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DIGITAL CONFIGURATOR OF FACTORIES

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Abstract
This article introduces a new approach to the digital prototyping of factories. The problem we are describing here refers to a complex and lengthy decision-making process regarding the construction of a new factory or production. This specific area of research has been developed through many years, which is pointed in the first part of article. The solution we have offered brings a new methodology to the prototyping of factories. This solution helps to shorten the whole process of designing, building, operating and optimizing the production business. The most remarkable result of methodology application is digital configurator of factories.
This configurator serves as a tool for designing and comprehensive investment assessment of the planned factories. In our view, these results represent an initial step towards managing the whole process of building a new factory, which will minimize both time and resource requirements.

Keywords
digital prototyping of factories, modular production system, digital configurator of factories, conceptual designing.

1. The current state of designing of production systems

Each manufacturing system goes through the phases of its life cycle. Frequent changes of the production mix or frequent rebuilding of the production systems generate additional costs that can significantly affect the efficiency of the production system throughout its life cycle [3]. If the project leader looks at the designing of the production systems not in a short term, but through the whole life cycle of the production system, he naturally looks for solutions which ensure a simple, fast and inexpensive rebuilding of the projected production system.

Any change to which a company must respond poses a threat and an opportunity at the same time. Manufacturing companies and their production systems do not work in an ideal environment, but they are significantly influenced by their internal factors as well as their surroundings. The external impact is mainly manifested by the turbulence which company can react to by changing its structure, or the method of production planning, or by combining them both. Correct proposal of a new factory must combine all significant factors (people, capital, material, energy, other factors) into an efficient and adaptive production environment [12].

A large number of articles on factory designing or the designing of manufacturing systems. have been published around the world The main knowledge base for designing factories previously used in the native land of the authors was published in Germany, the US and the former Soviet Union. These were gradually extended by articles published at ours and other departments of universities or companies in Slovakia. The most important and best-known articles about the designing of factories in the US were written by Mongensen [15] and Muther [16] and they have also been included and reflected in the author's articles.

German publications included the description of schools of factory designing existing in western and eastern Germany, and they still present rare sources of knowledge. The basics of complex designing of the factory are described in the extensive work of Aggtelek [1].

A more detailed view on the designing of modern companies was provided by Košturiak and Gregor [13], who took into account the use of most modern technologies.

In their publications and work Westkaemper and Zayn [21] focused on the designing of such factories which could be quickly changed and adapted to changing circumstances. This kind of companies was identified as "Wandlugsfähige" – "capable of change", and their attributes were presented in the form of the so-called Stuttgart business model (Das Stuttgarter Unternehmensmodell). According to Brath, [2] the future "value" of a company is created already in its designing phase. That's the reason why designing of factories has such a great importance, and that's why so much attention is paid to the preparation and implementation of projects. Great attention is devoted to both areas, to the designing of production systems but also to the workplace of the authors. Furmann is focused in his publications mainly on designing of manufacturing systems in the context of digital factory requirements and the use of progressive information technologies and software tools [7, 8]. Dulina in his research solves the problems of detailed designing of production and assembly workplaces from the perspective of ergonomics of work [5, 6]. Bučková, Grznár, Gregor, Vavrík and Pedan deal with the application of modelling and simulation tools for dynamic verification of proposed production and logistic systems [4, 9–11, 17, 19].

The current change in customer requirements as well as the new requirements of Industry 4.0's for future factories also require a change in the methodology of designing of production systems. That situation must reflect the current state of knowledge and the rapid development of advanced technologies. New technologies of digital factory [14] – detailed digitization and computer simulation - have brought revolutionary changes.

2. New environment and possibilities for investors

Investors operating in today's investment environment need a completely new environment for their decision-making. However, the tools for fast and right decision-making of investors is still missing.

An environment that will integrate individual approaches, technologies, methods, and methodologies, and connect the data so that the decisions could be taken more quickly, with higher quality and conducive to the required investment efficiency [18]. Fragmentation of the production environment and its environment increases the difficulty in obtaining the information needed for decision making. The final quality of investors' decisions depends on the availability, timeliness and quality of existing information.

As it is clear from the previous section, there have been many publications that are devoted to proposal and designing of the manufacturing systems. Most of them, however, are oriented towards to the general designing principles for the areas of classical mechanical and electrotechnical production. There is not a methodology for making investment decisions about construction and operations of the factories which would integrate the latest knowledge on innovative approaches. Such as:

- reconfigurable manufacturing systems,
- modular production systems,
- latest methods (optimization, simulation),
- technologies (digital enterprise, artificial intelligence).

The analysis of the current state has further shown that the main problem is in the input data used in the investment assessment. From this perspective, it can be stated that between quality of input data and output quality of data there is a direct correlation. Low quality, superficially determined inputs cause total inaccuracy in the evaluation of investment proposals.

3. Digital Configurator of Factories

The entire decision-making process and the activities related to the decision, localization, design, construction and operation of a new factory can be viewed as a sequence of steps (Fig. 1). This process group is also called the lifecycle of the factory [12]. In Fig. 1 it is possible to see the overall process of planning, designing, building and operating of a new factory.

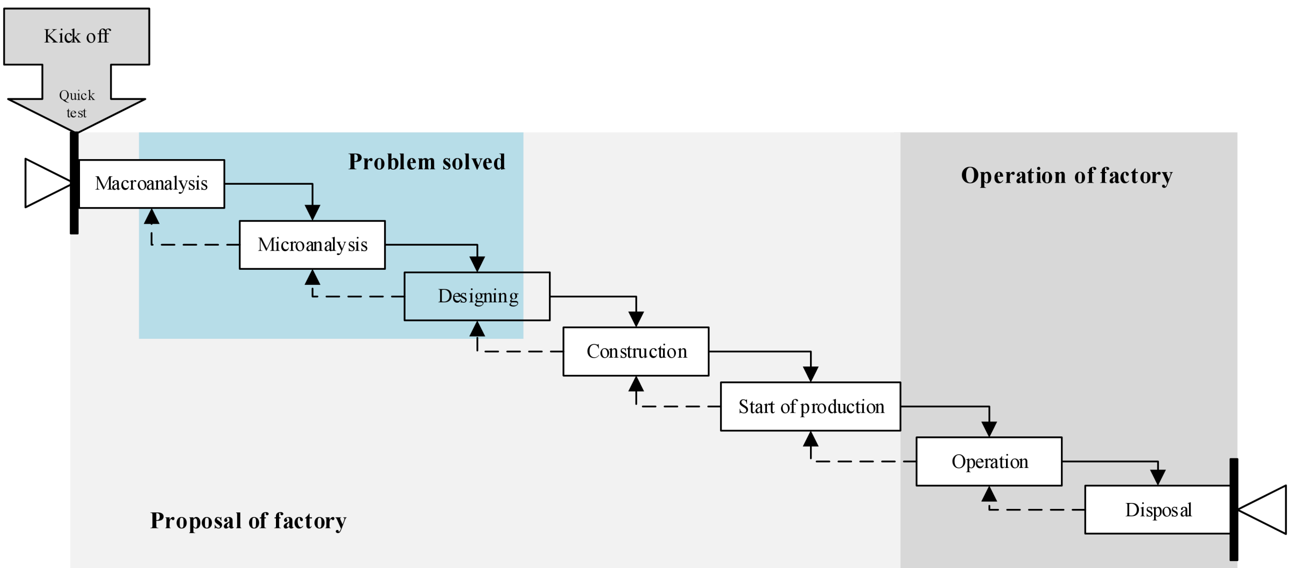

Fig. 1. Defined boundaries of solving problem from the point of view of lifecycle of the factory.

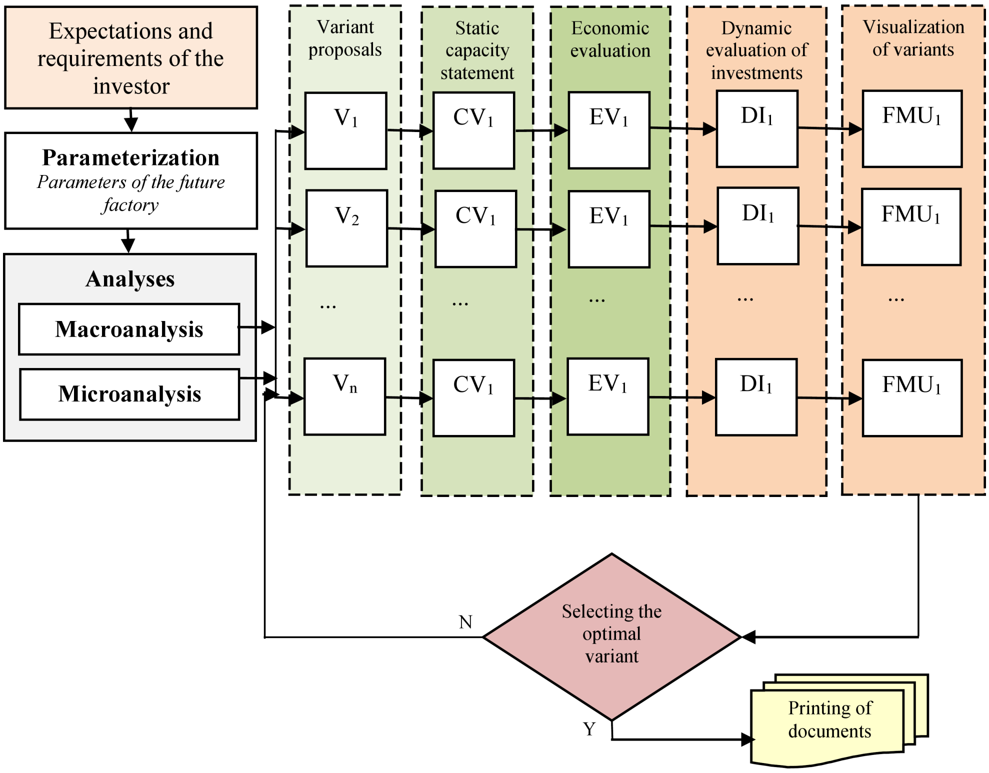

Fig. 2. Structure of Digital Configurator of Factories.

The digital configurator of the factory solves the conceptual design phase and activities related to macro-analysis, micro-analysis and designing (Fig. 1 – points 1, 2, 3). Data quality must meet the requirements of this decision-making level.

Digital Configurator of Factories (DCF) is designed for systematical capturing of steps of a digital prototyping of factories.

The structure of the DCF system consists from these two levels:

- process (ensures the processing of required analyzes),
- support (which forms the toolbox of methods and models).

Approach of an analyst to the DCF system is realized through appropriate interfaces (HMIs) and a module for visualizing and interpreting results. The software environment uses the database of configurator, process modules created in Excel and in the C ++ programming language. Designed is as a modular system. This system is adapted to the design of its own data base. Draft solution is created as a simple, user-friendly tool. The coarse structure of DCF is shown in Fig. 2.

4. The main algorithm of the digital prototyping methodology of the factory

The main algorithm of digital prototyping of factories (Fig. 3) describes the processes that must precede before the building of production factory. Priority focus is on the phase of evaluation of investment. This solution serves to quickly and comprehensively evaluate the proposed project variant, or to compare and evaluate several possible variants of project. The algorithm contains 9 threads or sub-algorithms **A1**–**A9**. Description of algorithms:

- **processes A1 and A2** represent input and preprocessing processes for Digital Configurator of Factories,
- **processes A3**–**A7** form the Digital Configurator of Factories core,
- **processes A8 and A9** are processable linked to Digital Configurator of Factories outputs,
- **A8 process** representing detailed designing can in practice take over the outputs of the Digital Configurator of Factories and further refine and refine their form into the final detailed project of the plant.

The whole process of prototyping a factory is preceded by one key step – identifying and addressing an investor planning to implement such a project.

Therefore, the main algorithm begins with the preparation of the initial investment plan and the investor's negotiation on the implementation of the project (step A1). The outcome of this process is the acquisition of an investor with an interest in the realization of the project, in the decision to carry on with the preparation of the project and, last but not least, the writing of investor comments and preferences for project realization, in other words the definition of frameworks and the directions of the project.

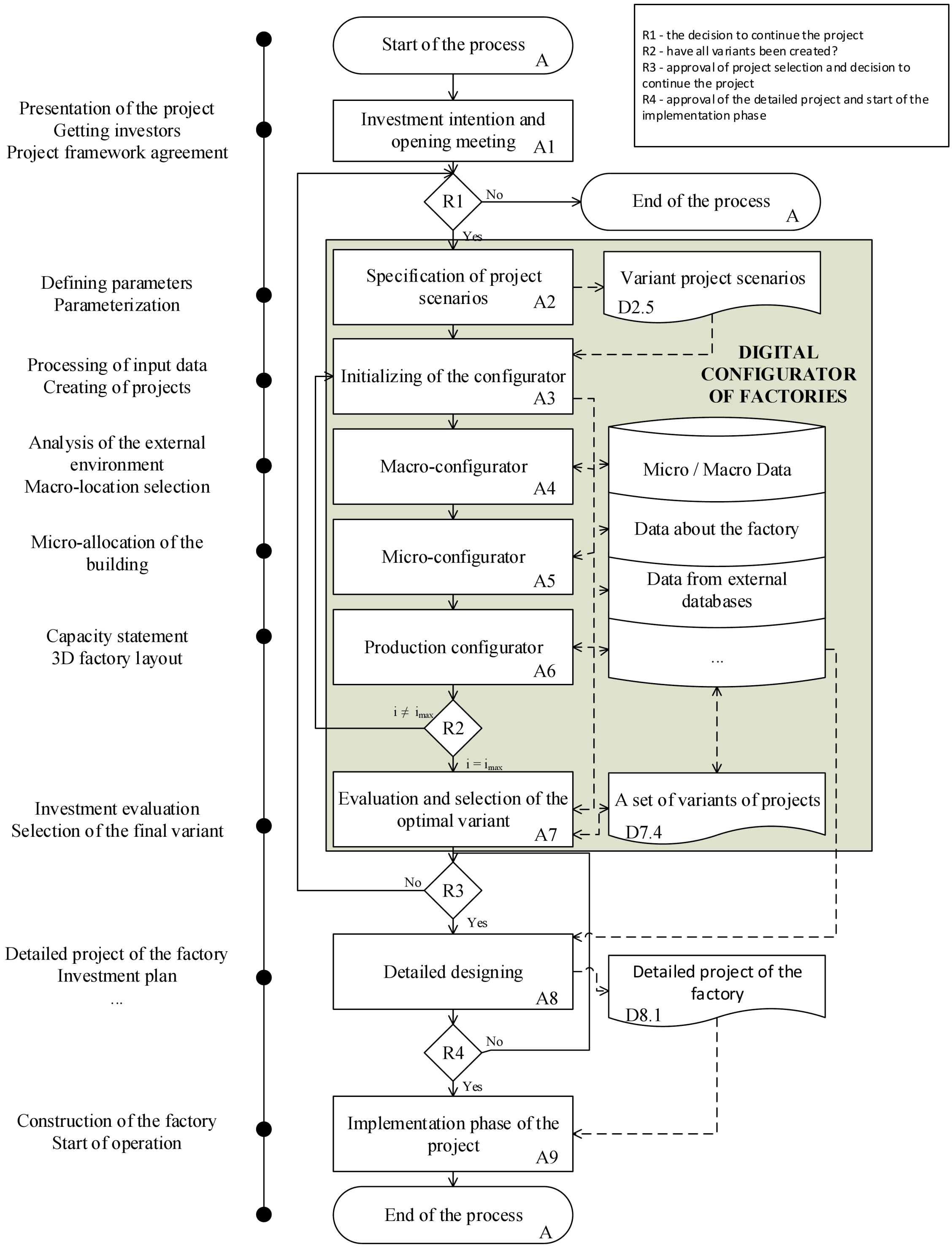

Fig. 3. The main algorithm of digital prototyping of factories.

Assuming the project has been approved, step A2 follows – the specification of project scenarios. Here, the analyst and coordinator who jointly define project scenarios (variants) are joining the game. These are further compared and evaluated in DCF environment. The scenarios are parameterized through their own DCF electronic forms.

As soon as the parameters for individual scenarios of the project are defined, configurator initialization begins (step A3). In this step, data from the input electronic forms are loaded into the configurator database and new projects could be created for each design variant.

Subsequently, automatic analytical processes A4 – macro-configurator, A5 – micro-configurator, and A6 – production configurator is triggered. Macro-configurator ensures the realization of selected macro-analysis steps and data preparation for decision-making on selected external environment issues. Output is the choice of a landscape for the project implementation.

The micro-configurator provides the selection of the site on the micro-level. The output is a comprehensive report, which compares the evaluated sites and provides a recommendation for the optimal selection of a suitable micro-site (county/district or specific location) for the building of the factory. The production configurator includes complex parametric capacities calculations, a basis for economic indicators, and a dynamic evaluation of the investment realized in Step A7.

Integrating these three tools provides an environment that allows investors to create and evaluate scenarios of variants of factory building, and quickly obtains the necessary information for investor decision-making.

In step A7, the algorithm then evaluates and summarizes the selected variants and suggests choosing the optimal variant for the project implementation, based on the predefined criteria. After the approval of the selection, another investment meeting should be held, regarding the decision about continuing in the project. That decision starts the detailed design phase (step A8), draws data from DCF and further refines the proposed plan. After the completion of the A8 phase and the final approval of the project implementation, the construction and start-up of the construction commences (step A9 – Implementation phase of the project).

5. Experimental verification of the methodology

The proposed methodology was applied in a complex assessment of variant solutions of manufacture for the production of sapphire monocrystals. The intention of the investor was to build a manufacture for the production of sapphire monocrystals for a specific area of production of bulletproof glasses (BPG – Bullet Proof Glass) designed for the heavy armament industry. The lifetime of the project will be 10 years based on the investor's knowledge. The investor plans a five percent annual growth in earnings.

The basis of the product mix is given and unchangeable in all evaluated variants. The main product will be product P1 – a rectangular block of sapphire bulletproof glass. In this production also a by-product will be created, which will have a triangular shape (P2). This by-product will be further sold as a semi-finished product of lower added value. An important intermediate product is a high-quality corundum semi-product (K1), whose production is essential especially for their own use. This semi-finished product will serve as input material for their own production of sapphire monocrystals.

The investor defined the requirement to review two different variants of annual production capacity: 500 pieces of BPG glasses and 800 pieces of BPG glasses. At the same time, due to limited investment resources, it will be considered in all variants to rent the production areas also. The investor also decides to use the second and third-generation HDC (Horizontally Directed Crystallization) devices. Summarizing of the basic parameters of each variant is shown in Table 1.

From the point of view of selecting macro and micro-locations, the investor has identified a set of rating criteria in the rated economic, political and technological categories. The selection of the criteria as well as the results of the analysis can be seen in Table 2. Index values shown in the tables were obtained from multi-criteria analysis.

The result of the macro-analytical part is the selection of the country, for realization of the given investment. With index level of 0.92 it is Slovak Republic. The investor defined the requirement of micro-location selection by himself. This zone will be the area of Eastern Slovakia. The zone was selected for a good location in terms of state aid eligibility to support the construction and operation of the manufacture.

The evaluation and selection phase of the optimal variant is an important part of the solution that offers the analyst a summary view of the evaluated variants. The most important information are strengths and weaknesses from economic and financial sphere. The economic impact for each variant was assessed in the following steps:

- calculation of the necessary investment costs to build a manufacturing,
- calculating the annual operating costs of each variant,
- calculation of annual returns generated by business activities of the company,
- summarizing partial economic data in the form of profit calculation and return on investment by selected valuation methods.

Table 1
Comparison specification of the main variants.

Parameter	Variant V1	Variant V2	Variant V3
Product mix	K1 + P1 + P2	K1 + P1 + P2	K1 + P1 + P2
Semi-finished material	Al_2O_3 (Aluminum Oxide)	Al_2O_3 (Aluminum Oxide)	Al_2O_3 (Aluminum Oxide)
Dimensions of the semi-finished [mm]	$420 \times 240 \times 40$	$420 \times 240 \times 60$	$420 \times 240 \times 60$
Production volume [pcs]	500	500	800
Price of one HDC machine [€]	550 000	625 000	625 000
Maintenance of HDC machine [€/ cycle]	1250	1350	1350

Table 2
Multi-criteria assessment of macro-locality.

Weights of criteria			Evaluation of locality selection	Switzerland	Germany	Poland	Slovakia
Economical	**64%**	12%	Index of potential tax benefits	0.50	0.60	0.90	1.00
		15%	Index of State aid potential	0.10	0.10	0.50	1.00
		1%	Index of labour productivity	0.90	0.85	0.70	1.00
		4%	Index of the impact of the local currency risk	0.95	1.00	0.75	1.00
		17%	Index of energy price	0.53	0.58	1.00	0.77
		5%	Index of rental price areas	0.61	0.64	0.87	1.00
		10%	Index of labour cost	0.39	0.51	0.91	1.00
Political	**18%**	5%	Index of political stability of the country	1.00	0.69	0.54	0.69
		2%	Index of state regulation	1.00	0.90	0.92	0.88
		2%	Index of influence of environmental legislation	0.85	0.90	0.98	1.00
		9%	Index of influence of export regulations	0.72	0.70	0.65	1.00
Technological	**18%**	3%	Index of technological level of country	0.98	1.00	0.82	0.78
		2%	Index of amount investment to the innovations	0.94	1.00	0.70	0.64
		8%	Index of infrastructure level in the country	1.00	1.00	0.94	0.91
		5%	Index of technological base in given area	0.60	1.00	0.85	0.98
	100%		**Resultant index of country**	**0.59**	**0.63**	**0.80**	**0.92**

The evaluation results are shown in Table 3. The analysis showed that variant V1 has an unacceptable return on investment of more than seven and a half years, which would have meant an appreciable increase in risk for the investment. The return of investment for variants V2 and V3 is on the contrary at an acceptable level.

For the final evaluation of the proposed variants, a more-critical assessment was carried out. The selected evaluation criteria, their individual weights and the results of the evaluation are presented in Table 4.

From the results of the multi-criteria evaluation it can be stated that the optimal variant is variant V3 with the best score of 0.96. This analysis also showed that for a given product mix, it is clearly better to use the second generation of HDC devices.

Table 3
Evaluation of investment variants.

Return on investment	Unit	Variant V1	Variant V2	Variant V3
Initial investment	€	−7 285 950	−4 792 200	−4 792 200
Annual operating costs	€	−2 396 610	−1 753 175	−2 196 952
Annual sales revenue	€	3 366 889	3 364 925	4 361 837
Annual company profit	€	970 279	1 611 750	2 164 886
Tax (Or Tax License)	€	−203 759	−338 468	−454 626
Annual depreciation of assets	€	200 879	167 727	167 727
Net annual profit of the enterprise	**€**	**967 399**	**1 441 010**	**1 877 987**
Return on investment	**Years**	**7.53**	**3.33**	**2.55**
Net Present Value	**Unit**	**Variant V1**	**Variant V2**	**Variant V3**
The required annual evaluation	%/Year	8%	8%	8%
Discounted Lifetime Profit	€	6 686 685	9 960 297	12 980 693
Initial investment	€	−7 285 950	−4 792 200	−4 792 200
Net Present Value	**€**	**−599 265**	**5 168 097**	**8 188 493**

Table 4
Final multi-criteria evaluation of variants.

Weight	Multi-criteria evaluation of variants	V1	V2	V3
23%	Net present value index	0.06	0.68	1.00
12%	Index return on investment	0.34	0.77	1.00
15%	The risk index from the initial height investment amount	0.66	1.00	1.00
10%	Risk Index from the size of the volume of production	1.00	1.00	0.63
20%	Index of efficiency of machine capacity utilization	0.63	0.63	1.00
15%	Index of the semi-finished material use efficiency	0.78	1.00	1.00
5%	Index of country selection	0.93	0.93	0.93
100%	**Result index of the variant**	**0.54**	**0.82**	**0.96**

6. Conclusion

The described solution of Digital Factory configurator (DCF) has since its inception targeted companies that offer a unique, specific and difficult to implement manufacturing technologies, such as technology for the production of single crystal sapphire.

For these processes, the DCF should be a base stone of the sale of these unique technologies, because this tool can show the potential customer a detailed image of the future factory and help to evaluate the investment. At the same time, this solution can also work well for companies that offer key solutions and need to get a quick design concept for the client to open the gateway to large complex projects for detailed designing of factories. Last but not least, this tool can be used directly for entrepreneurs (investors) who consider building a new factory and need facts to make decisions.

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References

[1] Aggteleky B., *Fabrikplanung: Werksentwicklung und Betriebsrationalisierung. Bd.3: Ausfuehrungsplanung und Projektmanagement*, ISBN 3-446-13209-0, 1990.

[2] Brath H., *Fabrikplanung SS 2014. Vorlesungsunterlagen*, Universität Duisburg Essen, 55 p.. 2014.

[3] Bubenik P., Plinta D., *Interactive scheduling system. In Management: Management*, Journal of Contemporary Management Issues, 10, 2, 89–98, ISSN 1331-0194, 2005.

[4] Bučková M., Krajčovič M., Edl M., *Computer simulation and optimization of transport distances of order picking processes*, Procedia Engineering, ISSN 1877-7058, vol. 192 (2017), online, pp. 69–74, 2017.

[5] Dulina Ľ'., *Ergonomics analysis of a digital factory with the support of augmented reality*, [in:] Chosen applications of computer modelling in mechanical engineering, London: Pearson Education Limited, 2015, ISBN 978-1-78447-830-8, pp. 207–230, 2015.

[6] Dulina L'., Bartánusová M., *Ergonomics in practice and its influence on employees' performance*, [in:] Communications: scientific letters of the University of Žilina, ISSN 1335-4205, vol. 16, no. 3A (2014), pp. 206–210, 2014.

[7] Furmann R., Furmannová B., *3D design of the production layouts*, [in:] InvEnt 2016: Industrial Engineering – Toward the Smart Industry: Proceedings of the International Conference 15.6–17.6.2016, Rožnov pod Radhoštěm, CZ. Žilina: University of Žilina, ISBN 978-80-554-1223-8, pp. 28–31, 2016.

[8] Furmann R., Krajčovič M., *Modern approach of 3D layout design*. In: TRANSCOM 2011, 9-th European conference of young research and scientific workers : Žilna, June 27-29, Slovak Republic. Section 2: Economics and management - part 1 (A-Mi). Žilina: University of Žilina, ISBN 978-80-554-0370-0. S. 43-46, 2011.

[9] Gregor M., Gregor T., Patka J., *Továrne budúcnosti a pokrokové technológie*, In ProIN, ISSN 1339-2271, Roč. 17, č. 4 (2016), pp. 22–25, 2016.

[10] Gregor M., Medvecký Š., *Application of Digital engineering and simulation in the design of products and production systems*, Management and Production Engineering Review, 1, 1, 71–84, ISSN 2080-8208, 2010.

[11] Gregor M., Palajová S., Gregor M., *Simulation metamodeling of manufacturing systems with the use of artificial neural networks*, [in:] MITIP 2012, 14th International Conference on Modern Information Technology in the Innovation Processes of the Industrial Enterprises, Hungarian Academy of Science, Budapest, pp. 178–190, ISBN 978-963-311-373-8, 2012.

[12] Gregor T., Krajčovič M., *Digitálne projektovanie závodov na produkciu monokryštálov*, ProIN, roč. 16, č5-6, pp. 42–46, ISSN 1339-2271, 2015.

[13] Košturiak J., Gregor M., *Podnik v roku 2001. Revolúcia podnikovej kultúry*, Grada Praha, 1993, 311 p., ISBN 80-7169-003-1, 1993.

[14] Kuehn W., *Digitale Fabrik. Fabriksimulation fuer Produktionsplaner*, Carl Hanser Verlag, Muenchen, 474S, ISBN 978-3-446-40619-3, 2006.

[15] Mogensen A.H., *Plant Layout*, [in:] Factory Management and Maintenance, 94, 5. 1943.

[16] Muther R., *Systematic layout planning*, John Wiley & Sons, 360 p., 1973.

[17] Pedan M., Gregor M., Więcek D., *Simulation as a decision making tool*, [in:] InvEnt 2017, Industrial Engineering – Invention for Enterprise: Proceedings of the international conference, 19.6–21.6.2017, Szczyrk, Poland, Wydawnictwo Fundacji Centrum Nowych Technologii, ISBN 978-83-947909-0-5, pp. 104–107, 2017.

[18] Schuh G., *Fabrikplanung. Vorlesung 3. Standortplanung II*, Standortplanung und – bewertung, WZL RTWH Aachen, Fraunhofer Institut fuer, 2016.

[19] Škorík P., Gregor M., *Simulácia a optimalizácia výrobných systémov s využitím nástrojov umelej inteligencie*, [in:] MOPP 2009, Plzeň, 2009, ISBN 9788070438442, 2009.

[20] Vavrík V., Gregor M., Grznár P., *Computer simulation as a tool for the optimization of logistics using automated guided vehicles*, [in:] Procedia Engineering, ISSN 1877-7058, vol. 192 (2017), online, pp. 923–928, 2018.

[21] Westkamper E., Zahn E., *Wandlugsfähige Produktionsunternehmen*, Das Sttuttgarter Unternehmensmodell, Springer Verlag Berlin, 321 p., ISBN 978-3-540-21889-0, 2009.