SHS Web of Conferences **83**, 01066 (2020) https://doi.org/10.1051/shsconf/20208301066
Current Problems of the Corporate Sector 2020

Management of business processes using stochastic simulation

Miroslav Špaček[1], *Petr* Půlpán[2]and *Zdeněk* Kopecký[3]

[1]Vysoká škola ekonomická v Praze, Nám. W. Churchilla 4, 13700 Praha 3, Czech Republic

[2]WAK System, s.r.o, Petržílkova 2654/21, 15800 Praha 5, Czech Republic

[3]Vysoká škola ekonomická v Praze, Nám. W. Churchilla 4, 13700 Praha 3, Czech Republic

Abstract. The paper deals with risks and uncertainties that are related to business processes. The risks and uncertainties (risk factors) can significantly influence organizational performance, value creation and long term-sustainability. Managers are often puzzled with making decisions in the environment of breakthrough discontinuities. The main outcome of the paper is the presentation of purposefully developed software tool that uses stochastic simulation of risks and uncertainties of business processes to support making optimum managerial decisions. This software is able to simulate any process risk factors that are describable by a mathematical model. The model was tested on the examples of production and investment cases. The research applied Business Process Modelling Notation Approach (BPMN) as well as mathematical and stochastic modelling. In addition, contextual interviews with company managers and risk specialists were used to get unbiased, reliable, and professional information on determination and analysis of process risk factors. The research was also supported by the evidence provided by the case study that illustrates software based decision-making process relating to opting for technology variant.

1 Introduction

Business and entrepreneurship in the environment of Industry 4.0 is tied with multiple risks and uncertainties. These phenomena often roofed by the term risk factors place a burden on future company development. The business is impacted by great many of risk factors (price and sales uncertainty, unpredictability of investment expenditure, competition behaviour, shortening product life cycle etc.). These risk factors can vary both continuously and discontinuously. Individual risk factors act with varying intensity and, in addition, may be mutually statistically dependent. In addition, there are pending externalities which can mediate negative multiplication effects on company prosperity. These externalities usually refer to climatic and weather effects (e.g. extending and repeating dry periods etc.), migration crisis, population aging, various forms of political instability etc. Reliable managerial decisions that would include the influence and interdependence of these factors are thus made with difficulties. It is apparent that managers cannot still cope with high degree of economic uncertainty and very frequently incline to intuitive decisions that are often faulty. This fact should be considered the main problem which is necessary to be solved by the application of advanced tools of risk management. In spite of these problems it is imperative for the company management to create the value for both customers and shareholders. Capability to manage companies in periods of breakthrough business discontinuities remains highly valuated managerial competence. The paper submitted reacts to this situation and by means of the application of SW supported risk analysis tool offers to company managers logic and rational way-out of this problem. The main outcome of the research is the software tool that is able to identify and analyse key business risks, determine the impact of risk factors on main characteristics of company performance and contribute to search for optimum decisions which are supportive to the stability of entrepreneurship. Especially simulation Monte Carlo that has been used since the War II attracted a great deal of popularity. This approach is frequently used in the financial sector where it is applied for various economic analysis [10].

2 Methods used in the research

Research team used Business Process Modelling Notation (BPMN) approach that is proven, quite flexible and sufficiently illustrative. By means of BPMN the basic work consisting in key company process description was carried out.

Stochastic simulation comes out of identification of the most important risk factors. Risk factors were identified either by sensitivity analysis or by expert opinion. The former consisted in sensitivity testing of output variable (usually net profit, cash flow or Net Present Value) against key input variables (risk factors) like unit price, sales volume, investment expenditures or the rate of production capacity utilization. Risk factor identification was accomplished either by creativity methods like brainstorming, brainwriting, Crawford Slip or Delphi [1] or contextual interviews with experts who were pretty well familiar with company business processes. Contextual interviews were conducted in a form of semi-structured interviews that were aimed at following points: (i) processes that are essential for company business, (ii) the approaches to the assessment of process risks (iii) risk measurement and (iv) mitigation provisions that company actually applies.

Eventually, case study research was applied for the confirmation of the model. Qualitative case study is a thorough, holistic description and the analysis of constrained phenomenon that may be program, institution, person, process, or social unit. Case study is a frequently used research technique that enables from qualitative point of view to explore problems and related circumstances Yin [15] perceives case study as contemporary phenomenon which exists in the framework of a real life, especially when the frontiers of the phenomenon are not quite clear. Researchers possess only limited control both over the phenomenon and the context. Case study is then an empirical query that examines specific case by means of purposefully formulated questions "How" and "Why?" Merriam [6] considers case study specific, complex, and functional thing, basically integrated system, that processes certain problematics within specific social constrains.

3 Theoretical aspects of process modelling and simulations

3.1 Process modelling

Business Process Modelling (BPM) represents the set of technologies and standards that are used in design, execution, administration, and monitoring of business processes [4]. BPM facilitates understanding the organization´s work, comprehends the process in details and then uses technological support for improvements to human activities [14]. The aim of BPM is to develop a model that mirrors the organization functionality of existing or newly and established business processes and can be regarded as a predecessor to business process simulation that is carried out by using simulation tools or software. The core to BPM is the process modelling languages. Within a variety of BPM languages so called Business Process Modelling Notation (BPMN) plays an important role. This approach that was developed in 2001 represents visual design layer for a transactional workflow system. It involves the set of principles and rules that are oriented to the visualisation of company processes. Over past two decades BPMN has become an acknowledged management standard for graphic notation that displays consequence of steps in a business process. It simultaneously offers users comprehensive business process modelling capabilities in the unified environment. BPMN is composed of five basic categories that are [11]:

- flow objects,
- connecting objects,
- pools and swim lanes,
- data objects, artifacts (i.e. a product created or modified by the enactment of a process element).

Other components that are closely related to BPMN are processes, collaborations, and choreographies. Once a business process is described by using BPMN, a modeller can use a process simulation approach to discover its optimized form [8]. In course of time this approach attracted the attention of many reputable companies (Oracle, Intel, SAP etc.) that are now using BPMN.

3.2 Process simulation

Simulations are a vital component in developing smart manufacturing systems, predicting the behaviour of the manufacturing operations to support production planning, scheduling, and maintenance decision within manufacturing environment [2]. Simulation modelling involves model development which imitates real-world operations, statistical analyses, and their performance with the aim to improve efficiency and effectiveness [9]. In the past the companies were quite satisfied with the "what if" method that provided them with sufficient treatment of uncertain future by means of the development of definite number of strategic scenarios. Nowadays the situation became more complex when number of risk factors dramatically increased, these factors are under permanent change and they are mutually statistically dependent. This situation triggered the attempt to apply process simulation that would include excessive number of risk factors as well as their unexpected behaviour into business planning. Process simulation becomes the method of choice when it is impossible or too expensive to get data, the system to be analysed is too complex, analytical solution to the problem is immensely difficult, and it is impossible or too costly to validate mathematical experiment [12]. Similarly the simulation is applicable when input data are encumbered by quantifiable uncertainties, output value must represent the most probable values of input data, calculated uncertainty of output value must exactly reflect input data uncertainties, calculated uncertainty of output value must be an exact measure of model validity. The nature of simulation approach is a simulation of great many scenarios, number of which may range from ten to hundred thousand [13]. Method is based on choosing pseudorandom numbers. Input values (like any financial figure) are expressed by means of their probability distribution. Output value (e.g. net profit, cash flow, profit margin, Net Present Value - NPV) is obtained in a form of probabilistic distribution (histogram). Successful application of simulation approach is contingent upon viable mathematical model that describes in a mathematical logic the processes in question. Mathematical (sometimes perceived as financial model) represents backbone of simulation approach. Mathematical model describes stochastic dependence between dependent and independent variables as snown by equation 1.

$$Y = f(X_1, X_2, \dots X_n) \tag{1}$$

where parameter Y is output (dependent) variable and parameters X_1, X_2,…..X_n are input (independent) variables.

This model clearly states which output criteria will be observed. Next step is risk factors determination by sensitivity analysis or expert assessment. Proper assignment of specific type of probability distribution to any risk factor is necessary. It is possible to use historic data which may be approximated to fit with pre-defined probabilistic distribution. Oftentimes historic data are not available at all or available at lesser extent. If this is the case there is no chance to deduce probability distribution from them. In this respect experts´ opinions and statements which are mostly grounded on subjective perception and professional intuition are considered. In the extreme they may be even based on the belief in very occurrence of mass (statistical) phenomenon. Despite apparent on-exactness this approach is fully substantiated since it very often exploits long-term experience and knowledge of experts about specific problematics. Moreover, it very often represents the only applicable approach to the determination of probability distribution of risk factors. It is also possible to transfer data from another cases (cross sectional data).

Very important step rests in a proper determination of correlation between pairs of risk factors. By means of statistic dependence of risk factors we understand their mutual interconnection and conditionality. Variables in the model are usually dependent each other. In such a case the value of one input variable is at least partially determined by the value of another input variable. The least probable alternatives are thus excluded. Mutual correlation is of high importance and substantially influences output parameter distribution. Proper correlation setting is achieved by the incorporation of correlation matrix which enables the expert to enter correlation coefficient for any pair of risk factors.

To avoid high complexity of the system, setting correlation coefficient may be simplified and determined on an expert basis as pointed out in Table 1.

Table 1 Setting correlation coefficient

Positive deterministic dependency	High degree positive correlation	Low degree positive correlation	No correlation	Low degree negative correlation	High degree negative correlation	Negative deterministic dependency
1	0,75	0,5	0	-0,5	-0,75	-1

Finally, it is inevitable to set the number of runs (50-100 thous.) that is conditional for smooth and successful simulation. The more runs are carried out the higher preciseness is achieved. When using low number of runs the distribution curve is jagged instead of being smooth. Process simulation is a powerful tool that simplifies and facilitates managerial decision-making. Gudcemir and Hasan [3] proposed an integrated decision support system that combines simulation modelling and multi-criteria decision making. They managed to successfully optimize shop dispatching rules while using three renowned performance-oriented criteria and one customer-oriented criterion: (i) mean flow time, (ii) percentage of tardy orders and (iii) make span and (iv) mean percentage deviation from the customer expectations. Process simulations are also occasionally used for the determination of cash flows that are tied with a high degree of risk. Kazakova [5] developed a system-dynamic model for predicting the financial flows of an enterprise taking into account the risk and uncertainty of interaction. Unfortunately, the model was subjected to testing on experimental level only.

4 Software support for facilitating managerial decisions

The aim of the project was to create a SW-supported managerial decision-making tool that will support and facilitate strategic business decisions. The model was built on the grounds of Osterwalder´s concept of Business Model Canvas (BMC) which was deliberately adapted to the purposes of the project [7]. The main adjustments consisted in the simplification of BMC that rested in exclusive reckoning on elements that could be subjected to clear mathematical description. The elements that were not describable by a mathematical model were excluded from the model. Therefore, the original BMC was partly simplified and adapted to purposes of the project. Fig. 1 illustrates the design of interface of the software tool that represents BMC. Is also shows how was BMC model adapted to one specific testing case (tractors production).

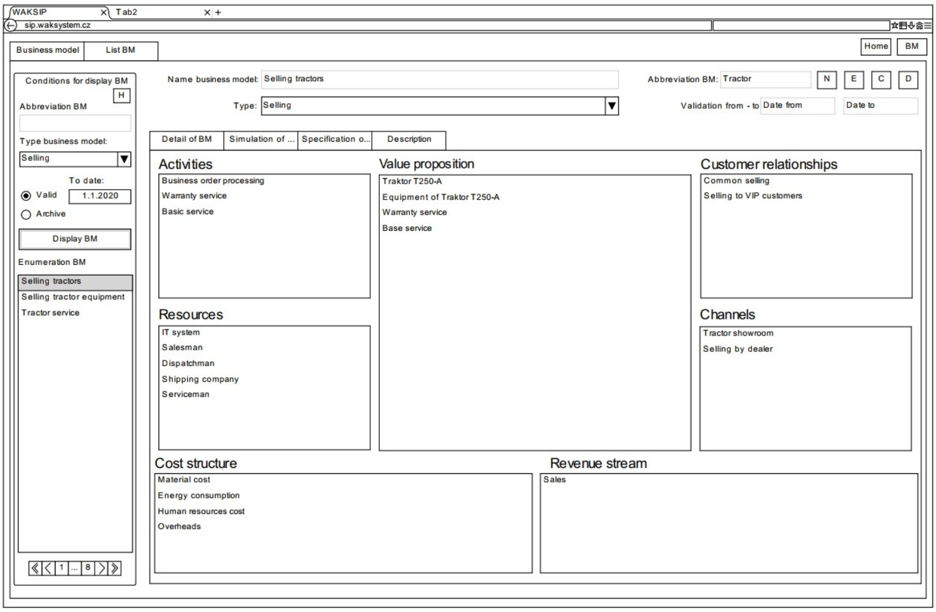

Fig. 1 Adapted Business Model Canvas (BMC)

The tool takes into account business uncertainties by replacing discrete input (independent) variables with their statistical distribution. By this way the possible variability of this variable were addressed. The tool, using a simple correlation matrix, considers the possible degree of cross-correlation of input variables. The tool allows the expert to model output variables (profit, cash flow, return on investment parameters, value creation parameters, etc.) for the considered business variants and thus support the reliability of managerial decisions. The tool allows to consider key risk factors, to link the initial assumptions with the expected results and to propose appropriate management measures. Fig. 2. shows cases of using a software tool from the perspective of a simulation modeller.

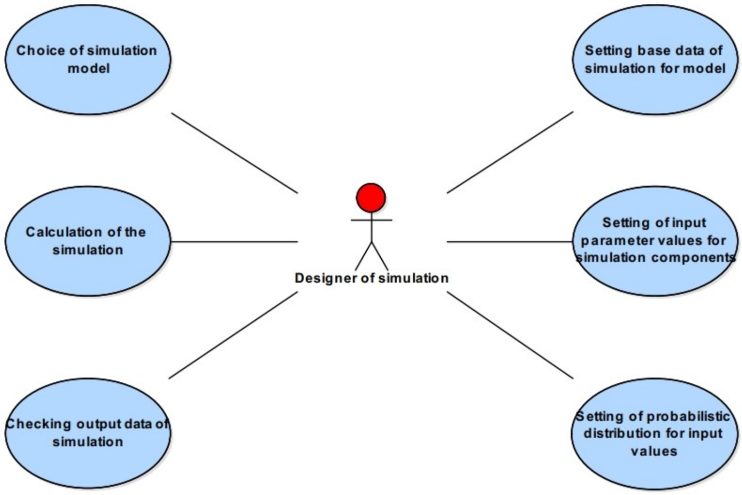

Fig. 2 Cases of using software tool from the perspective of simulation modeller

Design pattern that illustrates general functionality and the interaction among components of the model is shown in Fig. 1. It also illustrates basic software tool libraries integrating BMC elements, BPMN language classes, and simulation model classes.

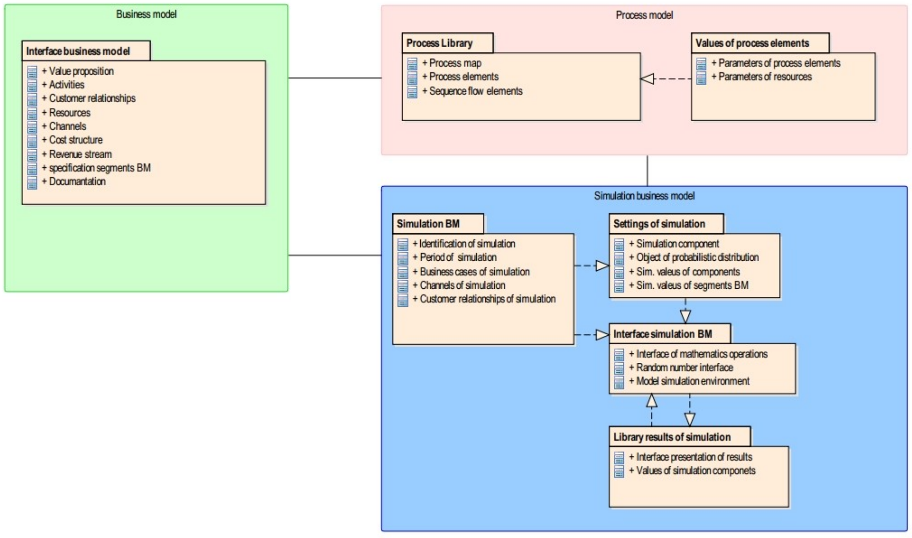

Fig. 1 Design pattern of the simulation model

4.1 Case Study

Chemical company intends to implement technology of the production of Corey lactone which is a versatile chemical compound frequently used in the pharmaceutical production There were several ways how to commercially produce this compound. After a thorough technological research and testing various possibilities in a pilot plant company´s R&D put two possible technologies on a short list. The first technology used dicyclopentadiene (DCPD) as a starting material. This technology process consisted of lower number of reaction steps, but the technology was more demanding to operate. Moreover, this technology was highly parameter sensitive. The second technology came of norbornadiene (NB) that is easily available carbohydrate. This technology process was composed of higher number of reaction steps that were quite robust and showed lower sensitivity to the fluctuation of technology parameters. Either technology was considered the candidate for the implementation. Both technologies were technically feasible and met requested safety and environmental standards. The parameters that appeared to be decisive were production costs and reproducibility of the technology.

Key economic data were determined as key input variables (risk factors). The set of risk factors involved material costs, energy costs, personnel costs, capital expenditure etc. Since this product was purposefully produced for company captive production and there was no intention to commercialize this product. The present value of costs (PV) was thus determined to be key output variable. Key input variables were assigned probability distribution that fitted in with triangular distribution. Mathematical model was developed to be in consonance with the formula for the calculation of Present Value (PV) (equation 1):

$$PV(costs) = \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2} + \ldots\ldots + \frac{CF_n}{(1+k)^n} = \sum_{i=1}^{n} \frac{CF_i}{(1+k)^i} \tag{1}$$

where
CFi - cash flow in i-year
k - discount rate (Weighed Average of Capital Costs – WACC)

Parameters of simulation:
- Financial model of the project was calculated in nominal prices.
- Supposed project lifetime was 10 years.
- The number of risk factors was 117 (58 for NB technology and 59 for DCPD technology).
- Discount rate was calculated as Weighed Average of Capital Costs (WACC)
- The number of simulation steps was in both cases determined as 50000.

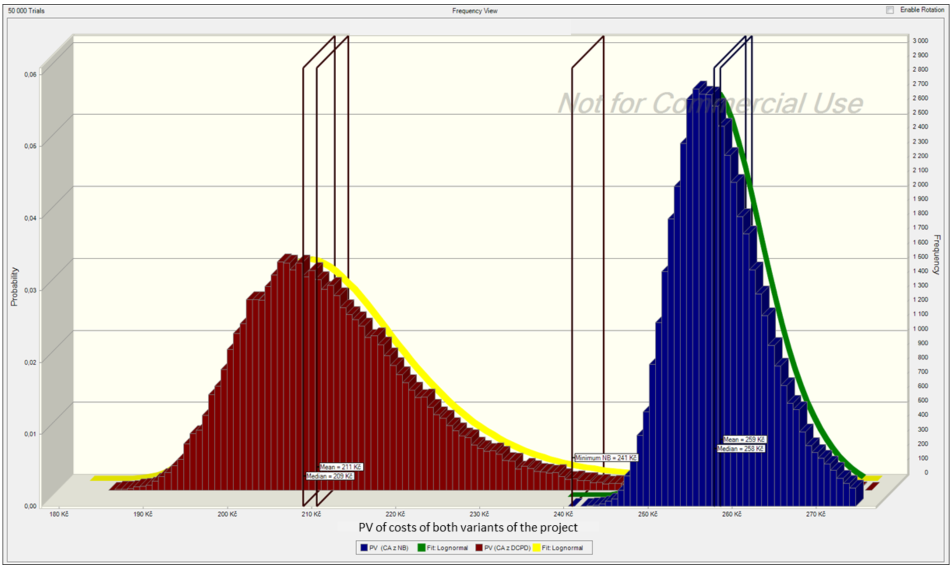

Fig. 2 Comparison of PV of costs for two variants of technology

The interpretation of the results is quite illustrative. Table 2 shows the most probable value of costs PV for both variants (modus) as well as the variance for both variants. It is apparent that DCPD technology operates more economically than NB one, but the former is riskier than the latter. Decision on the option for either type of technology may be also supported by the first rule of stochastic dominance. For the differentiation between technology variants of Corey lactone production from NB or DCPD the first rule of stochastic dominance can be used. In view of the fact that it deals with PV of costs („the lower, the better ") it is necessary to interpret the picture contrarily to routine criteria of revenue type. On the basis of the comparison of statistic distribution it can be concluded that technology variant DCPD dominates technology variant NB since the value of distribution function for variant DCPD is for almost any value of costs criterion more advantageous than for variant NB. On the basis of analyses performed it was recommended to owners to implement the project in technology variant DCPD which offers the best value of economic effectiveness parameters. This decision was made with the notion that risks of this technology will be in course of time and continuing optimization in decline. Moreover, probability that DCPD technology shows worse economic characteristics than NB one is 2,5% only.

Table 2 Comparison of moduses for both technologies

Technology variant	PV of costs (mil. CZK) (modus)	Variance (CZK)
Production of the product from DCPD	206	116
Production of the product from NB	257	33

5 Results and discussion

Software based decision-making tool provided reliable results when being tested on production, investment and service cases. Simulation of key performance characteristics like net profit, operational cash flow or Net Present Value offered a valuable contribution to decision-making process. The project faces some limitation that rest in fact that some processes cannot be easily described by a mathematical model. The advantage of the solution is its openness and adaptability to specific company need. Research team intends this tool to help managers make important decisions upon risk and uncertainty and simultaneously minimize failures of these decisions. The software was purposefully simplified so as not to deter managers from its use. Typically, triangular distribution of input variables (risk factors) was chosen as a preferred alternative because of its easiness to determine the lowest, the highest and the most probable value of the parameter. Since the simulation proceeds very quickly it is recommendable to use 50 000 – 100 000 simulation runs to obtain more reliable results.

Conclusion

Repeated failures made during decision-making processes on complex problematic that requires multicriterial approach persuasively showed that opting for intuitive decision-making approach was untenable. The managers are forced to make key decision under risk and uncertainty in shortening time. Elaboration of the software which was intended for the facilitation of decision-making processes can be considered approach of choice. Software tool enables simulation of any business processes which are describable by a mathematical model. Basically, it is applicable in routine situations where the reality is transformable to mathematical model like decision on purchase, closure analysis of a production unit, decision on outsourcing, assessment of variants of a business plan etc.

Mastering the software in question requires basic training in statistical methods and risk assessment methodology. Interpretation of the output values that are expressed in terms of probabilistic distribution also necessitates some probabilistic and statistical skills. Managers got accustomed to deterministic view of reality which prevents them from multifaceted perception of dynamic business systems. Increasing number of publications dealing with simulation approach showed that there was scarcity of any competitive managerial tools that would be conducive to the solution of complex managerial problems. Research team is in close contact with the experts in practice to get important feedback to this solution. The software based decision-making support shows enormous potential of this approach that can be even increased by the interconnection with artificial intelligence algorithms in the future.

Acknowledgements

This work was subsidized by the Ministry of Industry of the Czech Republic, program TRIO, Tools for the innovation and optimization of company processes performance within the framework of INDUSTRY 4.0 (grant number FV30110).

References

1. K. Al Badi, Discrete event simulation and pharmacy process re-engineering. *International Journal of Health Care Quality* **32,** (2) 398-411 (2019)
2. P. Goodall, R. Sharpe, A. West, A data-drive simulation support remanufacturing operations. *Computers in Industry*, **105**, 48-60 (2019)
3. H. Gucdemir, S. Hasan, Integrating simulation modelling and multi criteria decision making for customer focused scheduling in job shops. Simulation Modelling Practice and Theory **88**, 17-31 (2018)
4. M. Havey, *Essential Business Process Modelling,* O'Reilly Media, Inc., Sebastopol, CA (2005)
5. H. Kazakova, I. Zayarky, M. Medvedev, Forecasting of financial flows in business systems taking into account the risk and uncertainty of interaction. *International Conference on Numerical Analysis and Applied mathematics* (ICNAAM-2018), Rhodes, Greece, AIP Conference proceedings, **2116,** Article No. 430021 (2019)
6. S. B. Merriam, *Qualitative Research and Case Study Applications in Education: Revised and Expanded from Case Study Research in Education*. 2nd edition, San Francisco, CA: Jossey-Bass (2007)
7. Osterwalder, A.; Pigneur, Y. *Business Model Generation*. Wiley & Sons, Hoboken, New Jersey (2010)
8. J. L. Pereira, A. P. Freitas, Towards a characterization of BMP tools ´simulation support: the case of BPMN process models. *International Journal for Quality Research* **13,** (4) 783-796 (2019)
9. V. Schindlerová, I. Šajdlerová, Use of dynamic Simulation to Reduce Handling Complexity in the Manufacturing Process. *Advances in Science and Technology Research Journal* **14**, 1 81-88 (2020)
10. S. A. Silva, P.H.C. de Abreu, F. R. De Amorim, Application of Monte Carlo simulation for analysis of costs and economics risks in a banking agency. *IEEE Latin America Transactions* **17,** (3) 409-417 (2019)
11. B. Silver, *BPMN Method and Style,* 2nd Edition, with BPMN Implementer's Guide. Aptos, CA, USA: Cody-Cassidy Press, 2009.
12. R. Y. Rubinstein, D. P. Kroese, *Simulation and the Monte Carlo Method*, 2nd Edition, Wiley-Interscience (2007)
13. M. Špaček, Pravděpodobnostní přístupy k analýze rizik investičních projektů a jejich využití v praxi. NAVA - Nakladatelská a vydavatelská agentura, Plzeň (2015)
14. D. Tbaishat, Process architecture development using Riva and ARIS: comparative study, *Business Process Management Journal* **24,** (3) 837-858 (2018)
15. R. K. Yin, *Case Study Research: Design and Methods.* SAGE Publications, Inc; 5th edition (2014)