ACTA SIMULATIO

International Scientific Journal about Simulation

electronic journal
ISSN 1339-9640

2024 Volume 10 Issue 1

CONTENTS

(MARCH 2024)

Acta Simulatio - International Scientific Journal about Simulation
Volume: 10 2024 Issue: 1 Pages: 1-4 ISSN 1339-9640

https://doi.org/10.22306/asim.v10i1.103

Received: 26 Jan. 2024
Revised: 20 Feb. 2024
Accepted: 03 Mar. 2024

Examination of manufacturing procedures in TestBed 4.0

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Keywords: process analysis, TestBed 4.0, competitiveness.

Abstract: This article delves into the systematic examination of production processes within the context of TestBed 4.0. The study bifurcates these processes into distinct categories, namely pre-production procedures and core production processes, encompassing essential sub-steps crucial for ensuring the seamless execution of customer orders. The analysis sheds light on how TestBed 4.0, with its integration of Industry 4.0 elements, contributes to heightened efficiency and innovation in manufacturing. By exploring the interconnectedness of production equipment and digital models, the study highlights the potential for creating intelligent and automated industrial enterprises. The findings underscore the role of TestBed 4.0 in responding to market dynamics and fostering competitiveness for industrial enterprises, particularly within the European market.

1 Introduction

In the industrial sector, there is a growing focus on exploring ways to enhance production processes. This necessitates the examination of individual components constituting the production process, utilizing workplaces and laboratories equipped with integrated elements from Industry 4.0. The analysis of these processes not only reduces the time it takes for products to reach the market but also enhances the company's offering diversification [1-3].

TestBed 4.0 adapts to market changes and demands, providing the capability to establish intelligent industrial enterprises that are fully automated and consistently optimized through the integration of production equipment with digital models. The opportunities presented by TestBed 4.0 for implementing innovative designs play a vital role in ensuring the competitiveness of Slovak industrial enterprises in the European market [4-6].

2 Division of processes

In industrial enterprises, a large number of processes are carried out, which are necessary for the correct course of production and ensuring the delivery of the ordered product to the customer on the specified dates. Such processes take place gradually, with a certain continuity. Therefore, in order to achieve high performance of the company, it is necessary to organize and control these processes effectively in order to ensure high production efficiency in the company at the lowest possible costs [7].

We divide these processes into two main parts:

Pre-production processes, which include processes such as:

- Communication with customers.
- Creating an offer for the customer.
- Order acceptance.
- Construction processing.
- Processing of production technology.
- Purchase of necessary material for production.

The production processes include:

- Planning of production.
- Production management.
- Shipping of the finished product.

2.1 Communication with the customer about a potential order

This process consists of the request of the customer who asks for the preparation of an offer, which includes the price, the delivery date, and the conditions under which the industrial enterprise can deliver the goods. The customer also specifies the number of necessary manufactured

Acta Simulatio - International Scientific Journal about Simulation
Volume: 10 2024 Issue: 1 Pages: 1-4 ISSN 1339-9640

pieces. An industrial company tries to develop an offer so that it is profitable and at the same time the price must not discourage the customer, because the customer sends the request to several companies. The data about the shipment will be taken over by the business center (Fig. 1) of the company, which will record and store it. Based on these documents, he instructs the preparation of an offer for the customer.

Figure 1 Workplace for product data management

2.2 Creating an offer for the customer

The offer for the customer includes the price, terms of delivery of the products, and the date of delivery of the goods. The offer must be processed in such a way that the company receives more funds from the order than the costs associated with the material, the price of labor, the operation of machines, energy, the use of company premises, and other production costs. He has to design the offer in such a way that it is profitable and he has to take care of the delivery of the goods on time and to the agreed place specified by the customer. This whole process must be prepared in advance and correctly, which can sometimes be difficult. The use of PLM software and their databases make this process easier for us because they allow us to compare a new order with a previous order of a similar kind and, based on this information, determine the time required for production.

The price offer is prepared by the business center of the company, which collects data from:

• **Construction departments**
- sells his statement on the construction of the product and its complexity.

• **Technology departments**
- sells his estimates for the price of material consumption, work, or cooperation.

• **In stock**
- sells price estimates for materials and cooperation.

After incorporating all the data, the business center adds a corporate margin and sends the prepared offer to the customer.

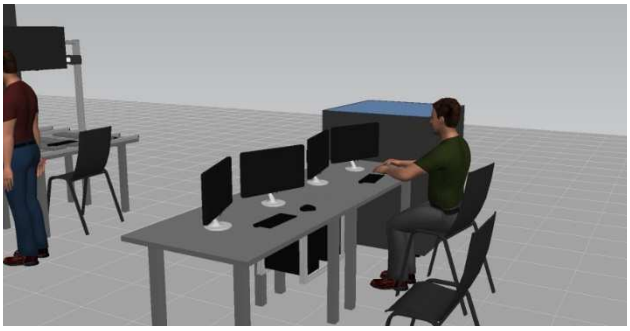

Figure 2 Price offer processing workplace

2.3 Order acceptance

The customer receives price offers and considers the most suitable one, prepares an order, and sends it to the chosen company. The customer will reject other offers. Based on the received order, and ordering contract, the company issues an instruction to start the preparatory processes of production.

The order is processed by the business center of the company, which registers it and instructs individual departments to prepare complete documentation for production planning.

2.4 Construction department

He is responsible for the correct construction of the product and the verification of the correct functionality (Fig. 3), the development of technological documentation and the creation of the parts list for the given product.

Figure 3 Workplace for structural design verification

2.5 Technological department

He is in charge of developing the technological process of production for the given product - estimation of material consumption, or proposes cooperations.

2.6 Warehouse

The role of the warehouse is to ensure continuous and smooth operation in terms of material security, it is responsible for ordering missing material and ordering cooperation.

After all the details have been worked out, the documentation is sold to the production planning department.

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Volume: 10 2024 Issue: 1 Pages: 1-4 ISSN 1339-9640

2.7 Planning of production

This process has the task of designing an optimal production plan (Fig. 4) so that all orders are produced at the agreed time, at the same time it ensures that production is not too complicated and everything is produced as quickly as possible, with the highest utilization of people and machines in the company.

The production planning section is responsible for creating the plan, which takes care of the effective implementation of technological processes into the current production plan and takes into account across the entire company:

- Material stock.
- Cooperation with other companies.
- Priority orders.
- Order delivery date.
- Production capacities.

The production plan is subsequently taken over by the production management department.

Figure 4 Workplace optimization of production procedures

2.8 Production management

The production management section is responsible for adapting the production plan to the current state of production. Production plans are made ahead of time. When creating a production plan, production planners cannot foresee situations that may arise in production, for example, machine failure, lack of material, or absence of a production employee. Production management must respond adequately to these deficiencies and adjust the production plan in cooperation with the production planner in order to ensure the smoothness of production processes and information flow (Fig. 5) throughout the company. The production manager has the task of correctly assigning work to individual sections in production, at the same time he is also responsible for issuing the material necessary for production and solving the most common problems occurring in production.

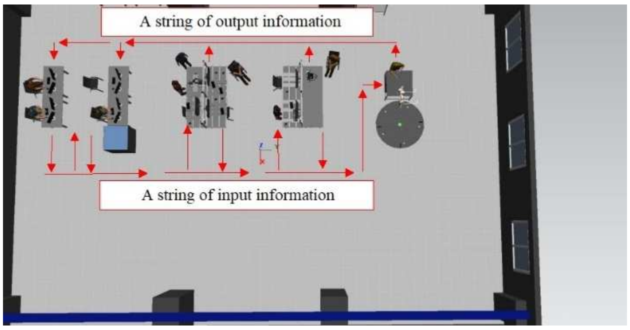

Figure 5 Information flows within workstations

2.9 Shipping of the finished product

The shipment of goods is handled by a warehouse employee who, on the basis of the shipping document, which determines what and when needs to be sent, prepares the finished products and gives instructions for the preparation of the necessary shipping materials, for example:

- Billing sheet.
- Delivery document.
- CRM confirmation.

This process ends with the final shipment of the product to the customer according to the agreed terms.

3 Conclusion

The production management section is responsible for adapting the production plan to the current state of production. Production plans are made ahead of time. When creating a production plan, production planners cannot foresee situations that may arise in production, for example, machine failure, lack of material, or absence of a production employee. Production management must respond adequately to these deficiencies and adjust the production plan in cooperation with the production planner to ensure the smoothness of production processes and information flow throughout the company (refer to Fig. 5).

The production manager has the task of correctly assigning work to individual sections in production while also overseeing the dynamic nature of the production environment. This involves effective communication and collaboration with various departments to address unforeseen challenges and maintain optimal workflow. The coordination between production management and planners is crucial for agile responses to disruptions, ultimately contributing to the overall efficiency and reliability of the production processes [8].

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, 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 and VEGA 1/0508/22 Innovative and digital technologies in manufacturing and logistics processes and system.

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Review process
Single-blind peer review process.

Acta Simulatio - International Scientific Journal about Simulation
Volume: 10 2024 Issue: 1 Pages: 5-9 ISSN 1339-9640

https://doi.org/10.22306/asim.v10i1.104

Received: 25 Feb. 2024
Revised: 10 Mar. 2024
Accepted: 19 Mar. 2024

Plackett-Burman design

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Keywords: Plackett-Burman Designs (P-B Plans), experimental design, factorial experiments, Main Effects Analysis.
Abstract: This article focuses on Placket t-Burman designs (P-B plans) for experiments, which represent an efficient tool for experimental designs, especially in investigating the influence of a large number of factors. Unlike traditional designs such as full factorial experiments (FFE) and fractional factorial experiments (FrFE), P-B plans allow for the effective processing of experiments with a higher number of factors without the need for an exponential increase in the number of trials. Although P-B plans do not directly enable the analysis of interactions between factors, they are ideal for exploring and analyzing the main effects of factors. The article examines in detail the advantages and disadvantages of P-B plans, including their ability to provide experimental error estimates and their efficiency in screening studies. The orthogonality and balance of P-B plans are emphasized, and their application in practice is illustrated with an example of a manufacturing process influenced by multiple factors. The approach based on P-B plans is shown to be a significant contribution to the field of experimental design, especially in situations where it is necessary to efficiently evaluate the impact of a large number of factors with a limited number of trials.

1 Introduction

Plackett-Burman designs allow experimental planning, with a focus on handling a multitude of factors without necessitating a corresponding increase in the number of experiments. This unique feature stands in stark contrast to traditional factorial designs, which require a geometric increase in experiments with the addition of each factor, making them less feasible for large-scale studies. Plackett-Burman designs, with their ability to provide a linear increase in the number of experiments, offer a pragmatic solution for preliminary screening in complex experimental setups. By focusing on the main effects and employing a resolution III or IV design, they enable researchers to discern the most influential factors without the convoluted analysis of interactions typical in higher-resolution designs. This approach is not only cost-effective but also time-efficient, making it an invaluable tool in fields where rapid and reliable identification of significant factors is crucial. Plackett-Burman designs have limitations in analysing interactions, which is a drawback. However, this limitation is balanced by their usefulness in the initial stages of experimental design. In these early phases, the main objective is to reduce the list of potential factors for a more detailed analysis. In the realm of experimental design and statistical analysis, the Plackett-Burman design continues to find diverse applications across various scientific disciplines, as evidenced by recent research endeavors. For instance ref. [1], in their study harness the Plackett-Burman design to streamline the experimental process required for evaluating the critical fracture energy in bonded composite joints. This research not only underscores the design's efficacy in reducing experimental redundancy but also critically evaluates its strengths and limitations within the context of mechanical engineering and materials science. Similarly ref. [2], in their publication utilize the Plackett-Burman design followed by a central composite design. This methodological approach aims to refine the process of sulfonamide detection in environmental samples, showcasing the Plackett-Burman design's adaptability in analytical chemistry for optimizing complex extraction processes. Further extending the design's application ref. [3] demonstrate the utilization of Plackett-Burman alongside Central Composite Design. This study focuses on augmenting the production of insecticidal agents from acid-hydrolyzed wastewater, highlighting the design's utility in bioprocess optimization and environmental engineering. Lastly ref. [4] illustrates the application of

Plackett-Burman and Box-Behnken designs in the extraction optimization of phenolics from Seabuckthorn leaves. This study emphasizes the design's role in food science and technology, particularly in developing innovative extraction techniques for valuable natural compounds. These studies collectively underscore the Plackett-Burman design's versatility and efficacy in experimental optimization across a spectrum of research fields, from materials science and environmental engineering to analytical chemistry and food technology. At its core, the article delves into the application and efficacy of Plackett-Burman designs in optimizing experimental frameworks across various scientific domains. Central to this exploration is the design's capacity to efficiently manage a large number of factors with a minimal increase in the number of required experiments, a feature that starkly contrasts with the exponential growth in complexity observed in traditional factorial designs. This article delves into the use of Plackett-Burman designs (P-B plans) in experimental design, particularly in comparison with full factorial experiments (FFE) and fractional factorial experiments (FrFE). P-B plans are presented as suitable for preliminary screening studies, where the main objective is to identify factors with the most significant impact on the phenomenon under study. These plans are characterised as balanced and orthogonal, meaning they provide unbiased estimates of the main effects. The article also discusses the possibilities of creating P-B plans, demonstrating how a specific vector of factors can be used to generate experimental conditions, as illustrated by an example with 7 factors.

2 Methodology

Plackett-Burman plans (P-B plans) for experiments have one significant advantage over full factorial experiments (FFE) and fractional factorial experiments (FrFE), which is their applicability even with a larger number of factors. P-B plans are usually not used for analysing factor interactions but are primarily utilised for in-depth analysis of the main factors. According to ref. [5], a disadvantage of P-B plans is that these plans allow for the evaluation of the impact of up to k = (n-1) factors with n experiments, which is often not necessary in practical use. The remaining columns of a P-B plan can be used for estimating the experiment's error. P-B plans are equivalent to FrFE plans $2_{III}^{(k-p)}$ where *III* is resolution, *k* is number of factors and *p* is number of excluded factors.

In the case of FrFE plans with two levels of factors, the number of required experiments increases geometrically. This results from the formula for the number of experiments for FrFE, where, as mentioned in previous chapters, the number of experiments is equal to $n = 2^{k-p}$, hence for k-p = 1, 2, 3, ... the number of experiments is 2^{k-p} = 2, 4, 6, 8, 16, 32, 64, 128, 256, etc.

For P-B plans, the number of experiments increases arithmetically (resolution level III), and therefore, they can also be used as plans with resolution level IV. In P-B plans, the number of experiments is thus: for k-p = 1, 2, 3, ... the number of experiments is equal to n = 4*k = 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, etc., which is a much slower growth compared to FFE and FrFE plans. As can be seen, the number of experiments in Plackett-Burman plans increases by a factor of 4. As [6] states, Plackett-Burman plans are balanced, orthogonal, and allow for the evaluation of effects of a maximum of n_{P-B}= n-1 = 3, 7, 11, 15,... factors or their interactions. PBP work well for linear dependencies of factors and interactions. Non-linear dependencies of factors are usually not included in P-B plans.

Individual rows (experiments) in P-B plans are created using a specific vector n_{P-B}= n-1 factors. For example, using a specific vector n = 7 to create an 8-row P-B plan, where the specific vector is formed (+1, +1, +1, -1, +1, -1, -1).

Now consider a manufacturing process influenced by 7 factors (A, B, C, D, E, F, G). The first 7 rows in column A of the PBP are the specific vector mentioned above. The first row in column B will have the level of the 7th row of column A, i.e., (-1), followed by the first 6 elements of the specific vector from column A. The first row in column C will have the value of the 7th row in column B, i.e., (-1), after which follows the first 6 elements of column B. The first row of column D will have the level of the 7th row of column C, i.e., (+1), after which follows the first 6 rows of column C. The levels of all other columns, up to column 7, are created in a similar manner. The last row, i.e., the 8th row, will have the level (-1) for all columns. The principle of creating P-B plans is evident from Figure 1.

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PBP for 7 factors

Specific vector = (+1, +1, +1, -1, +1, -1, -1)

Trial number	A	B	C	D	E	F	G
1	+1	-1	-1	+1	-1	+1	+1
2	+1	+1	-1	-1	+1	-1	+1
3	+1	+1	+1	-1	-1	+1	-1
4	-1	+1	+1	+1	-1	-1	+1
5	+1	-1	+1	+1	+1	-1	-1
6	-1	+1	-1	+1	+1	+1	-1
7	**-1**	**-1**	**+1**	**-1**	**+1**	**+1**	+1
8	-1	-1	-1	-1	-1	-1	-1

Figure 1 The principle of creating P-B plans

The creation of P-B plans can be easily achieved through the rotation of a specific vector, as shown in Figure 2.

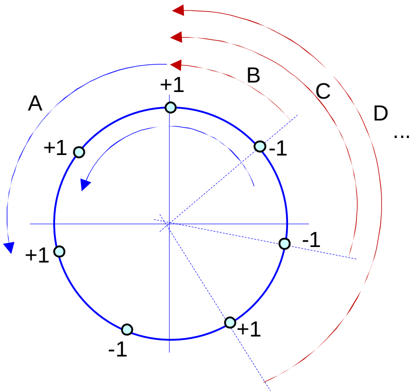

Figure 2 The creation of P-B plans by rotating the specific vector

Table 1 presents the P-B experimental plan for 7 factors, thus comprising 8 rows (trials).

Table 1 P-B plan for 7 factors

Trial number	A	B	C	D	E	F	G
1	+1	-1	-1	+1	-1	+1	+1
2	+1	+1	-1	-1	+1	-1	+1
3	+1	+1	+1	-1	-1	+1	-1
4	-1	+1	+1	+1	-1	-1	+1
5	+1	-1	+1	+1	+1	-1	-1
6	-1	+1	-1	+1	+1	+1	-1
7	**-1**	**-1**	**+1**	**-1**	**+1**	**+1**	+1
8	-1	-1	-1	-1	-1	-1	-1

Examples of specific vectors for P-B plans according to [7]:

n_{P-B} = 4 (-1+1+1)
n_{P-B} = 8 (+1+1+1-1+1-1-1)
n_{P-B} = 12 (+1+1-1+1+1+1-1-1-1+1-1)
n_{P-B} = 16 (+1+1+1+1-1+1-1+1+1-1-1+1-1-1-1)
n_{P-B} = 20 (+1+1-1-1+1+1+1+1-1+1-1+1-1-1-1-1+1+1-1)

In P-B plans, we also carry out factor screening. To display the results, it is appropriate to use a main effects plot. An example of such a graph is shown in Figure 3.

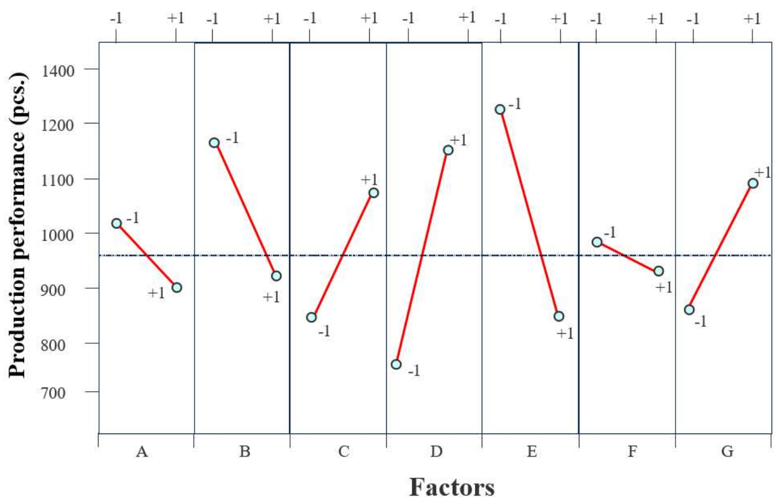

Figure 3 Main effects plot

Simulations, especially those involving complex systems or requiring high computational resources, can be time-consuming and costly [8]. PBPs mitigate this by reducing the number of required experiments to a feasible level, thus saving on both computational resources and time, without compromising the integrity of the findings.

3 Results

Consider an example of a simple production system in which we want to verify the impact of two factors and two levels on its production performance. Details about the factors under investigation are provided in Table 2.

Table 2 Factors and their levels

Factor	Description	Lower level (-)	Upper level (+)
A	Number of maintenance workers	7	12
B	Batch size	200	2800

As seen from Table 3, we have 2 factors, so for FFE, we need to conduct four simulation runs. To ensure at least partial independence, we carry out two simulation experiments, and in each of them, we conduct four simulation runs (thus a total of 8 simulation runs). The results of the experiments are summarised in Table 3.

Table 3 The experiment results

Simulation run (trial)	Factor		Interaction	Production performance	
	A	B	AB	Experiment 1	Experiment 2
1	-1	-1	+1	10	11
2	-1	+1	-1	12	12
3	+1	-1	-1	19	18
4	+1	+1	+1	23	22

Now we can determine the effect of individual factors and their combinations. The effect of a given factor is determined as follows:
A^- = the sum of production performances achieved at the lower level of the factor divided by the number of values.
$A^- = (10 + 11 + 12 + 12) / 4 = 11.25$
$A^+ = (19 + 18 + 23 + 22) / 4 = 20.5$

Then, the resulting effect of factor A will be:
$A = | A^+ - A^- | = | 20.5 – 11.2 | = 9.3$

Similarly, for factor B it will be:
$B^- = 14,5$ $B^+ = 17.25$
$B = | B^+ - B^- | = 2.75$

The effect of the combination of factors will be:
$AB^- = 15.25$ $AB^+ = 16.5$
$AB = | AB^+ - AB^- | = 1.25$

The greatest effect determines the "main influence." Factor A has the greatest impact, followed by factor B, and the combination of factors AB has the smallest effect. The calculations suggest the optimal combination of factors is A^+B^+. Thus, factors A and B achieve the greatest effect at the level $A^+ B^+$.

4 Discussion and conclusion

The utilisation of Plackett-Burman designs signifies a substantial contribution to the realm of experimental design, particularly in addressing challenges associated with analysing a multitude of factors. This study corroborates their efficacy in preliminary factor screening, enabling researchers to swiftly and efficiently pinpoint the main factors influencing a given phenomenon. A notable advantage of employing Plackett-Burman plans is the elimination of the need for an exponential increase in the number of trials, a common requirement in traditional experimental designs. This aspect is especially beneficial in scenarios where resources and time are limited. However, the inherent limitation of Plackett-Burman designs in not directly addressing factor interactions warrants consideration. While this attribute underscores their suitability for initial stages of experimentation, it may necessitate subsequent, more detailed analysis techniques to fully understand complex factor interrelationships. Therefore, the strategic integration of Plackett-Burman designs with other experimental methods, such as fractional factorial or central composite designs, could provide a more holistic approach to experimental investigation. The practical implications of this study extend across various scientific domains, demonstrating the versatility of Plackett-Burman designs. Whether in optimising manufacturing processes, enhancing product quality, or streamlining research methodologies, the application of these designs can lead to significant advancements and innovations. Furthermore, the ability to conduct efficient screening studies with Plackett-Burman plans empowers researchers and industry professionals alike to make informed decisions, ultimately contributing to the enhancement of experimental design practices. In conclusion, Plackett-Burman designs represent a valuable strategy for managing the complexity inherent in experimental studies involving a large number of factors.

Through the efficient identification of main effects, these designs facilitate a streamlined approach to experimental planning, reducing both time and resource commitments. Despite limitations regarding interaction analysis, the strategic application of Plackett-Burman designs, in conjunction with other analytical methods, offers a comprehensive framework for experimental exploration.

Acknowledgement
This work was supported by the Slovak Research and Development Agency under the contract no. APVV-21-0308. This article was created with support of VEGA project: VEGA 1/0150/24.

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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**

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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**

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