ACTA SIMULATIO

International Scientific Journal about Simulation

electronic journal
ISSN 1339-9640

2025 Volume 11 Issue 2

CONTENTS

(JUNE 2025)

https://doi.org/10.22306/asim.v11i2.120

Received: 21 Mar. 2025
Final revised: 15 Apr. 2025
Accepted: 05 May 2025

Use of location technology to create a digital guide for material flow analysis in the prototype and innovation centre

Marek Mizerák
Technical University of Kosice, Faculty of Mechanical Engineering, Institute of Management, Industrial and Digital Engineering, Komenskeho park 9, 042 00 Kosice, Slovak Republic, EU,
marek.mizerak@tuke.sk (corresponding author)

Peter Trebuňa
Technical University of Kosice, Faculty of Mechanical Engineering, Institute of Management, Industrial and Digital Engineering, Komenskeho park 9, 042 00 Kosice, Slovak Republic, EU,
peter.trebuna@tuke.sk

Jozef Trojan
Technical University of Kosice, Faculty of Mechanical Engineering, Institute of Management, Industrial and Digital Engineering, Komenskeho park 9, 042 00 Kosice, Slovak Republic, EU,
jozef.trojan@tuke.sk

Erik Varjú
Technical University of Kosice, Faculty of Mechanical Engineering, Institute of Management, Industrial and Digital Engineering, Komenskeho park 9, 042 00 Kosice, Slovak Republic, EU,
erik.varju@tuke.sk

Keywords: tracking sheet, location technology, material flow.

Abstract: This paper discusses the use of RTLS (Real-Time Location System) technology to track and optimize material flows in the Prototyping and Innovation Center. The objective was to develop and implement a digital tracking sheet that allows accurate real-time monitoring of material movement. For this purpose, an RTLS network was experimentally built in the centre to provide continuous monitoring of selected production processes from the input of the semi-finished product to the completion of the final product. As part of the testing, various elements of production were monitored, including material movement, logistics operations and pallet truck handling. The RTLS software enabled detailed analysis of material flow using spaghetti maps, heatmaps and zone maps, which provided valuable data on movement trajectories and identified bottlenecks in production. The analysis revealed the problem of long delays in the manual grinding area after machining on the mill, indicating the need to optimize this process. The results confirm that the implementation of an RTLS system contributes to a more efficient management of production operations, minimizing downtime and improving material flow continuity. In addition, the system enables better production planning and provides data for further optimization of logistics processes within industrial production.

1 Introduction

Currently, industrial enterprises and innovation centers are increasingly focusing on the digitization of their processes in order to enhance production efficiency and optimize logistics operations. Part of this transformation is the implementation of smart solutions for monitoring and analyzing material flows. One of the modern approaches to managing the movement of materials and components in industrial processes is the use of location technologies, which allow precise tracking of objects in real time.

Material flows represent a dynamic system in which individual parts, components, or finished products move within production and logistics processes. Efficient management of this system requires accurate data on the location, movement, and condition of materials. Traditional tracking methods, such as paper documents or manually entered data into information systems, are often inefficient, error-prone, and unable to provide sufficient flexibility for modern manufacturing processes. For this reason, technologies are increasingly being implemented in industrial enterprises that enable automated tracking of material movements and their analysis in real time [1-5].

One solution that significantly contributes to the efficiency of material flows is the digital tracking sheet. This is a concept that combines location technologies, such as RFID (Radio-Frequency Identification), UWB (Ultra-Wideband), RTLS (Real-Time Location Systems), and IoT (Internet of Things)-based systems, with digital information platforms. The digital tracking sheet replaces traditional paper or manually recorded documents and provides precise information about the movement of materials, their location, and their current condition in real time. In this way, it enables the optimization of production processes, prevents losses, and improves the coordination of logistics operations [6,7].

Location technologies play a key role in the industrial environment in automating the tracking of material movements. By utilizing these technologies, it is possible to precisely identify where individual components are located, when they move between various production or warehouse operations, and how efficiently transportation and storage capacities are being utilized. The data obtained can then be analyzed in the enterprise information system, which allows for the optimization of not only logistics processes but also the production operations themselves.

The use of the digital tracking sheet based on location technologies contributes to increased transparency of material flows and ensures better traceability of production processes. This approach enables enterprises to eliminate inefficiencies caused by incorrect movement of components or delays in the supply chain. In addition, data obtained from the digital tracking sheet can be used to predict bottlenecks in processes, leading to more efficient planning and optimization of production capacities. [8].

The implementation of the digital tracking sheet in the environment of the Prototype and Innovation Center brings additional advantages, as it allows for precise tracking of material flows already in the early stages of product development. Thanks to its integration with intelligent production systems and advanced analytical tools, the digital tracking sheet can serve as the basis for developing adaptive manufacturing processes that dynamically adjust to changes in production. This approach increases manufacturing flexibility and reduces the time needed to bring new products to market [9-11].

The introduction of location technologies into the management of material flows requires a thorough analysis of existing processes, the selection of an appropriate technological solution, and its integration with enterprise information systems. Depending on the specific manufacturing environment, different technologies can be used while RFID is suitable for tracking individual components over short distances, UWB and RTLS provide more precise real-time location data, which is especially beneficial in large production and storage areas. IoT sensors can be used for continuous monitoring of conditions such as temperature, humidity, or vibrations, allowing for a more comprehensive analysis of material flows and the condition of individual components [12].

2 Design and Implementation of the Digital Tracking Sheet in the Environment of the Prototype and Innovation Center (PaIC)

The Prototype and Innovation Center (PaIC) is a specialized facility focused on supporting the development of new engineering products and innovations. Its main task is to provide an environment for the rapid creation of prototypes, testing, and design of new products. Within these activities, efficient management of material flows is crucial to ensuring process continuity and minimizing time losses when searching for components. For example, when manufacturing a prototype, it is often necessary to quickly obtain specific components or materials. By using location technologies, their exact position can be immediately identified, which reduces the time needed to search for them and minimizes the risk of delays. Additionally, these technologies enable the tracking of the usage of individual devices and workstations, which helps with planning and optimizing production capacities.

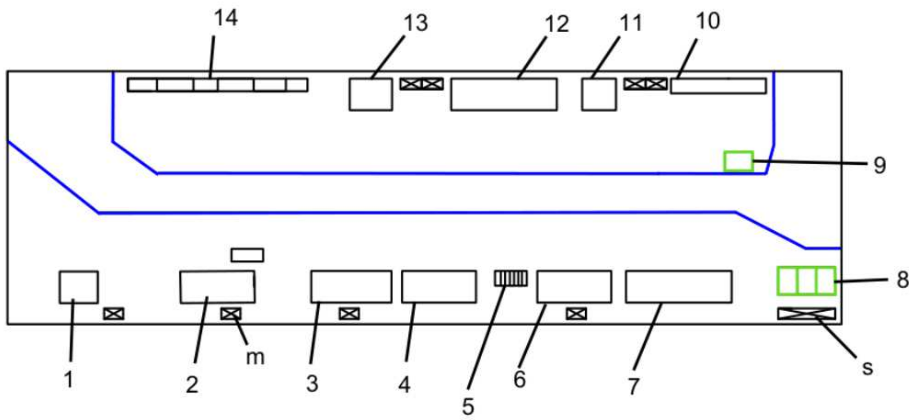
At the Prototype and Innovation Center, a location-based RTLS network will be created as part of our research and testing to serve as a basis for testing the concept of the digital tracking sheet. The goal is to implement and test a system that will track the movement of materials and components in real time during the development and manufacturing process. This approach will enable more efficient management of material flows, minimize time losses, and increase process transparency.

By creating an RTLS network at this center, we will obtain accurate data on the location and movement of materials, which is key to implementing the digital tracking sheet. This will allow us to verify how this system simplifies production management and optimizes logistics in the environment of innovation and prototyping. Testing this solution in real conditions will provide valuable data on its performance and benefits for the efficiency of manufacturing and logistics operations.

Figure 1 Prototype and Innovation Center (PaIC)

At the beginning, it was essential to meet all the technical prerequisites for assembling the program to track material movement in production. A key step in this process was to convert the production space into a 2D model that would accurately reflect the layout and flow of materials. For this purpose, the total area of the room was measured, including the precise placement of all main equipment, production lines, warehouses, and other key infrastructure elements. This detailed model serves as the basis for creating and subsequently testing the RTLS system that will monitor material movement in real time.

Based on this data, an accurate digital map was created, which serves to simulate the movement of materials in various stages of production. In this way, a realistic picture was created of potential bottlenecks in the process and areas that require optimization. The model also helped identify optimal locations for sensor installation, maximizing accuracy and efficiency in material tracking. All these steps are crucial for implementing a robust and reliable system that ensures smooth management of material flows [13,14].



Legend: 1 - CNC Turning-Milling Center, 2- 5-Axis CNC Milling Machine, 3 - 5-Axis CNC Milling Machine, 4 - Laser Machine, 5 - Measuring Laboratory, 6 - Wire Cutting Machine, 7 - CNC Turning-Milling Center, 8 - Semi-finished Products Reception, 9 - Shipping, 10 - Packaging Workplace and Finished Products Warehouse, 11 - Press Brake, 12 - CNC Turning-Milling Center, 13 - 3-Axis CNC Milling Machine, 14 - Technical Preparation of Production, m - Interim Storage for Machines, s - Storage of Materials and Semi-finished Products

Figure 2 Layout PaIC

Design and Production of a Special Box

One of the key components of the material movement tracking system in production are the tracking devices – tags. To ensure their practical application in the manufacturing environment, a special protective box was designed, which is attached to a base with a drawing or material sheet, allowing the worker to move comfortably through the production process without the tags interfering. The box was designed as a 3D model in SolidWorks software, taking into account the precise dimensions of the tag. After completing the design, it was printed using the FlexPrint 2 3D printer from 3Lab. The material used for production was organic PLA plastic (polylactic acid), known for its biodegradability and sufficient strength for producing functional parts.

Figure 3 Design of a special box for a digital guide

Before the start of the process, all workers were thoroughly familiarized with the procedure and informed that the tag would be attached to the workpiece to track its movement within the production process. They were also briefed on the necessary safety precautions when handling the tags and placing them on the workpieces, ensuring both tracking accuracy and workplace safety. All standard safety and operational measures were followed to ensure the smooth and uninterrupted flow of the entire production process.

For tracking material movement, the production process of a special component was selected in this case. The entire production process starts with the arrival of the raw material at the warehouse and continues through all phases of processing until the final completion and packaging of the finished product. Every step in this process is monitored, allowing for precise tracking of material movement and ensuring effective production management.

After the successful technical preparation, the workpiece is transferred to the machine tool, where the main manufacturing operation – machining the specific component – takes place. This process begins when the raw material arrives at the machine, where precise machining is performed, which takes approximately 1 hour and 50 minutes. During this phase, the workpiece is processed according to the set parameters and geometries.

Acta Simulatio – International Scientific Journal about Simulation
Volume: 11 2025 Issue: 2 Pages: 7-12 ISSN 1339-9640

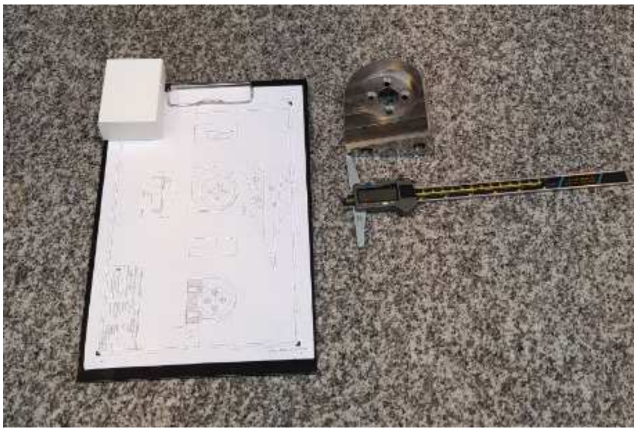


Figure 4 Example of the concept of a digital RTLS tracking sheet

After describing the current process, it is now possible to track all material movements in the process using SEWIO RTLS software, with selected tags represented, which were attached to the forklifts "Vozik_1." However, our main task will be to track how the raw material moves through the production facility – "Priebeh_Ocel_S335."
As part of the material flow analysis, data from tracking pallet trucks and their movements throughout the process were also entered into the system. These data provide a detailed overview of logistics and material movement between various production stations. Thanks to this information, it is possible to obtain a comprehensive picture of the material flow in real-time, which enables better planning, optimization of production processes, and identification of potential bottlenecks in logistics. In this way, the efficiency of the entire production cycle is increased, and the smooth progression of production is ensured.

Figure 5 Installation of RTLS tag on the pallet truck

2.1 Data analysis

After the completion of the production process and the arrival of the part at the finished goods warehouse, the RTLS software allows us to analyze the movement of specific tags in various ways, such as zone maps, heat maps, movement speed, or spaghetti maps. In my case, the spaghetti map method will be selected for movement analysis, which visualizes the route of material and equipment movements within the space, providing a detailed overview of their movement within the production facility. This type of map allows us to identify the most frequently used routes, optimize logistics, and eliminate inefficient or unnecessary material movements.

To select the spaghetti map method, simply click on the "SAGE Analytics" option in the main menu of the RTLS software, which includes various analytical tools for visualizing and evaluating material movements. In this way, valuable information is obtained for further optimization of production and logistics processes.

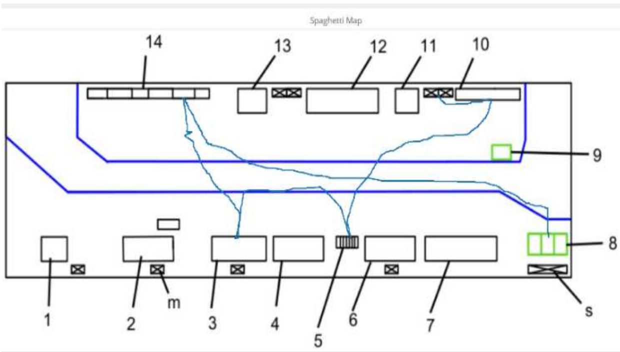


Figure 6 Movement analysis using the Spaghetti Map Method

In Figure 6, the spaghetti map method is shown, which allows for precise tracking of material movement in production. This method helps identify whether there are unnecessary movements or inefficient transfers of materials in certain directions. During the analysis of this map, we identified several areas where material movement was repetitive or where unnecessary detours occurred, indicating potentially inefficient placement of production stations. This problem can lead to increased time losses and excessive material movement between individual production steps.

In Figure 7, the Heatmap method is shown, which illustrates where the most frequent movements occur in the production process. This type of analysis helps us identify bottlenecks and potential issues in logistics and material distribution. In this case, we found that some zones are overloaded, leading to frequent delays, which could cause a slowdown in production. These zones would require optimization to improve production flow and minimize downtime.

Use of location technology to create a digital guide for material flow analysis in the prototype and innovation centre
Marek Mizerák, Peter Trebuňa, Jozef Trojan, Erik Varjú

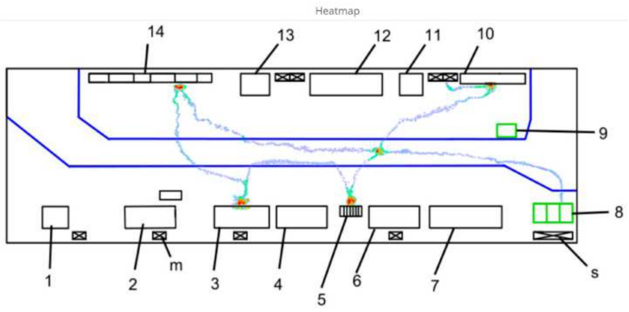


Figure 7 Movement analysis using the Heatmap

Another analysis method provided by the RTLS software is the Zone map (Figure 8). Using this method, it is possible to clearly see which zones the material passed through during its movement through the production process and how long it remained in each zone. In the analysis using the Zone map, we identified an issue in one of the zones, where the material unnecessarily lingered longer than required. This problem was related to the manual grinding process of the component after its final machining on the milling machine. Longer times in this phase could have caused an overall slowdown in the production cycle and inefficient use of labor time.

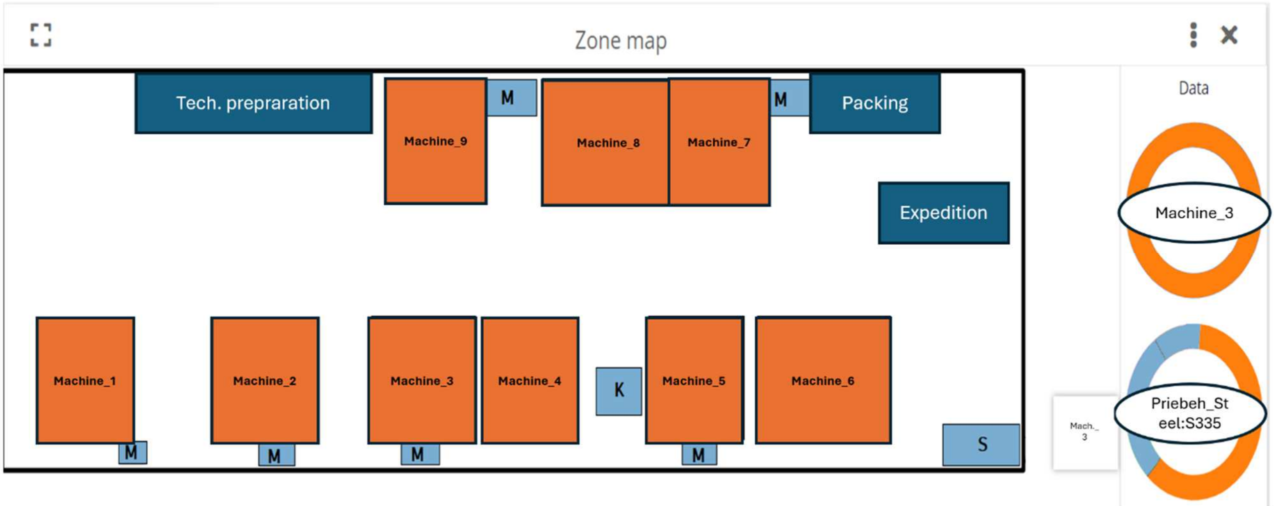


Figure 8 Zone map

3 Conclusions

As part of the experimental research, an RTLS network was designed and implemented at the Prototype and Innovation Center, enabling detailed tracking of material movement in real time. This technology was tested on selected manufacturing processes to analyze the efficiency of material flow and identify potential bottlenecks in logistics [15].

The analysis of the collected data through spaghetti maps, heatmaps, and zone maps provided important insights. The spaghetti map visualized the trajectories of material movement and helped uncover repeated and redundant transfers, indicating inefficient layout of production stations. The heatmap identified areas with high concentrations of movement, where congestion and delays in logistics could occur. The most significant finding came from the analysis using the zone map, which revealed excessive delays of material in the manual grinding area after machining on the milling machine. This phenomenon pointed to a bottleneck in the production process that extends the overall production time and could be subject to further optimization [16].

The results confirmed that the implementation of the RTLS system significantly contributes to optimizing material flows, minimizing unproductive movements, and more accurate management of production processes. The ability to monitor in real time allows companies to quickly react to inefficiencies, thereby reducing downtime and improving overall productivity [17].

In the future, it is recommended to expand the testing of the RTLS network to other production processes and focus on automated analysis of the collected data using artificial intelligence and machine learning. These advanced methods could help predict bottlenecks in production and enable even more precise optimization of logistics flows. The results of this study confirm the potential of RTLS technologies as an effective tool for the digital transformation of production processes and enhancing their competitiveness within Industry 4.0.

Acknowledgement
This article was created by the implementation of the grant project APVV-17-0258 "Digital engineering elements application in innovation and optimization of production flows", APVV-19-0418 "Intelligent solutions to enhance business innovation capability in the process of transforming them into smart businesses", VEGA 1/0508/22 „Innovative and digital technologies in manufacturing and logistics processes and system", VEGA 1/0383/25 "Optimizing the activities of manufacturing

enterprises and their digitization using advanced virtual means and tools", KEGA 020TUKE-4/2023 "Systematic development of the competence profile of students of industrial and digital engineering in the process of higher education". KEGA 003TUKE-4/2024 Innovation of the profile of industrial engineering graduates in the context of required knowledge and specific capabilities for research and implementation of intelligent systems of the future.

References

[1] GREGOR, M., GRZNAR, P., MOZOL, S., MOZOLOVA, L.: Plackett-Burman design, *Acta Simulatio*, Vol. 10, No. 1, pp. 5-9, 2024. https://doi.org/10.22306/asim.v10i1.104

[2] SADEROVA, J., ONDOV, M., KOVAC, J., SZUCS, M., BETUS, M.: Simulation of material flow using vertical transport by a double-action mine hoist, *Acta Simulatio*, Vol. 8, No. 4, pp. 47-50, 2022. https://doi.org/10.22306/asim.v8i4.91

[3] MAKYSOVA, H., GALGOCI, F., GYURAK BABELOVA, Z., STARECEK, A.: The improvement of the production process performance through material flow and storage efficiency increases serial production, *Acta Logistica*, Vol. 11, No. 1, pp. 57-65, 2024. https://doi.org/10.22306/al.v11i1.449

[4] MALKUS, T., KOZINA, A.: The features of negotiations within reverse logistics cooperation, *Acta Logistica*, Vol. 10, No. 1, pp. 111-119, 2013. https://doi.org/10.22306/al.v10i1.364

[5] KOVALČÍK, J., BALOG, M.: Automatic identification systems for management – material flow control and stock status, *Acta Logistica*, Vol. 8, No. 1, pp. 55-64, 2021. https://doi.org/10.22306/al.v8i1.202

[6] MIZERÁK, M., TREBUŇA, P., DUDA, R., TROJAN, J.: *Analysis of material flows through the use of progressive RTLS localization technology*, Research, Production and Use of Steel Ropes, Transport and Handling Equipment: 21st International Conference, Košice, Slovakia, pp. 108-112, 2022.

[7] SCHRÉTER, R., STRAKA, M.: The fundamental questions and problems of corporate network with data centre from the perspective of information flows and information logistics, *Transport & Logistics*, Vol. 13. No. 29, pp. 1-9, 2013.

[8] STRAKA, M., KACMARY, P., ROSOVA, A., YAKIMOVICH, B., KORSHUNOV, A.: Model of unique material flow in context with layout of manufacturing facilities, *Manufacturing Technology*, Vol. 16, No. 4, pp. 814-820, 2016.

[9] STRAKA, M., KHAOURI, S., ROSOVA, A., CAGANOVA, D., CULKOVA, K.: Utilization of computer simulation for waste separation design as a logistics system, *International Journal of Simulation Modelling*, Vol. 17, No. 4, pp. 583-596, 2018.

[10] VOTAVA, V., ULRYCH, Z., EDL, M., TRKOVSKÝ, V., KORECKÝ, M.: *Analysis and Optimization of Complex Small-lot Production in New Manufacturing Facilities Based on Discrete Simulation*, EMSS 2008, Genova: Diptem Universita di Genova, pp. 198-203, 2008.

[11] Zber dát z výrobných procesov, [Online], Available: https://sova.sk/zber-dat-z-vyrobnych-procesov [20 Mar 2025], 2025. (Original in Slovak)

[12] Zber dát z výroby, [Online], Available: https://allysoft.sk/product/zber-dat-z-vyroby/sald0010.htm [20 Mar 2025], 2025. (Original in Slovak)

[13] Zber a archivácia dát vo výrobe, [Online], Available: https://consystech.sk/produkt/zber-a-archivacia-dat-vo-vyrobe [20 Mar 2025], 2025. (Original in Slovak)

[14] Zber a vyhodnocovanie výrobných údajov, [Online], Available: https://www.iczgroup.com/sk/produkty-a-sluzby/intralogistika-a-vyroba/zber-a-vyhodnocovanie-vyrobnych-udajov [20 Mar 2025], 2025. (Original in Slovak)

[15] Optimalizácia výroby, [Online], Available: https://itas.sk/wp-content/uploads/2020/04/Bro%C5%BD%C3%BAra-1-Optimaliz%C3%A1cia-v%C3%BDroby.pdf](https://itas.sk/wp-content/uploads/2020/04/Bro%C5%BD%C3%BAra-1-Optimaliz%C3%A1cia-v%C3%BDroby.pdf [20 Mar 2025], 2025. (Original in Slovak)

[16] Optimalizácia výroby, [Online], Available: https://itas.sk/wp-content/uploads/2020/04/Bro%C5%BD%C3%BAra-1-Optimaliz%C3%A1cia-v%C3%BDroby.pdf](https://itas.sk/wp-content/uploads/2020/04/Bro%C5%BD%C3%BAra-1-Optimaliz%C3%A1cia-v%C3%BDroby.pdf [20 Mar 2025], 2025. (Original in Slovak)

[17] Asseco CEIT, [Online], Available: https://www.assecoceit.com/sk/?gclid=CjwKCAjw9J2iBhBPEiwAErwpeaBrkKkb14iOObt47_ih4K9-i52HNRRinuv-wc5W3OYXyzhHgLxNMxoC2fwQAvD_BwE [20 Mar 2025], 2025.

Review process

Single-blind peer review process.

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**

The journal focuses mainly on the original and new, interesting, high-quality, theoretical, practical and application-oriented contributions to the field of science and research as well as to pedagogy and education in the area of simulation.

Acta Simulatio journal supports the San Francisco Declaration on Research Assessment (DORA). The primary directives include open access, reuse of outputs, diversity among authors and reviewers, peer review, description of provided services and related publishing charges.

Publisher:	**4S go, s.r.o.**
Address:	Semsa 24, 044 21 Semsa, Slovak Republic, EU
Phone:	+421 948 366 110
Publisher e-mail:	**info@4sgo.eu**

Responsibility for the content of a manuscript rests upon the authors and not upon the editors or the publisher.