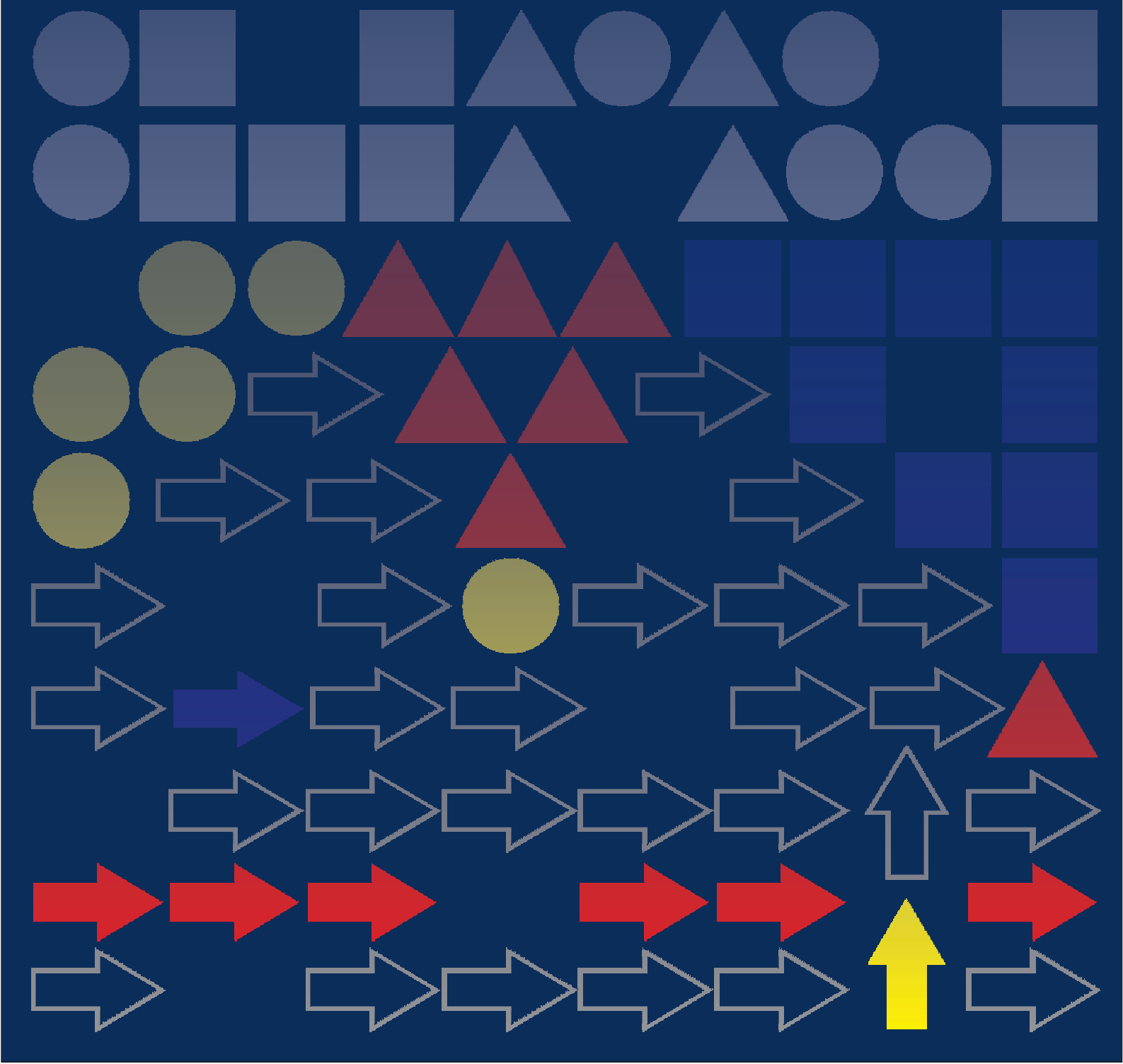
# ACTA SIMULATIO

International Scientific Journal about Simulation

electronic journal
ISSN 1339-9640

2020 Volume 6 Issue 3



# CONTENTS

**(SEPTEMBER 2020)**

Acta Simulatio - International Scientific Journal about Simulation
Volume: 6 2020 Issue: 3 Pages: 13-17 ISSN 1339-9640



*doi:10.22306/asim.v6i3.57*

*Received: 09 Jun. 2020*
*Revised: 29 Jun. 2020*
*Accepted: 15 Jul. 2020*

# USE OF COMPUTER SIMULATION FOR OPTIMIZATION OF ENERGY CONSUMPTION IN THE MANUFACTURING PROCESS

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***Keywords:*** computer simulation, energy consumption, industrial engineering
***Abstract:*** This article provides information on using computer simulation to optimise energy consumption in manufacturing. Simulation of energy consumption in operation is always performed to analyse large amounts of data. Results of computer simulation offer the possibility to analyse different scenarios of production or use of machines. Each of the variants brings different scenarios to optimise energy use in order to reduce costs and improve the operation. The article also describes the sequence of steps that a user can take to create a quality simulation model. At the same time, there are graphical examples of energy consumption measurements made during simulation runs.

## 1 Introduction

The development of technology and software solutions is relentlessly moving forward. Most often, new technologies and devices are purchased, or different methods and standards are implemented in companies, allowing them to reduce production time and increase production [8]. It also brings the possibilities of continuous improvement and detailed observation of processes in the company that have not been visible by computer simulation. Many computing ideas could be emerged by other digital factory tools such as virtual reality, augmented reality, mixed reality [10]. Computer simulation is no longer used not only to improve material flows and processes but also to improve working conditions in the workplace and optimise the investments.

At the Department of Industrial Engineering, we have been using computer simulation in projects for several years. Over the years, its use has been extended to several areas to help designers evaluate their designs, improvements and detailed results from their production. This article will describe the use of software tools to optimize energy consumption in production and the results they provide.

Simulation of the energy consumption of operation is always performed to analyse large amounts of data. In order to measure the partial productivity of energy at lower levels of the company, it is necessary to monitor the amount of energy consumed throughout the company [2]. For solving this problem, it is possible to use the sequence of steps described in this article. These steps must be taken by the user to create a simulation model.

## 2 Computer simulation of energy consumption

Energy monitoring is an exact regular measurement of energy consumption with a correlation of energy consumption (concerning the product produced). Computer simulation results show how energy is consumed, and then the potential for energy savings can be identified. Monitoring and evaluating energy consumption are necessary from different perspectives [1]:

- **Energy consumption can be monitored over time -** When data is exchanged, those responsible for energy management - staff, dispatchers and others - can analyse and modify their activities.
- **Eliminate energy problems** - Continuous monitoring of energy consumption helps to identify problems. A sudden unexplained increase in consumption requires that the reasons be investigated immediately.
- **Investing -** Usage of computer simulation helps to identify which places in the company have the highest energy consumption, and by this save the costs. By simulation, it is possible to test different conclusions, and by changing the parameters in the simulation, it is possible to monitor energy fluctuations.
- **Identification of critical points -** The primary elements on which consumption of different types of

energy can be measured are machines, containers, conveyors, robots, etc.

A significant part of the energy - electricity consumption is in production, mainly in machinery and equipment. However, after the development of possibilities of computer simulation software, it is possible to include here lighting, ventilation, cooling, or system failures also. Even though these indicators may not have a significant impact on production, they may trigger other problems that may stop the smooth running of production and increase costs. Manufacturing processes are so complex, interconnected with internal and external logistics that it is impossible for long-term disruption of production due to an unverified decision. For example: "Decentralized coordination and route planning face the challenges such as scalability, dynamic changes in the environment, continuous planning, and coordination issues "[4].

The software tool that is used by the Department of Industrial Engineering, Tecnomatix Plant Simulation, provides a statistical tool for energy consumption assessment called Energy Analyzer. This tool is patented by SIEMENS (U.S. Patent App'l Pub. No. 2013/001863) [6]. Energy Analyzer leads to a decrease in the cost of labour, energy and other costs, also help managers to create right decisions. It is, therefore, primarily a supportive tool for decision-making. The energy consumption indicators for machines or equipment that we can evaluate with Tecnomatix Plant Simulation include [kW]:

- Total energy consumption indicator.
- Energy consumption of operation.
- Total energy consumption of any object while it was working.
- Power consumption during the setting of the object.
- Operating energy consumption.
- Energy consumption at the time of machine or equipment failure, etc.

## 3 Data collection for needs of creation of the simulation model

Data collection for needs of creation of this kind of simulation model of energy consumption may run for example by using information system or by a physical collection of data. In the industrial field, productivity, quality, reliability, and safety heavily depend on the performance of the technologies employed [3]. Many technologies could help gain data from real-time machine performance evaluation:

- **Current technologies -** require integration of many different technologies, including wireless communication, virtual integration and interface platforms (Dynamic Data Exchange Interface, SQL/Oracle Interface, Open DataBase Connectivity Interface, and other). Companies need to have an integrated telecommunication network and information technology through which they can transmit the necessary information and dates within the organisation too. The next stage of evolution within these long-standing, leisurely-evolving technologies is here and the new generation of internal and external logistics is already knocking on the door, waiting to change logistics as we know it today [11]. It enables interconnection of software applications between sensors, mobile devices and cameras placed on the equipment, thanks to which it is possible to gain a vast amount of data. The industrial equipment (machine, forklift, etc.) is monitored and controlled for analysing compression, temperature, moisture, and vibrations. Databases realise the import of these data (for example, SAP, ORACLE and other) into the simulation software.
- **Future of technologies -** Developments of technologies change sensors, how we know them to the Smart sensors, combined with the internet of things and clouds. They are changing the way of how manufacturers collect data and communicate with staff. Then it is a technology called Very Large Scale Integration, what is the process of miniaturization of computer chips. Also, very interesting is the development of modular equipment, drones, artificial intelligence, computer vision, cobots, augmented reality and others.

So that all data obtained from simulation software could be used and shared in a link to virtual reality, internet of things, expert systems, link to extended reality, decision support systems and other. In order to create simulation model, it is necessary to know the basic steps of its creation, in order to avoid unnecessarily prolonging the time of its creation and to avoid errors that can have serious consequences. Figure 1 shows a shortened process of creating a simulation model (Figure 1).

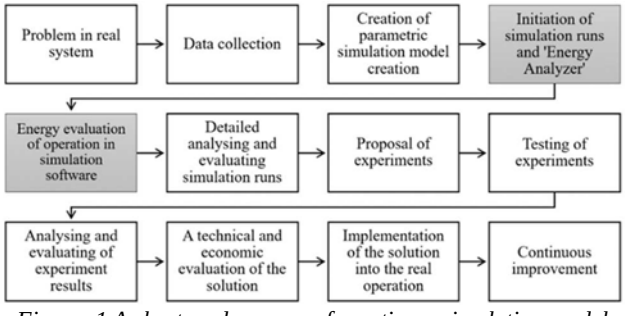


*Figure 1 A shortened process of creating a simulation model [Main author]*

Before the step of the creation model, it is necessary to named and described problems in the company. Only then it is possible to do a step of constructing a real-system simulation model and its settings. It consists of settings of passive elements (machines, warehouses, handling units, conveyors, etc.), active elements (products, staff, entities,

**USE OF COMPUTER SIMULATION FOR OPTIMIZATION OF ENERGY CONSUMPTION IN THE MANUFACTURING PROCESS**

Monika Bučková; Martin Gašo; Štefan Mozol

etc.) and program settings (time constraints, safety constraints, system constraints, etc.) and other settings. After the simulation model is set up, it is possible to start a simulation runs. If the simulation software does not find errors in the basic settings and its match with the user's requirements, is it possible to continue with advance settings. Energy consumption settings include additional data that staff need to collect in the system, as already mentioned using current technology or manually, examples of data [1]:

- **Conveyors** [Power input - kW] – working state of the machine, setting up, operation, failed, standby, Off state of the machine.
- **Machines** [Power input - kW] – working state of the machine, setting up, operation, failed, standby, Off state of the machine.
- **Machines** [Transition times] – Operational – Off, Off – Operational, Operational – Standby, Standby – Operational, Standby – Off, Off – Standby, etc.
- **Manipulation machines** [Battery] – Charge [Ah], Basic consumption [A], Capacity [Ah], Charge current [A], Driving consumption [A], Reserve [Ah], etc.

## 4 Evaluation of simulation model results

The information described under Machines is the same for equipment in warehouses, dedicated storage, buffers and robots. After the first simulation runs, experiments are conducted with the simulation model to produce results that need to be correctly interpreted and used to improve the system. Only after these steps, when the validation and verification of the model confirmed its accuracy, it is possible to start statistically evaluating the energy evaluation of the operations. After these steps, there should be no significant changes in the model that would affect the statistical evaluations. The following explained figures were also created at the Department of Industrial Engineering.

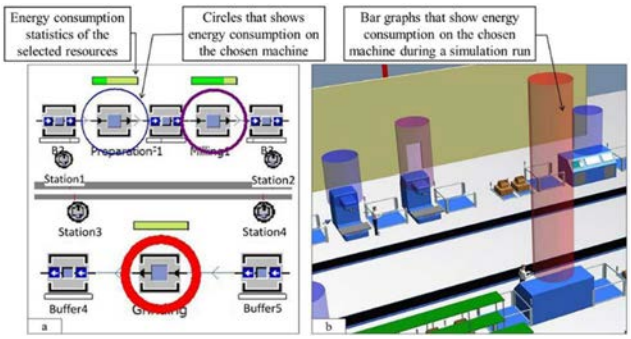


*Figure 2 The sample of the machines energetic evaluation in the 2D (a) and 3D (b) visualization [Main author]*

Figure 2 shows the 2D (a) and 3D (b) views of simulation using Tecnomatix Plant Simulation. The circles represent the energy consumption of the machines on which the is measuring is running. The energy consumption during the simulation run can be visualized in two ways, in 2D and 3D view. In the 2D view, it is possible to see circles (Figure 2 (a)):

- **Red wide circle** - highlights the highest energy consumption.
- **Purple circle** - points to average energy consumption.
- **Thin blue circle** - points to the lowest energy consumption.

In the 3D view, on the Figure 2 (b), graphical visualization is represented by bar graphs of any colour. In the watch mode, the graphic is automatically updated after each modification of a displayed value, the value must be observable [1]. Energy Analyzer, as a patented Simulation Energy Measurement Tool, developed by Siemens, provides energy status data [6]. Displaying results after simulation runs gives information about total energy consumed in each production cell or a production hall. Directly during the simulation, it measures within the set time frame how much energy was consumed during operation (Figure 3). Utilization of computer simulation will make it possible to monitor the energy delivery-chain systems, reduce the energy consumption, and prevent the failures of energy systems and blackout of the power systems.

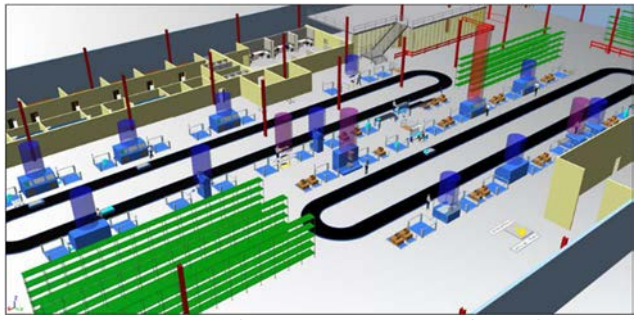

*Figure 3 The sample of 3D simulation model of manufacturing process [Main author]*

Before named technologies and their introduction into industrial practice often result in side effects, and these are problems with another consuming of energy. Therefore, the so-called energy networks arise that help to extract and distribute excess energy. At the same time is developing in progress of energy storage systems that excess energy which is provided during a period of an energy shortage, or even allowing the use of stored energy in other contexts. Among the most monitored energy consumption that can be verified by computer simulation and examples shown next, are lightning, conveyors work, machines and handling equipment work:

- **Lighting** - It has an economic impact, but also affects the work of employees, affects work safety, provides the possibility of further development of technologies

(connection to sensors, smart lighting). Lights can be found in all essential parts of the company. It also creates better conditions for spreading RF communication and the ideal place for installing cameras and sensors, or other technologies to collecting a higher amount of data. An illustration of the measurement of electricity consumption of lighting during the simulation run was created in the Tecnomatix Plant Simulation 14.2.3 simulation software (Figure 4). Power Input shows the power consumption measurement at the time of production for three days, in kW. If the company does not have installed sensors, an example of such results (Figure 4) after simulation runs can help managers to decide whether buying of smart sensors will help to for example reduce electricity consumption for lighting. Such sensors can record movement in the workspace. When the movement in the workspace is detected, the lamps will turn on lights, when movement stops for a specific time, the lights are switched off. This small step also reduces energy costs. Usage of computer simulation only for this type of energy consumption is expensive, so it is better to use it within as part of more extensive solutions. Usage of the various software solutions accurate analyses of the current state of workplaces are made, as well as new production cells to achieve the lowest possible electricity consumption and thus contribute to overall production higher efficiency.

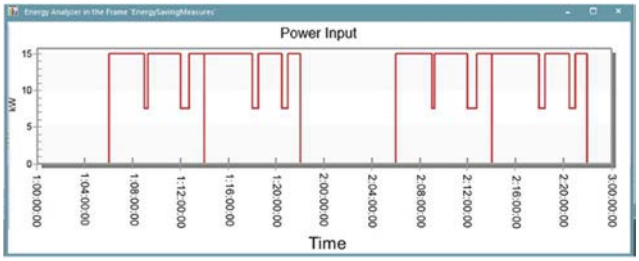


*Figure 4 Graph of measurement of electricity consumption for lighting [Main author]*

- **The energy needed to work of conveyors** - Software solutions allow optimizing the operation of conveyors. If the conveyor is accumulating, and all parts have accumulated and no new part enters, the conveyor stops to save energy (and reduce belt friction) [6]. If the operator has any problems during manufacturing, all products start to accumulate on the conveyor, and no new part enters, the conveyor stops to save energy (and reduce belt friction). In the simulation, it is possible to find out how much energy can be saved by this step. An illustration was created in the Tecnomatix Plant Simulation 14.2.3 simulation software (Figure 5) also. Power Input shows the power consumption measurement at the time of production one workday, in kW. Additional energy consumption may occur when the operator is waiting for products, for maintenance, or unexpected external effects such as failure to deliver the material.


*Figure 5 Graph of measurement of electricity consumption by the conveyor [Main author]*

- **The energy needed to work on machines and handling equipment** - The reason for the loss depends on the machine. Machine tools include numerous motors and auxiliary components [5]. For electrical machines which include motors and generators, for example, the losses are electrical resistance in conductors, current heating in the magnetic circuits, mechanical friction, windage friction in addition to other factors. Computer simulation can help reduce energy loss on machines during this and another different state (for example working, repairing, waiting, and so on.). An illustration of the measurement of electricity consumption by the machine during the simulation run was created in the Tecnomatix Plant Simulation 14.2.3 simulation software (Figure 6). Power Input shows the power consumption measurement at the time of production for 8 hours, in kW. Also, it is possible to see an energy consumption on Lathe 2, in the throughput is it possible to see a calculator of manufactured products. Energy Analyzer tool is described in the previous chapters.
- From the start of the process itself to individual component consumption, savings potential can be evaluated, and measures defined for more efficient use of energy during this process. One area of potential savings comes from the machine tool base load, which consumes energy even in non-productive phases. The base load is determined substantially by the machine's auxiliary components. Besides the use of energy-efficient motors in these components, many opportunities for reducing the base load can be found [5]. Some energy consumers, for example, can be switched off by the machine control during non-productive phases. Scrap also inevitably increases energy consumption. Also, it is possible to calculate the energy for lighting, ventilation, and air conditioning too.

**USE OF COMPUTER SIMULATION FOR OPTIMIZATION OF ENERGY CONSUMPTION IN THE MANUFACTURING PROCESS**

Monika Bučková; Martin Gašo; Štefan Mozol

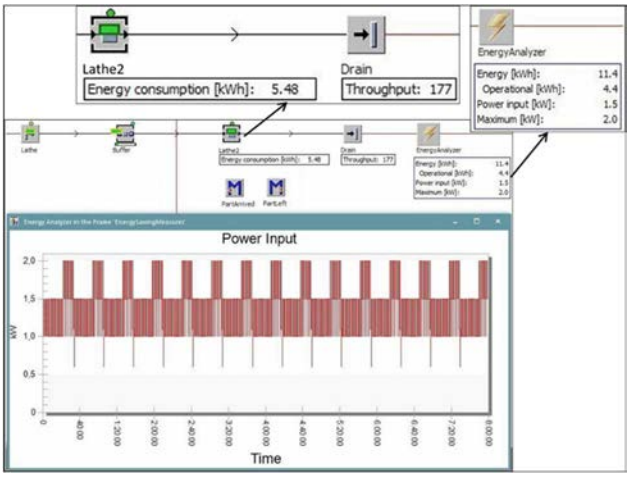


*Figure 6 Graph of measurement of electricity consumption by the machine [Main author]*

## 5 Conclusion

One of the primary goals of each company is to increase the effectivity of the particular processes by using simulation [9]. Energy consumption monitoring can be used to reduce energy consumption based on the results of simulation runs. Software products have built-in solutions whose proper use will bring benefits of digital factory to all levels of the business. The term digital factory summarizes the various efforts in depicting a factory operation process with the aid of a simulation environment [7]. The simulation and other digital factory tools become a reliable support tool for the forthcoming 4th Industrial Revolution, called Industry 4.0. After periods of use of first manufacturing machines, mass production, and integrated PLC systems, there comes a time of smart factories and manufacturing, in which modern technology will play a primary role. Energy consumption and management are essential aspects of this kind of production and planning. All enterprises create their own procedures of success, use similar methods, tools, and techniques [3].

**Acknowledgement**

This paper was supported by research project KEGA 017ŽU-4/2019 Digitalization in industrial engineering for students of technical focus, and the project University Science Park TECHNICOM for Inovation Application Supported by Knowledge Technology, ITMS: 26220220182, supported by the Research and Development Operational Program funded by the ERDF.

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# JOURNAL STATEMENT


| | |
|---|---|
| Journal name: | **Acta Simulatio** |
| Abbreviated key title: | Acta Simul |
| Journal title initials: | AS |
| Journal doi: | 10.22306/asim |
| ISSN: | 1339-9640 |
| Start year: | 2015 |
| The first publishing: | March 2015 |
| Issue publishing: | Quarterly |
| Publishing form: | On-line electronic publishing |
| Availability of articles: | Open Access Journal |
| Journal license: | CC BY-NC |
| Publication ethics: | COPE, ELSEVIER Publishing Ethics |
| Plagiarism check: | Worldwide originality control system |
| Peer review process: | Single-blind review at least two reviewers |
| Language: | English |
| Journal e-mail: | **info@actasimulatio.eu** |


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