposited on a separate conveyor leading to a buffer of packaging machine. When a worker places the barrel in a designated place, runs a machine that grabs the barrel opens it and tilts. Then the beverage is poured into the bottles that are closed with caps. The first inspection step is carried out in the machine scanning bottles. It checks the degree of filling of bottles and correctness of spins. The product is screened when passing through the machine. Bottles not meeting the requirements are marked. Then the sensor located at the end of the machine finds defected bottles and changes their trajectory. Next, the correct bottles are labeled. After that, bottles are checked by two quality controllers during transport to the packing machine. They selectively raise them from conveyor and examine. They are looking for disqualifying defects in the products, such as abnormal sticking labels, damaged bottles, chips on the bottles or bent nuts. Employees' rating is the most important element of quality control. Bottle packing machine for cardboard is the last stage of production.

FlexSim

The FlexSim allows to analyze the technological line only in 3D. Therefore, the analysis of the functionality and features of this scheme has been described in the previous paragraph. With the ability to change the view of the scene, the simulation can be watched from different angles. Simulation of an industrial robot and the other machines takes place by changing their kinematics. Creation of an animation of changing the position of the element during the simulation can be also performed. Additionally, custom 3D models can be loaded and new libraries can be created. In order to coordinate and control the work, transporters and operators can use the Dispatcher object. Task sequences are sent to the Dispatcher from an object and the Dispatcher delegates them to the transports or operators that are connected to its output ports.

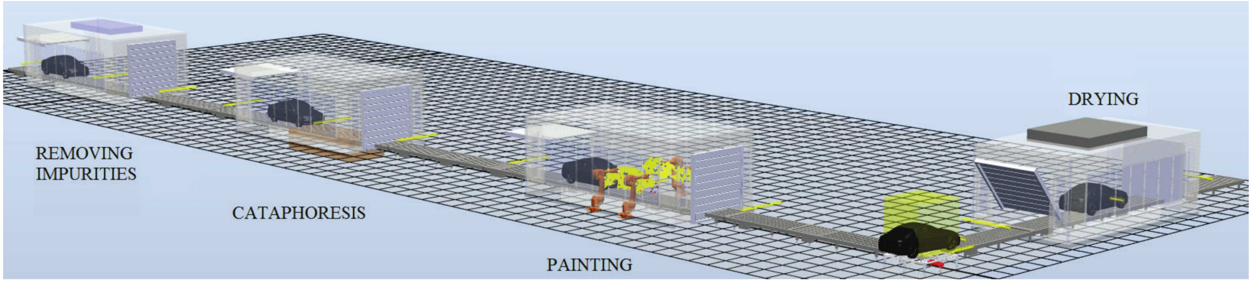

Fig. 9. 3D simulation of cars painting in RobotStudio.

RobotStudio

RobotStudio is a software used for offline programming of robots and simulation of how they work in production line. The program is developed by the ABB company [17]. Using this program, an automatic production line can be created. Simulation can only be done in 3D. Design process of a production line consists of placing all the required components and setting their configuration. The program has embedded ABB robots models. Using simulation and analysis, the robots' workspaces and coordination of all paths can be determined without risk of collisions. In order to program the robot, the simulation must install RobotWare that reflects the actual controller and allows the robot operation in a virtual environment. The program has an extensive database of machine models. It can be expanded with users' own models. Models published by other users on the manufacturer's website can be used as well. RobotStudio is delivered as 30-day trial version. The program has a large number of instructional materials, such as: films and production lines examples.

In this application it is not possible to use the tools performing statistics and analysis of flow elements. Work of robots and machines is coordinated by the controller and inputs and outputs of each element of the model. The trajectories of the tool of the robot can be modeled by creating virtual paths by points in space, using the virtual joystick or the Rapid language. In order to give proper functionality to machines and components, object named SmartComponent is used. Sensors are placed and objects are programmed to work as the complete machine. The application also allows the detection of two alarm states: the state before the collision and the collision state. By declaring the appropriate alarm conditions, information on the work of the whole can be contained, such as: possible conflicts, lack of power line components, information about the speeds of the moving parts and the position of the robots' arms.

The simulation designed using RobotStudio involves cars painting (Fig. 9). Robots paint the hull with mounted fenders, hood, doors and flaps. After entering the paint shop, next car is subjected to the pre-treatment. The body is rinsed with a special mixture of water with the appropriate chemicals that remove impurities. After that, the body is drained from the remaining liquid on tilting station. Next is cataphoresis – a process in which the body is immersed in a bath filled with water-borne paint. The surface is covered using the resultant electric field which contributes to very good coverage of paint. The sheet gets anti-corrosion properties. This is the first procedure that gives protection of the car. In the next block, three layers of paint are applied: lacquer primer, topcoat and clear. Paint is applied by electrostatic method which will allow it to reach hardly penetrable places. It is pulverized by four robots (Fig. 10). After application of the clearcoat, body moves to a dryer, where it is thoroughly dried.

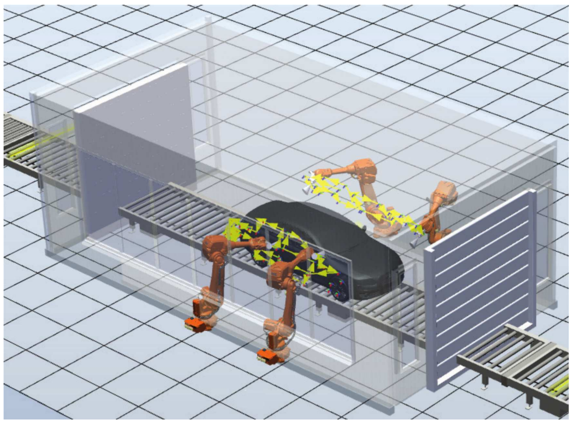

Fig. 10. 3D simulation of robots' motion in RobotStudio. Planned trajectories of the end effectors are visible.

Conclusions

Computer simulation of the processing line is an important step in the process of its design. Implementation of this step by using traditional methods, i.e. manual calculations would be extremely time-consuming due to the huge amount of data. In the simulation programs analytical calculations, such as those of machine capacity and efficiency, are processed automatically. The 2D modeling allows for the necessary studies related to the logical model of the process. It allows the user to test all decision-making processes, throughput and the number of batches. In contrast, the 3D simulation optimizes the deployment plan and prepares equipment for ergonomic workplaces in the most efficient way. At the stage of the design and simulation the equipment that will be used in the target project is selected. Thanks to this, before the final choice, the designer can test several different machines and select those that best meet the expectations.

FlexSim, Arena and Tecnomatix are dedicated for making analysis and logic diagrams. This is particularly a drawback whenever the production line involves robotic manipulators (industrial robots). In those programs we can simulate the work of robots, but it is impossible to program them, and check the validity of their workspaces and trajectories. If only the logic diagram has to be created, Arena from Rockwell offers the easiest and fastest tools to do that. Creating not only the production line logic diagram, but also adding some properties to them can be achieved more efficiently in Tecnomatix or FlexSim. All of these programs allow simulation in 3D environment.

RobotStudio differs significantly from the mentioned three programs. It is used mainly for off-line programming of robots. This program allows to plan trajectories for the robots, check the collisions possibility, and develop programs for the robots, but lacks an ability to create logic diagrams nor does it offer any tools for production flow analysis.

Thus, it should be considered as a tool supporting the production automation course in these areas, where the production plant/line simulators are not specific enough.

Simulation programs combine the issues of production and process engineering. Thanks to such programs, students learn how to design different production scenarios. Simulation programs can also serve as mock factories, where all the relevant information on production processes are located. Optimization of logistic efficiency and optimal use of resources provides as the result the information needed to make rational decisions at a very early stage of planning.

Unfortunately clearly identifying a single perfect application is not possible. Program selection is done individually, depending on the technological processes and the aspects of simulation that are most important to the particular project.

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