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ANALYSIS OF THE SELECTED SIMULATION SOFTWARE PACKAGES: A STUDY

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Abstract: The simulation software market is becoming more complex and universal. Computer simulations are thus more accessible and are becoming a modern tool that has a wide application in industry. Their potential and benefits can be used in small and large projects. A simulation model can take into account inventory, assembly, production and human resources, leading to decisions that can maintain or improve efficiency at the lowest possible cost. The data obtained through the simulation allow to test different combinations and scenarios in the virtual world. The benefits of manufacturing simulation include reducing investment risk, minimizing waste, improving efficiency, reducing energy consumption and even increasing worker health. The question arises as to which of the possible simulation packages is the most suitable for a given company, so that the investments made are the best possible. In the first part of the paper the theoretical basis of simulation in Industry 4.0 is presented, including the description of the possible simulation modelling tools. The second part of the paper offers comparative and descriptive analysis of six selected discrete-event simulation software packages – AnyLogic, Arena, FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS. The given simulation tools are compared based on their main characteristics, simulation features, application areas and popularity among the companies which use simulation software packages.

1 Introduction

The Fourth Industrial Revolution (Industry 4.0) assumes a new approach to production based on the massive introduction of information technology in industry, large-scale automation of business processes and the development of artificial intelligence. The advantages of the Industry 4.0 are clear: increased productivity, greater worker safety by reducing jobs in hazardous working conditions, increased competitiveness, ground-breaking products, and much more. Achieving Cyber-Physical Systems and Smart Factories is the goal of the Fourth Industrial Revolution.

The desire to implement its concept leads to the need to use the capabilities of modern computer simulation, since it is an effective means of researching new processes and testing new products, devices and technologies. Due to the complexity and interconnectedness of scientific and production tasks formulated within the framework of the Industry 4.0 concept, it becomes necessary to apply a variety of types of simulation, regardless of whether it is customary to call them simulation modelling or not.

1.1 Industry 4.0

The Fourth Industrial Revolution (Industry 4.0) is a transition to fully automated digital production controlled by intelligent systems in real time in constant interaction with the external environment, going beyond the boundaries of one enterprise, with the prospect of uniting into a global industrial network of things and services. The purpose of Industry 4.0 is to build a highly flexible production model of personalized and digital products and services, with real-time interactions between people, products and devices during the production process [1]. In a narrow sense, Industry 4.0 is the name of one of 10 projects of the Germany's Hi-Tech strategy 2020, describing the concept of Smart Manufacturing based on

the global industrial network of the Internet of Things and Services [2].

Industry 4.0 consists of a wide range of fundamental concepts such as Smart Factory, cyber-physical systems, decentralization, individualization of distribution and procurement, adaptation to human needs etc. [3]. There are three main elements ensuring the effectiveness of the Industry 4.0 performance [4]:

- Horizontal integration across the entire value creation network (it includes every link, which is in the value chain as well as the relationships that are formed, developing and maintaining value-creating and value-adding networks) [5][6][7][8][9].
- Manufacturing systems, vertical and network integration (it is the process of connecting all levels of a manufacturing enterprise – from the technological site and workshop to the level of administrative management).
- End-to-end engineering (analysing data collected throughout the manufacturing process in a systematic manner, allowing for quick decisions and product or service follow-up with an emphasis on quality and customer satisfaction).

The main difficulties in implementing Industry 4.0 are associated with the following factors:

- Price. Although it is potentially beneficial to upgrade systems to Industry 4.0 standards, a significant initial investment is needed.
- Technical difficulties. With more technology and less human oversight, there is a risk of technical problems that can be costly.
- Layoff. With any technology upgrade, there is a risk of job loss, and Industry 4.0 is no exception, however, there are also forecasts that industrialization will create more jobs than it will eliminate.
- Cybersecurity issues. When the entire enterprise is connected to the Internet, cyber security issues may arise.

However, there also exists a number of considerable benefits such as the following:

- New opportunities. With the help of analytics and data, companies can find ways to expand their business and enter new markets.
- Efficiency. Using robotization and automation, products can be produced faster and more efficiently, especially when smart technologies are involved.
- Saving money. By adopting Industry 4.0 principles and technologies the risk of costly mistakes can be reduced.
- Improvement of the customer experience. The analysis of customer needs and customization lead to fast reactions on customer demands and increased competitiveness.
- Increased income. Despite the high initial investment, Industry 4.0 can generate much more revenue for companies. This can be attributed to higher efficiency, fewer defects, new opportunities, and better customer experience.

Industry 4.0 is based on digital and physical technologies with the former considered to be closely connected to modern communication and information technologies and the latter to manufacturing. Those technologies are the following [10]:

- Additive manufacturing
- Artificial intelligence
- Augmented reality
- Autonomous robots
- Big data and analytics
- Blockchain
- Cloud
- Cobotic systems
- Cybersecurity
- Unnamed aerial vehicle
- Global Positioning Systems
- Internet of Things
- Mobile Technology
- Nanotechnology
- RFID
- Sensors and actuators
- Simulation

1.2 Simulation in Industry 4.0

The main purpose of simulation tools is to enable enterprise management to use the results of calculations when making decisions. Such tools help to check, confirm and ensure the declared properties of the product, produce the most complex and high-quality goods according to the highest standards, achieve economic efficiency of production, and minimize the design time and the number of full-scale tests. The importance of simulation tools in the infrastructure of modern production management is growing from year to year as the requirements for product quality and the complexity of technical objects increase.

Simulation is also a basic element of some Industry 4.0 technologies and concepts, for example, its application in hybrid modelling, data analytics, simulation-based training/product design, designing connectivity. Thus, simulation has an important role in fulfilling the Industry 4.0 vision [11].

The prerequisite for the implementation of the simulation is the creation of a model in the simulation program. Together modelling and simulation represent a problem-solving tool for various spheres such as engineering design, education, prototyping and concept evaluation, forecasting, education and training, risk/safety assessment, performance evaluation, sensitivity analysis, evaluation of decisions or action alternatives etc. [12] One of the most prominent application domains for simulation is manufacturing: there its full potential can be fulfilled and, moreover, some issues in industry can only be solved with the help of simulation product development variations. Apart from obvious advantages, simulation

offers manufacturing a great number of benefits such as providing efficient trainings for new operators or for refreshing skills of experienced ones, reducing risks, start-up times, commissioning time and cost [13].

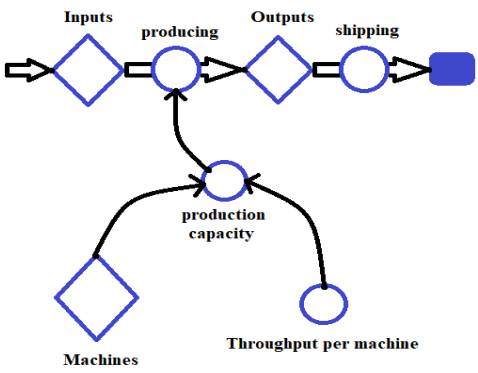
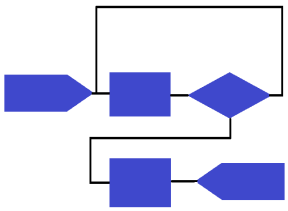
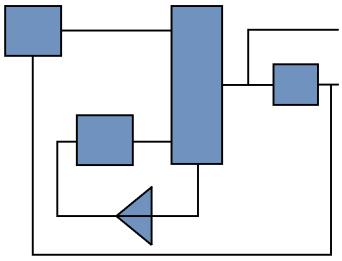
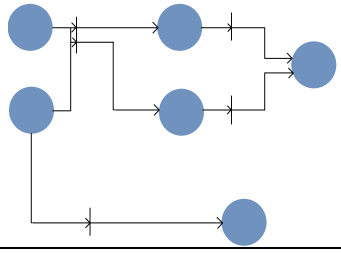
1.3 Simulation modelling tools

Today there is a great number of analytical software products focused on simulation on the information technology market. The range and variety of such software continues to grow. As the dominant basic concepts in modern simulation modelling are used [14]:

- discrete-event simulation systems (description-based systems for process description);
- systems based on network paradigms (are used in structuring causal relationships and modelling systems with parallel processes, serving for stratification and algorithmisation dynamics of discrete and discrete-continuous systems);
- systems based on process models and organizational structures;
- systems focused on continuous modelling;
- dynamic systems;
- other.

Table 1 shows environments oriented towards different approaches in simulation modelling, which shows that the market is very uneven [14].

Table 1 Environments oriented towards different approaches in simulation modelling

Systems focused on continuous modelling		Vensim, iThink, Powersim, AnyLogic
Discrete-event simulation systems		AnyLogic, Arena, SIMUL8, FlexSim, Tecnomatix Plant Simulation, WITNESS
Dynamic systems		MATLAB
Systems based on network paradigms		ARIS

In this paper the emphasis is going to be on the discrete-event simulation – the most commonly used simulation system. The majority of companies prefer commercial simulation software products to general-purpose programming language [13].

2 Methodology

The fulfilment of the tasks set in the work is carried out on the basis of the application of general scientific research methods within the framework of comparative analysis, as well as through the graphic interpretation of information. The study consists of the descriptive research of the six selected discrete-event simulation software packages that can be implemented in Industry 4.0 – AnyLogic, Arena, SIMUL8, FlexSim, Tecnomatix Plant Simulation, and WITNESS (Table 2). Those software simulation modelling tools are chosen for further comparative analysis of their main features and application areas. The literature review of those software's applications and case studies is conducted using 35 articles taken from academic journals published from 2015 to 2021 and one article published in 2010.

2.1 Application of the selected simulation software packages based on literature review

Tecnomatix Plant Simulation was used to analyse the bottleneck process and scheme comparison of two logistics solutions for an automatic plant [15] and for designing and simulation of the mining rail transport to get an objective view of their systems, though the program is mainly used for the manufacturing processes [16]. This software was considered the most appropriate tool for the computer simulation of automated guided vehicles systems [17] and one of the best solved software in the area of production solutions [18]. It was also noted that by using this simulation software, enterprises cannot only save costs but with the help of monitoring system they have undesirable effects and failures reported [19] and have considerable improvements in the production process efficiency [20].

Using **FlexSim** simulation software it is possible to determine the most cost-efficient way of production process reorganization and analyse individual results and subsequent optimization [21]. Moreover, the cyber learning factory for operations management-oriented smart factory education and training was created in FlexSim simulation environment and can be used to train information systems architects of IT companies and operations managers of manufacturing companies [22]. FlexSim can also be a helping simulation tool in decision making systems [23] and optimization of manufacturing industry [24]. It allows to experiment with other manufacturing processes without interrupting the running process [25] and is easy to use providing a dedicated environment for manufacturing simulation [26].

Models developed in **AnyLogic** simulation environment are used as a helping tool for analysts in decision making and allow to estimate the efficiency of vehicle schedules [27]. AnyLogic simulation software is also used for pedestrian flow simulation in crowded areas [28], for analysing and realizing the security system, including information security and perimeter [29], for comparison of different approaches to highway management [30] and for the integration of enterprise inventory resource [31]. The system also allows to use the built-in genetic algorithm to optimize the model's primary parameters [32].

Arena is a discrete-event simulation software originally developed by Systems Modelling Corporation and later acquired by Rockwell Automation. Mostly the discrete event methods are used but there are also tools available to cover areas in agent-based and flow modelling. This simulation tool uses flowchart modelling methodology and models can be enhanced with 3D animation [33]. Arena simulation software provided "as-is" model for adoption of Hold Baggage Security Screening (HBSS) system model at Kuwait International Airport in order to improve a system performance [34]. This simulation tool was also used to evaluate the performance measures of the queueing system [35], determine the reason of queueing occurring at berth allocation [36] and to design security-check systems for screening aviation passengers [37]. Arena is commonly used for conducting experiments based on abstract model to estimate the chances of the implementation and applicability of the proposed systems [38] and for improvement of the service level by exploring the staffing schemes [39].

SIMUL8 is a software package used for discrete event simulation but is commonly used for a process simulation, not a production one. Even though it may not be the most suitable software for the manufacturing processes analysis but it is easy to use and the results of the simulation performed in SIMUL8 environment can be simply interpreted [40]. It is a great tool to explore possible "what-if" scenarios, create a visual model of distribution and manufacturing purposes [41]. SIMUL8 is also used for rail system design, train formation operational processes and metro timetable evaluation, and railway utilization analysis since it provides a proper flexibility to perform simulation trials of various scenarios [42], [43]. The given software was compared with the four other simulation software packages – OpenTrack, Xpress MP, Arena, RailSys – to choose the most suitable one for railway simulation modelling to prove the feasibility of the proposed baggage transfer service. As a result, SIMUL8 was suggested as the best computer-based simulation software due to its easiness of use and user-friendly interface [44].

WITNESS simulation software uses simplified models that can recreate basic business processes and this system is capable of reproducing various situations. It can determine crucial processes and validate real output using production data [45]. WITNESS was also used to analyse issues connected with assembly line and resulted in

operator's productivity increase and assembly line efficiency improvement [46]. It represented a helping simulation tool when it came to optimal utilization of resources, solution for material handling in warehouses and smooth customer-oriented material flow [47]. Together with industrial engineering methods this simulation software package can be used for significant balance improvements of the production line [48]. WITNESS is a general purpose simulation software thus it was suitable for traffic and single-lane roundabouts simulation [49]. Considering its advantages and application industries, WITNESS served as a basis for a simulation method of teaching of logistics, giving students the opportunities and simulation environment to apply their theoretical knowledge and create production models [50].

Table 2 Environments oriented towards different approaches in simulation modelling

Software	Developer	Package modules	Areas of use	Deployment
AnyLogic	AnyLogic Company	System dynamics analysis, risk analysis, optimization, planning, decision support.	Supply chains, manufacturing, transportation, warehouse operations, rail logistics, mining, oil and gas, ports and terminals, road traffic, passenger terminals, healthcare, business/social processes, asset management, marketing, defense.	Mac, Windows, Linux
Arena	Systems Modelling Corporation	Model verification, analysis of inputs and outputs data, modelling, model verification.	Manufacturing, logistics operations, business processes, supply chain, medicine, military-industrial complex, banks and ATMs, vehicle planning and scheduling.	Windows
FlexSim	FlexSim	Model building, 3D simulation, model analysis, optimization	Manufacturing, material handling, healthcare, warehousing.	Cloud, SaaS, Web-Based, Windows
SIMUL8	SIMUL8	2D process visualisation, workflows animation, business process modelling, the possibility to share simulation and connect to live data sources	Healthcare, manufacturing, automotive, call centres, pharmaceutical chain and logistics, business process management, government and justice.	Cloud, SaaS, Web-Based, Windows
Tecnomatix Plant Simulation	Siemens	Manufacturing, transportation, loading and unloading operations, business process simulation, logistics, sales, scheduling, production rhythm, process verification, supply chain	Discrete manufacturing (automotive, electronics, shipbuilding, machine tools, assembly lines, etc.), logistics, sales, consulting, healthcare, banking.	Cloud, SaaS, Web-Based, Windows
WITNESS	Lanner Group	Manufacturing, optimization, planning, scheduling, business process modelling.	Aerospace, automotive industry, aviation, criminal justice and policing, defense, food sector, healthcare, logistics, manufacturing, nuclear, pharmaceuticals.	Cloud, SaaS, Web-Based, Windows

2.2 Comparative analysis of selected simulation software packages

FlexSim, SIMUL8, Technomatix Plant Simulation and WITNESS offer the most various deployment possibilities in comparison with AnyLogic and Arena.

The studied simulation tools are mainly used by the companies in the following industries:

- industrial machinery, supplies and equipment;
- hospitals and clinics;
- automotive;

- electronics;
- freight and logistics;
- management;
- aerospace and defense;
- food, beverages and tobacco.

All of the given simulation modelling tools are also used at universities and colleges for educational purposes.

Figure 1 represents the total amount of companies which used and are currently using each of the above mentioned simulation software. The information is provided by the HG Insights Inc. by using their go-to-market intelligence platform [51].

As it can be observed, most companies are currently using Arena simulation software solution and among the studied solutions this software is also the most commonly used one. WITNESS is the least commonly used simulation tool and relatively small number of companies are using it.

Table 3 represents main features of the simulation software packages.

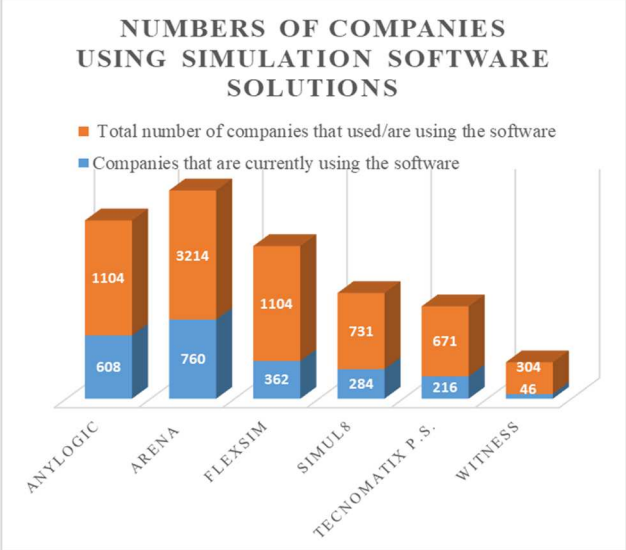


Figure 1 Technology and life

Table 3 Environments oriented towards different approaches in simulation modelling

Software	***AnyLogic***	***Arena***	***FlexSim***	***SIMUL8***	***Tecnomatix Plant Simulation***	***WITNESS***
3D Imaging	✓	✓	✓		✓	✓
Agent-Based Modelling	✓	✓	✓	✓	✓	
Continuous Modelling	✓	✓	✓	✓	✓	✓
Design Analysis	✓	✓	✓		✓	✓
Direct Manipulation	✓	✓	✓	✓	✓	✓
Dynamic Modelling	✓	✓	✓	✓	✓	✓
Graphical Data Presentation	✓	✓	✓	✓	✓	✓
Industry Specific Database			✓	✓	✓	✓
Motion Modelling	✓		✓		✓	
Presentation Tool	✓	✓	✓	✓	✓	✓
Stochastic Modelling	✓		✓	✓	✓	✓

As it can be observed, FlexSim and Tecnomatix Plant Simulation retain all the main features. Grabowik C. et al. [52] made a comparative analysis of simulation results got with these two software simulation packages in order to check how the choice of a software can influence the quality of simulation results. Specific production indexes were taken into consideration and it was proved that the difference between the simulation results was little and thus while selecting between FlexSim and Tecnomatix Plant Simulation other factors such as price, maintenance or interface should be taken into account.

Arena and SIMUL8 offer the least simulation options in comparison with other studied software packages. Using SIMUL8 software one cannot manipulate 2D data into three dimensional format and, since it doesn't offer design analysis option, there is a need of physical prototyping and

testing. Also, while using SIMUL8, Arena and WITNESS it is not possible to predict and understand the functional behavior of mechanisms and assemblies, which also causes difficulties in calculating the parameters for mechanical systems due to the lack of modelling motion feature in this programs. AnyLogic and Arena do not have an industry specific database, but Arena also does not have motion and stochastic modelling and without them it is impossible to predict results that take into account certain levels of unpredictability or randomness. Except for not obtaining motion modelling feature, WITNESS simulation software cannot offer agent-based modelling and thus there is no opportunity to examine the behavior of decentralized agents and how such behavior determines the behavior of the entire system as a whole.

3 Conclusion

Many companies are trying to introduce technologies of the fourth industrial revolution into production. Simulation modeling helps to solve the problems associated with the complexity of predicting the effect of changes on production lines, high testing costs in real production conditions and costly correcting deficiencies identified in new products after launch. This scenario assumes the widespread use of various modeling tools for describing and diagnosing systems, as well as conducting pilot projects on predictive modeling, the achievement of which is the ultimate goal. In this paper six discrete-event commercial simulation software packages – Arena, Anylogic, FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS – are described and compared taking into consideration their simulation features and application areas. All of the selected simulation software packages are aimed at analyzing the bottleneck processes, exploring possible “what-if” scenarios, providing “as-is” models, improving the existing systems and they are decision-making tools for enterprises. According to the literature review Tecnomatix Plant Simulation is commonly applied in logistics, manufacturing and engineering industry, FlexSim – in manufacturing and cyber learning, AnyLogic – in vehicle scheduling, pedestrian flow simulation, security systems and digital factories, Arena – in security systems and queueing systems, SIMUL8 – in distribution systems and railway simulation modelling, WITNESS – in assembly and production lines analysis, warehousing, traffic simulation and logistics. FlexSim, SIMUL8, Tecnomatix Plant Simulation and WITNESS offer different deployment alternatives – Cloud, SaaS, Web-Based and Windows, while AnyLogic and Arena offer relatively less amount of the deployment variants. Arena is a most widely used simulation software package among the selected ones and WITNESS is the least commonly used one. As a result of the comparative analysis FlexSim and Tecnomatix Plant Simulations appeared to obtain all the simulation features included in analysis and the main difference may be in price, maintenance or interface. Arena and SIMUL8 offer less simulation opportunities than other studied simulation software packages.

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