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MODELLING AND SIMULATION OF A DECISION-MAKING PROCESS SUPPORTING BUSINESS SYSTEM LOGISTICS

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Abstract
The article highlights the issue of accelerating the decision-making process in an exemplary business system that is designed to fulfil orders for customers. The information flow model with its mathematical representation is introduced. A pseudocode indicating the course of action in which simulations of the computational process is performed is shown. The simulation study illustrates the simulation procedure in order to extract data minimising the costs of making decisions in the discussed system. It is assumed that the most important goal when searching for a solution for the given input data is the need to find the satisfactory solution which allows to complete the business process. The thorough analysis of the obtained results made it possible to draw consistent conclusions for the business process taking into account the use of randomised input data. A lot of attention was paid to the problem of escalating the decision-making process.
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Key Words: Decision-Making, Business System, Mathematical Modelling, Simulation

1. INTRODUCTION

Sufficient decision-making efficiency is a key condition for ensuring the desired economic results of any enterprise. Decision-making must be implemented not only adequately and competently but also at the right moment which applies not only to all modern enterprises implementing processes in accordance with the Industry 4.0 initiative [1]. Historically, it has already been proven that decision-making has a direct impact on the company's financial income not only in terms of the quality of decision-making but also the timing of the decision and its implementation. Speeding up the decision-making process is reflected in the minimization of the costs of the final product. In business practice, there are no identical systems because there are always differences between them that affect how they work. The decision must always be implemented at the right time and with the use of management's own experience and knowledge as well as with the support of e.g. expert systems [2] or simulation tools using different approaches and technologies presented as the example in [3]. Systems in individual companies and their management are specific but generally applicable patterns can be identified from examples of good practice. The main goal of the article is to present the problem of decision-making in a logistics-type business system and to present a simulation model based on a relevant mathematical model, the principle and essence of which can be easily and effectively applied to the solution of concrete decision-making support for a number of similarly structurally and functionally established systems. The supplementary goal of the paper is to demonstrate how the process of business escalation can help to shorten the decision-making process. As part of the decision-making process, the escalation method is used as the method that defines how a problem or situation is gradually "escalated" to a higher level of responsibility or authority if a satisfactory solution has not been achieved at lower levels in order to minimize costs. The mentioned model has not yet been identified in any related publications known to the authors. The problem consists in finding the solution minimising the cost of making the order which is unavoidably connected with minimising the time of production. The contemporary approach to the problem of decision-making is thoroughly analysed in the related work chapter. Isolating the minimal values of costs found by means of sample separate methods leading to creating the optimised set of data is a specific way of solving the issue of minimizing the cost of making the customer's order.

2. RELATED WORKS

The content of the presented article mainly concerns the thematic areas of decision-making in the context of modelling and simulation. Business processes can be expressed by mathematical models which can be used to implement simulations. As stated in [4] simulations are an effective tool for identifying potential in all areas of business activities and processes. Business and complex business process models are created in accordance with the Business Process Model and Notation (BPMN) and can be used to implement process analysis suitable for supporting decision-making about business strategies and decisions [5, 6]. BPMN generally does not work with variability which is a limiting factor for further processing [7] and therefore Decision Model and Notation (DMN) is also used for decision-making purposes enabling the evaluation and definition of variability and variability rules in business processes [8]. Both papers mentioned notations as a part of different simulation tools available on the market, for example Camunda, which can also be commonly used for decision-making support. Decision-making is directly dependent on a large amount of input data [9] which today is standardly prepared using Business Intelligence [10]. Simulation models can also be combined to create the so-called hybrid simulation/analytical frameworks effectively using feedback simulation approaches [11]. Manufacturing and trading companies today represent complex and robust in-house logistics operations where the goal is to achieve the highest possible efficiency. According to [12] this is directly dependent on the management of key sets of operations including the management and implementation of individual orders. In many cases, the simulation model is represented by the so-called digital twin which according to [13] is the common standard for supporting integral management of all types of businesses. Overall, simulation models help create different scenarios of system behaviour [14] and eliminate faulty steps during production or other business or logistics processes [15] with a positive impact on cost reduction [16]. In order to reduce costs it is crucial to ensure a balance between production and distribution realized by reducing production at the moment of a high number of stock items and on the other hand by speeding up production in periods of increased demand [17]. The basis of the solution to the given problem is the management of order processing [18]. In [19] a model for assigning individual customer orders to selected branches with the aim of minimizing costs is presented, in [20] the issue of modelling managerial decisions and simulations in the production processes of diverse small-batch products in a discrete production environment is addressed and in [21], among other things, the issue of simulations based on MCDM (Multi-Criteria Decision-Making) is presented. In modern times, production management must respond quickly to fluctuations in demand [22], show an appropriate degree of agility and be in line with the concept of the Lean Company, all with the aim of ensuring an optimal pace of production [23]. The pace of production can be controlled, for example, by changing the configuration of individual machines both in terms of processing time and their number [24]. A mathematical model that also takes into account the outsourcing of processes in the framework of imperfect production with variable quantities is described in [25]. Mathematical models of supply chains can be found, for example, in [26] and for the service area in [27]. From the point of view of the creation of a mathematical model, the authors of the article took into account all the above-mentioned connections and proceeded in accordance with the procedure that has already been used effectively several times in the creation of various types of simulation models listed, e.g. in [28].

3. MATHEMATICAL MODEL

The decision flow problem is presented in graphical form in Fig. 1. The flow within the supply chain was adopted as the model. The decision flow begins with initiating an inquiry about the possibility of fulfilling an order placed in the order matrix. Decisions are made either in each unit or in the section of information transfer between elements of the logistics chain. After the decision is made in the supply area, the direction of the decision flow is alternated.

		D	SUP	CMS	PRS	MAN	REG	RPS	CSD	Z
Supply zone	D		← ▫							
Supply centre	SUP	▫ →		← ▫						
Charge material storage	CMS		▫ →			← ▫				
Production support unit	PRS					← ▫				
Manufacturing unit	MAN			▫ →	▫ →		▫ →	← ▫		
Regeneration unit	REG					← ▫				
Ready product storage	RPS					▫ →			← ▫	
Customer service department	CSD					▫ →				← ▫
Customer zone	Z								▫ →	

Figure 1: The concept of elaborating an inquiry for the customer in the units of the logistics chain.

Fig. 1 presents a sequential set of processes taking place in the example system emphasizing the concept of elaborating an inquiry for the customer in the units of the logistics chain which is subsequently represented by the mathematical model adequate to main processes. If any stage of passing information receives a workload that exceeds its processing capacity, there is likely to appear a bottleneck. In fact each logistics unit shown in Fig. 1 should be treated as a bottle neck as every information flow block in it directly influences awaiting period in the subsequent unit and for this reason any delay in passing the required information is accepted and should be minimised.

Let us assume there is a set of *M* customers who are interested in acquiring certain products of the sample company. The products are included in the set of *N* products which are currently on offer. Customers set orders at various stages, however, to begin making orders in the business system it is necessary to complete the whole order before it is sent to the company system to be made. The specific orders are placed in the matrix of orders:

$$Z^k = [z^k_{m,n}],\ m = 1, \dots, M,\ n = 1, \dots, N,\ k = 0,1, \dots, K \tag{1}$$

where: $z^k_{m,n}$ – the number of pieces of the n^{th} product to be made for the m^{th} customer at the k^{th} stage of the ready input data. Once the order matrix is completed, the inquiry is to be sent into the system units to obtain the information about the possibility and capacity of making customers' orders. This course of action generates unavoidable costs which have to be included in the final product price. Therefore, the search for the satisfactory solution is necessary to keep the costs of servicing clients' inquiries as low as possible. Let us introduce the vector of units arranged in series in the supply chain system:

$$\Theta_\beta = [\theta_\beta],\ \beta = 1, \dots, B \tag{2}$$

where: θ_β – the β^{th} unit in the logistics system. Let us introduce the vector of methods:

$$\Theta_\alpha = [\theta_\alpha],\ \alpha = 1, \dots, A \tag{3}$$

where: θ_α – the α^{th} method. Let us introduce the matrix of adjustments of methods to logistics units which can be considered in terms of elaborating customers' inquiries:

$$\Omega = [\omega_{\alpha,\beta}] \tag{4}$$

Unit costs are presented in the matrix of unit costs:

$$C^{unit\_k} = \left[c_{\alpha/(m,n)}^{unit(\beta\leftarrow)\_k} \,\middle|\, c_{\alpha/(m,n)}^{unit(\beta\leftarrow(\beta+1))\_k} \,\middle|\, c_{\alpha/(m,n)}^{unit(\rightarrow\beta)\_k} \,\middle|\, c_{\alpha/(m,n)}^{unit((\beta-1)\rightarrow\beta)\_k}\right] \tag{5}$$

Allowed times of elaborating and sending information are shown in the matrix of times:

$$T^{\_al\_k} = \left[\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow(\beta+1))\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{al\_(\rightarrow\beta)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{al\_((\beta-1)\rightarrow\beta)\_k}\right] \tag{6}$$

Predicted times of elaborating and sending information are placed in the matrix of times:

$$T^{\_pr\_k} = \left[\tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{pr\_(\rightarrow\beta)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{pr\_((\beta-1)\rightarrow\beta)\_k}\right] \tag{7}$$

Real times of elaborating and sending information are presented in the matrix of times:

$$T^{\_re\_k} = \left[\tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow(\beta+1))\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{re\_(\rightarrow\beta)\_k} \,\middle|\, \tau_{\alpha/(m,n)}^{re\_((\beta-1)\rightarrow\beta)\_k}\right] \tag{8}$$

Elements of matrices presented in Eqs. (5) to (8) are explained as follows:

i) elaborating the entering decision in the β^{th} unit of the system with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage:

$c_{\alpha/(m,n)}^{unit(\beta\leftarrow)\_k}$ – the unit cost, $\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow)\_k}$ – the allowed time,

$\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow)\_k}$ – the predicted time, $\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow)\_k}$ – the real time,

ii) sending the entering decision from the unit $(\beta + 1)$ to the unit β with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage:

$c_{\alpha/(m,n)}^{unit(\beta\leftarrow(\beta+1))\_k}$ – the unit cost, $\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow(\beta+1))\_k}$ – the allowed time,

$\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow(\beta+1))\_k}$ – the predicted time, $\tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow(\beta+1))\_k}$ – the real time,

iii) elaborating the leaving decision in the β^{th} unit of the system with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage:

$c_{\alpha/(m,n)}^{unit(\rightarrow\beta)\_k}$ – the unit cost, $\tau_{\alpha/(m,n)}^{al\_(\rightarrow\beta)\_k}$ – the allowed time,

$\tau_{\alpha/(m,n)}^{al\_(\rightarrow\beta))\_k}$ – the predicted time, $\tau_{\alpha/(m,n)}^{al\_(\rightarrow\beta)\_k}$ – the real time,

iv) sending the leaving decision from the unit $(\beta - 1)$ to the β^{th} unit with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage:

$c_{\alpha/(m,n)}^{unit((\beta-1)\rightarrow\beta)\_k}$ – the unit cost, $\tau_{\alpha/(m,n)}^{al\_((\beta-1)\rightarrow\beta)\_k}$ – the allowed time,

$\tau_{\alpha/(m,n)}^{al\_((\beta-1)\rightarrow\beta))\_k}$ – the predicted time, $\tau_{\alpha/(m,n)}^{al\_((\beta-1)\rightarrow\beta)\_k}$ – the real time.

It must be assumed that if the predicted times of sending the information between units and elaborating them in units before passing them to the neighbouring (or dedicated) units exceed the allowed times, the need for the escalation process arises as shown below:

i) $\tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k} > \tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow)\_k} \rightarrow \tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow)\_k} = \left(1 - \rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k}\right) \cdot \tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k}$

where: $\rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k}$ – the coefficient of the predicted time of elaborating the entering decision in the β^{th} unit of the system with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage; $0 > \rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow)\_k} > 1$;

ii) $\tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k} > \tau_{\alpha/(m,n)}^{al\_(\beta\leftarrow(\beta+1))\_k} \rightarrow \tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow(\beta+1))\_k} = \left(1 - \rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k}\right) \cdot \tau_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k}$

where: $\rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k}$ – the coefficient of the predicted time of sending the entering decision from the unit $(\beta + 1)$ to the unit β with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage; $0 > \rho_{\alpha/(m,n)}^{pr\_(\beta\leftarrow(\beta+1))\_k} > 1$;

iii) $\tau_{\alpha/(m,n)}^{pr\_(\rightarrow\beta)\_k} > \tau_{\alpha/(m,n)}^{al\_(\rightarrow\beta)\_k} \rightarrow \tau_{\alpha/(m,n)}^{re\_(\rightarrow\beta)\_k} = \left(1 - \rho_{\alpha/(m,n)}^{pr\_(\rightarrow\beta)\_k}\right) \cdot \tau_{\alpha/(m,n)}^{pr\_(\rightarrow\beta)\_k}$

where: $\rho_{\alpha/(m,n)}^{pr\_(\to\beta)\_k}$ – the coefficient of the predicted time of elaborating the leaving decision in the β^{th} unit of the system with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage; $0 > \rho_{\alpha/(m,n)}^{pr\_(\to\beta)\_k} > 1$;

iv) $\tau_{\alpha/(m,n)}^{pr\_((\beta-1)\to\beta)\_k} > \tau_{\alpha/(m,n)}^{al\_((\beta-1)\to\beta)\_k} \to \tau_{\alpha/(m,n)}^{re\_((\beta-1)\to\beta)\_k} = \left(1 - \rho_{\alpha/(m,n)}^{pr\_((\beta-1)\to\beta)\_k}\right) \cdot \tau_{\alpha/(m,n)}^{pr\_((\beta-1)\to\beta)\_k}$

where: $\rho_{\alpha/(m,n)}^{pr\_((\beta-1)\to\beta)\_k}$ – the coefficient of the predicted time of sending the leaving decision from the β^{th} unit to the unit $(\beta+1)$ with the use of the α^{th} method in case of making the n^{th} product for the m^{th} customer at the k^{th} stage; $0 > \rho_{\alpha/(m,n)}^{pr\_((\beta-1)\to\beta)\_k} > 1$.

The total cost of making one order of the nth product for the m^{th} customer at the k^{th} stage with the use of the α^{th} method is calculated as follows:

$$C_{\alpha/(m,n)}^{k} = \sum_{\beta=1}^{B} \tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow)\_k} \cdot c_{\alpha/(m,n)}^{unit(\beta\leftarrow)\_k} + \sum_{\beta=1}^{B} \tau_{\alpha/(m,n)}^{re\_(\beta\leftarrow(\beta+1))\_k} \cdot c_{\alpha/(m,n)}^{unit(\beta\leftarrow(\beta+1))\_k} + \\ + \sum_{\beta=1}^{B} \tau_{\alpha/(m,n)}^{re\_(\to\beta)\_k} \cdot c_{\alpha/(m,n)}^{unit(\to\beta)\_k} + \sum_{\beta=1}^{B} \tau_{\alpha/(m,n)}^{re\_((\beta-1)\to\beta)\_k} \cdot c_{\alpha/(m,n)}^{unit((\beta-1)\to\beta)\_k} \quad (9)$$

Let us introduce the matrix of bonus factors: $\Omega = \left[\omega_{m,n}^{k}\right]$, $m = 1, \dots, M$, $n = 1, \dots, N$, $k = 0, 1, \dots, K$, where: $\omega_{m,n}^{k}$ – the bonus factor for the n^{th} order to be made for the m^{th} customer at the k^{th} stage. At the same time: $0 < \varphi_{m,n}^{k} \leq \omega_{m,n}^{k} \leq 1$ where: φ – the minimal value of the bonus factor in case of the n^{th} order to be made for the m^{th} customer at the k^{th} stage. It is assumed that a bonus factor becomes active and is implemented only on condition there is no need to escalate the decision-making process which leads to lowering the time of making a decision in case of the nth order to be made for the m^{th} customer at the k^{th} stage. Otherwise, it remains inactive and $\varphi_{m,n}^{k} = 1$. In the case analysed in the paper the escalation management process ensures that customer service agents can provide satisfactory solutions to as many customers as possible in the shortest time. Moreover, the escalation process features ways to address issues at the lowest level possible resulting in the faster information flow. Due to the fact that the costs of order fulfilment cannot increase beyond the reasonably established price limits, the following restrictions should be adopted:

i) $\left(\xi + \frac{z_{m,n}^{k}}{\zeta}\right) \cdot C_{\alpha/(m,n)}^{k} \geq \gamma \cdot C_{\alpha/(m,n)}^{k} \Rightarrow C_{\alpha/(m,n)}^{mod\_k} = \gamma \cdot C_{\alpha/(m,n)}^{k}$

ii) $\left(\xi + \frac{z_{m,n}^{k}}{\zeta}\right) \cdot C_{\alpha/(m,n)}^{k} < \gamma \cdot C_{\alpha/(m,n)}^{k} \Rightarrow C_{\alpha/(m,n)}^{mod\_k} = \gamma\left(\xi + \frac{z_{m,n}^{k}}{\zeta}\right) \cdot C_{\alpha/(m,n)}^{k}$

where: ξ – the basic quantitative factor; ζ – minimizing denominator; γ – maximum permissible value.

Overall costs of making the order at the k^{th} stage with the use of the α^{th} method are calculated as follows:

$$C_{\alpha}^{tot\_k} = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{\alpha/(m,n)}^{mod\_k} \quad (10)$$

The minimal costs of making the n^{th} product for the m^{th} customer at the k^{th} stage within all available methods are calculated as follows:

$$C_{m,n}^{min\_k} = \min_{1\leq\alpha\leq A} C_{\alpha/(m,n)}^{mod\_k} \quad (11)$$

Minimal overall costs of making the order at the k^{th} stage with the use of all available methods A are calculated as follows:

$$C_{\min\_\alpha}^{tot\_k} = \sum_{n=1}^{N} \sum_{m=1}^{M} C_{\alpha/(m,n)}^{min\_k} \quad (12)$$

4. SIMULATION STUDY

The mathematical model presented in this article is the subject of verification of its correctness in terms of implementation by means of the extended analytical method. For this purpose, a decision-making process simulator created with the full application of the previously presented mathematical model of the decision-making process was used. The data for the simulation process was obtained randomly. First of all, it was necessary to determine all the ranges from which the initial data for the simulation process is obtained (Table I).

Table I: Data for the randomization of initial values.

Range for drawing	**min**	**max**
Orders	0	1000000
Bonuses	0.95	0.99
Allowed times for elaborating information	10	100
Predicted times for elaborating information	10	100
Unit costs for elaborating information	3	15
Allowed times for sending information	3	7
Predicted times for sending information	3	7
Unit costs for sending information	2	5

First of all, the orders matrix elements were drawn which is presented in Table II.

Table II: Final order matrix.

***z*(*m*, *n*)**	***n* = 1**	***n* = 2**	***n* = 3**	***n* = 4**	***n* = 5**
***m* = 1**	926,350	809,018	742,193	317,876	667,813
***m* = 2**	919,980	275,086	473,422	302,860	718,563
***m* = 3**	652,971	665,312	781,688	715,920	229,998
***m* = 4**	91,027	648,621	54,317	82,879	12,924
***m* = 5**	135,078	244,026	989,930	50,792	748,450
	Total: 12,257,094				

Subsequently, bonuses were drawn and they can be used to reduce the final costs for a data set characterized by the minimum value of the cost of making all order elements included in the order matrix (Table III).

Table III: Drawn bonuses for the set of data generating the minimum value of the cost of making all orders.

***z*(*m*, *n*)**	**n = 1**	**n = 2**	**n = 3**	**n = 4**	**n = 5**
***m* = 1**	0.96	0.96	0.95	0.97	0.95
***m* = 2**	0.98	0.95	0.97	0.97	0.99
***m* = 3**	0.97	0.97	0.98	0.98	0.97
***m* = 4**	0.99	0.97	0.99	0.99	0.99
***m* = 5**	0.96	0.97	0.98	0.97	0.96
	Total: 24.26				

As part of the simulation study, in accordance with the data contained in Table I, the simulation and calculation process was carried out five times in order to extract a satisfactory solution. For each sampling, a separate set of result data was created α, $\alpha = 1, ..., 5$, which was then subjected to a thorough analysis and comparison. As a result of comparing the resulting data on the basis of Table IV, it was found that the set of input data for α_3 led to obtaining the best result in terms of contract performance costs.

The comparison of α_min = α_3 and α_opt is presented in Fig. 2. This type of graphical comparative analysis leaves no doubt that the α_opt option is always the best for any order configuration.

Table IV: Comparison of costs of making individual orders.

(m,n)	z(m,n)	α_1 (E+05)	α_2 (E+05)	α_3 (E+05)	α_4 (E+05)	α_5 (E+05)	α_min (E+05)	α_opt (E+05)
(1,1)	926350	86095	73793	73450	77137	94849	73450	21982
(1,2)	809018	75190	64446	64147	82835	82835	64147	19198
(1,3)	742193	68979	59123	58848	75993	75993	58848	17612
(1,4)	317876	29543	25322	25204	32547	32547	25204	7543
(1,5)	667813	62066	53198	52951	68377	68377	52951	15847
(2,1)	919980	85503	73286	72945	94197	94197	72945	21831
(2,2)	275086	25566	21913	21812	28166	28166	21812	6528
(2,3)	473422	44000	37713	37538	48474	48474	37538	11234
(2,4)	302860	28148	24126	24014	31010	31010	24014	7187
(2,5)	718563	66783	57241	56975	73574	73574	56975	17051
(3,1)	652971	60687	52016	51774	66858	66858	51774	15495
(3,2)	665312	61834	52999	52753	68121	68121	52753	15788
(3,3)	781688	72650	62269	61980	80037	80037	61980	18549
(3,4)	715920	66538	57030	56765	73303	73303	56765	16989
(3,5)	229998	21376	18322	18236	23549	23549	18237	5458
(4,1)	91027	8460	7251	7218	9320	9320	7218	2160
(4,2)	648621	60282	51669	51429	66412	66412	51429	15392
(4,3)	54317	5048	4327	4307	5562	5562	4307	1289
(4,4)	82879	7703	6602	6571	8486	8486	6571	1967
(4,5)	12924	1201	1030	1025	1323	1323	1025	307
(5,1)	135078	12554	10760	10710	13831	13831	10710	3205
(5,2)	244026	22680	19439	19349	24986	24986	19349	5791
(5,3)	989930	92004	78858	78492	101360	101360	78492	23491
(5,4)	50792	4721	4046	4027	5201	5201	4027	1205
(5,5)	748450	69561	59622	59345	76634	76634	59345	17761
Σ	12257094	1139174	976400	971868	1237292	1255004	971865	**290861**

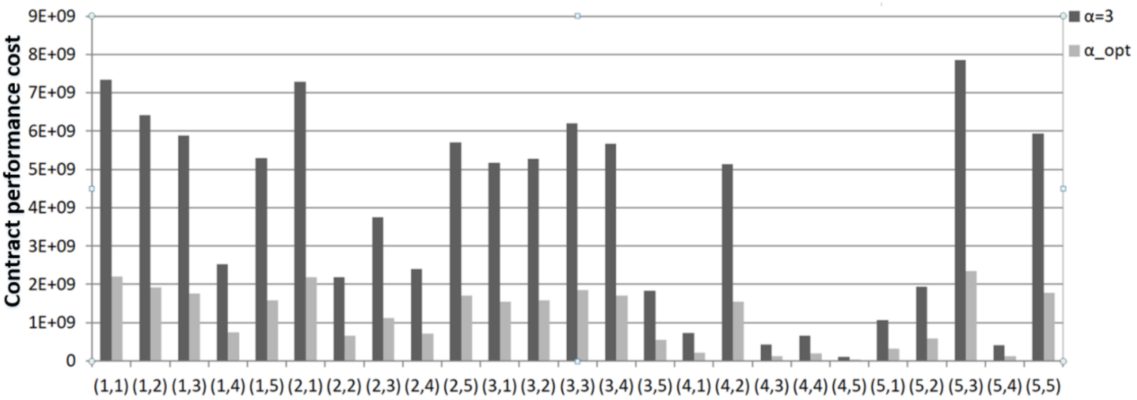

Figure 2: Comparison of *α*_min = *α*_*3* and *α*_opt.

In order to illustrate how the final result data was reached, an overwritten calculation for the *α*_3 data set is shown in Table V. The calculations for the remaining data sets, i.e. *α*_1, *α*_2, *α*_4 and *α*_5, obtained randomly from the predefined range of input data were performed in the same way. If an action within the system has already been performed, the status of this particular action becomes 1, otherwise the value of this action remains at 0 while waiting for an action to improve (accelerate) making the right decision. In addition, it should be assumed that the prepared message coming from a given unit of the logistics chain is marked as []→·, the transmission of information between units of the logistics chain as []→[], while the prepared message coming from the previous unit of the logistic chain is marked as ·→[].

Based on the results obtained after conducting five simulations for the *α*_1, …, 5 input data, the best results can be selected among them, i.e. minimizing the time and cost of carrying out each operation for each calculation stage. For this reason, Table VI containing the results that minimize the time of each stage of information transmission and its elaborating in the supply chain units was created. It lists the costs and minimization times along with the data set for which they were obtained.

Table V: Calculations carried out for the α_3 dataset.

Action	**State**	**Start time**	**Allowed times**	**Predicted times**	**Unit cost**	**Need for escalation**	**Real time**	**End time**	**Stage *k***	**Total cost**
Z→·	1	0	50	27	4	NO	27	27	1	108
Z→CSD	1	27	6	6	8	NO	6	33	2	48
·→CSD	1	33	19	76	9	YES	73	106	3	657
CSD→RPS	1	106	6	6	3	NO	6	112	4	18
·→RPS	1	112	94	47	3	NO	47	159	5	141
RPS→MAN	1	159	4	3	9	NO	3	162	6	27
·→MAN	1	162	57	50	9	NO	50	212	7	450
MAN→REG	1	212	4	5	5	NO	4	216	8	20
·→REG	1	216	12	91	11	YES	88	304	9	968
MAN→PRS	1	304	4	5	9	NO	4	308	10	36
·→PRS	1	308	69	10	14	NO	10	318	11	140
MAN→CMS	1	318	5	4	13	NO	4	322	12	52
·→CMS	1	322	25	89	9	YES	86	408	13	774
CMS→SUP	1	408	5	4	8	NO	4	412	14	32
·→SUP	1	412	84	68	3	NO	68	480	15	204
SUP→D	1	480	5	6	3	NO	5	485	16	15
·→D	1	485	43	51	11	YES	48	533	17	528
D→·	1	533	18	88	4	YES	85	618	18	340
D→SUP	1	618	5	6	5	NO	5	623	19	25
SUP→·	1	623	84	39	8	NO	39	662	20	312
SUP→CMS	1	662	6	3	8	NO	3	665	21	24
CMS→·	1	665	82	64	4	NO	64	729	22	256
CMS→MAN	1	729	6	3	6	NO	3	732	23	18
REG→·	1	732	39	38	14	NO	38	770	24	532
REG→MAN	1	770	4	6	11	YES	5	775	25	55
PRS→·	1	775	73	34	10	NO	34	809	26	340
PRS→MAN	1	809	6	4	3	NO	4	813	27	12
MAN→·	1	813	99	26	6	NO	26	839	28	156
MAN→RPS	1	839	6	6	6	NO	6	845	29	36
RPS→·	1	845	17	99	3	YES	96	941	30	288
RPS→CSD	1	941	3	5	9	YES	4	945	31	36
CSD→·	1	945	53	24	8	NO	24	969	32	192
CSD→Z	1	969	4	3	7	NO	3	972	33	21
·→Z	1	972	76	92	12	YES	89	1061	34	1068
				Ratio Yes/No: 0.36			Cost of making one product: 7929			
				Cost of making all products: 97186498326						

Table VI: Optimising times and costs.

States		**State**	**Start time**	**Allowed times**		**Predicted real times**		**Unit cost**		**Real time**		**End time**	**Stage *k***	**Stage cost**
1	0													
Z→·		1	0	51	α = 5	16	α = 1	3	α = 2	16	α = 1	16	1	48
Z→CSD		1	16	3	α = 5	3	α = 1	3	α = 2	3	α = 1	19	2	9
·→CSD		1	19	18	α = 1	21	α = 4	6	α = 3	21	α = 4	40	3	126
CSD→RPS		1	40	3	α = 2	3	α = 5	5	α = 5	3	α = 2	43	4	15
·→RPS		1	43	21	α = 3	37	α = 1	5	α = 1	37	α = 1	80	5	185
RPS→MAN		1	80	3	α = 2	4	α = 1	5	α = 4	3	α = 5	83	6	15
·→MAN		1	83	11	α = 3	51	α = 1	4	α = 1	48	α = 1	131	7	192
MAN→REG		1	131	3	α = 3	4	α = 5	6	α = 4	4	α = 3	135	8	24
·→REG		1	135	14	α = 3	14	α = 1	5	α = 3	14	α = 1	149	9	70
MAN→PRS		1	149	3	α = 2	3	α = 1	3	α = 3	3	α = 1	152	10	9
·→PRS		1	152	40	α = 3	28	α = 1	4	α = 5	28	α = 1	180	11	112
MAN→CMS		1	180	3	α = 3	3	α = 2	3	α = 3	3	α = 2	183	12	9
·→CMS		1	183	15	α = 2	34	α = 4	3	α = 3	34	α = 4	217	13	102
CMS→SUP		1	217	3	α = 2	3	α = 5	3	α = 2	3	α = 5	220	14	9
·→SUP		1	220	18	α = 1	23	α = 3	6	α = 4	23	α = 3	243	15	138
SUP→D		1	243	3	α = 4	4	α = 2	6	α = 2	4	α = 2	247	16	24
·→D		1	247	21	α = 5	22	α = 4	5	α = 5	22	α = 4	269	17	110
D→·		1	269	24	α = 3	21	α = 3	4	α = 2	21	α = 3	290	18	84
D→SUP		1	290	3	α = 2	3	α = 4	3	α = 3	3	α = 4	293	19	9
SUP→·		1	293	36	α = 1	11	α = 5	9	α = 3	11	α = 5	304	20	99
SUP→CMS		1	304	3	α = 3	3	α = 5	5	α = 1	3	α = 5	307	21	15

CMS→·	1	307	13	α = 1	40	α = 1	5	α = 2	37	α = 1	344	22	185
CMS→MAN	1	344	3	α = 5	4	α = 3	3	α = 5	3	α = 5	347	23	9
REG→·	1	347	14	α = 2	25	α = 5	8	α = 2	25	α = 5	372	24	200
REG→MAN	1	372	3	α = 3	3	α = 4	4	α = 5	3	α = 4	375	25	12
PRS→·	1	375	13	α = 2	11	α = 5	7	α = 3	11	α = 5	386	26	77
PRS→MAN	1	386	3	α = 1	3	α = 1	5	α = 3	3	α = 1	389	27	15
MAN→·	1	389	63	α = 3	11	α = 2	3	α = 1	11	α = 2	400	28	33
MAN→RPS	1	400	3	α = 1	4	α = 2	7	α = 2	4	α = 2	404	29	28
RPS→·	1	404	17	α = 3	10	α = 1	5	α = 4	10	α = 1	414	30	50
RPS→CSD	1	414	3	α = 3	3	α = 1	3	α = 3	3	α = 1	417	31	9
CSD→·	1	417	24	α = 5	14	α = 1	7	α = 1	14	α = 1	431	32	98
CSD→Z	1	431	4	α = 1	3	α = 3	5	α = 2	3	α = 3	434	33	15
·→Z	1	434	38	α = 5	34	α = 3	7	α = 2	34	α = 3	468	34	238
											Unit cost:	2373	
											Total cost:	29086084062	

The most important results of the simulation process have been collected and presented in Table VII divided into sets of input data generated from a predefined range separately for each set. In addition, an optimization solution was presented, in which there is no escalation factor, because the best solutions for data transfer and their development do not contain it.

Table VII: Final results of the simulation process.

System	Time of making one unit	Cost of making one unit	Time of making all orders	Costs of making all orders	Escalation rate
***a* = 1**	1151	9294	14107915194	113917431636	0.789
***a* = 2**	995	7966	12195808530	97640010804	0.619
***a* = 3**	1061	7929	13004776734	97186498326	0.360
***a* = 4**	1135	10239	13911801690	125500385466	0.545
***a* = 5**	871	8327	10675928874	102064821738	0.308
α_opt	468	2373	5736319992	2917188372	*)

* In the case of optimizing times and costs, the escalation rate is not taken into account due to the fact that solutions minimizing the times and costs of service transfer do not include this option.

Times of making one unit of order are compared in Fig. 3 indicating that the minimum result was obtained using a set of random data α_opt which was definitely advantageous. Costs of making one unit of order are compared in Fig. 4 where the minimum cost was obtained using the set of random data α_opt. Accordingly, the times of making all orders are shown in Fig. 5 again indicating the result minimizing the execution time of all orders using the combined set of random data α_opt. Costs of making all orders are shown in Fig. 6 confirming that the lowest total cost of making all orders is provided by the combined set of random data α_opt which was much more advantageous. The escalation ratio has been compared for all input data sets in order to indicate a set that should be assigned bonuses due to its value minimizing the need for an escalation process. As it can be seen in Fig. 7, the set α_5 is awarded due to the lowest escalation ratio, however, further comparison shown in Fig. 8 indicates that this approach does not guarantee a better result than for α_3 = α_min as α _opt still boasts the best result.

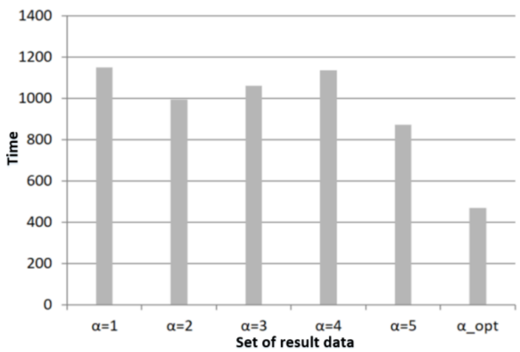

Figure 3: Times of making one unit of order.

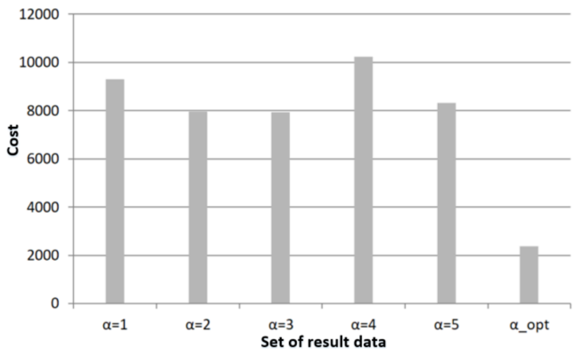

Figure 4: Costs of making one unit of order.

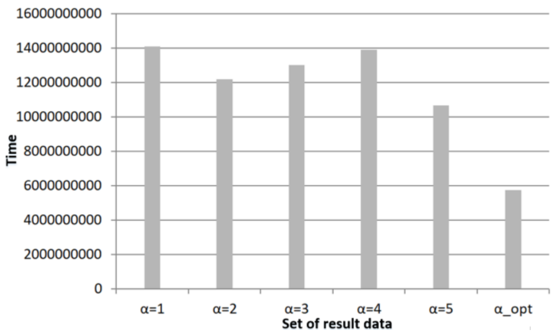

Figure 5: Times of making all orders.

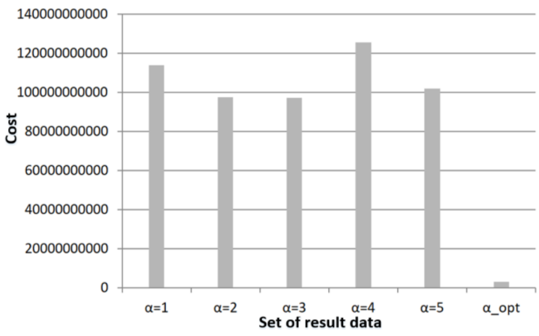

Figure 6: Costs of making all orders.

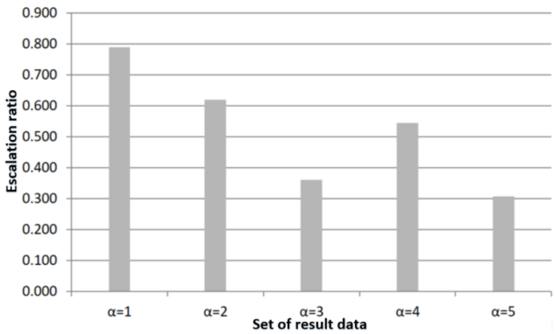

Figure 7: Escalation ratio.

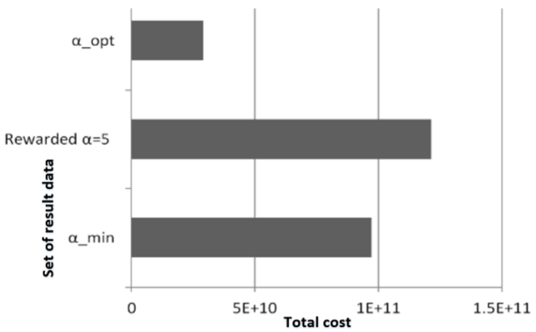

Figure 8: Comparison of total costs using the bonus approach.

The main goal of the simulation study was to verify the correctness of the presented theoretical assumptions. The input data for the computational task can be transformed from a ready file created manually or randomly generated. In the simulation study, it was decided to carry out calculations for data generated at random. First, the data for the randomization of initial values was extracted. For the generated values of the order matrix, adequate bonuses were created for the subsequent use for lowering the total cost of making all orders for the data set that reaches the minimum unit cost of producing an order matrix element. After performing the calculations for five independent sets of input data, the comparison of costs of making individual orders is presented. Illustratively, the calculations carried out for the α_3 dataset are shown. Optimizing times and costs consisted in extracting the minimum computational data from five sets of computational input data which is presented in the form of a separate set of results α_opt optimizing the decision-making process. The issue of the escalation process aimed at unblocking the decision-making process and reducing its costs was also raised. As a result of the calculation process, it was found that, regardless of any procedure, in each case the best results are achieved by applying the optimization procedure α_opt. The comparison of total costs using the bonus approach proves that even the implementation of bonuses for the best escalation ratio for the assumed input data is not able to measurably approach the result guaranteed by the optimization procedure α_opt.

5. CONCLUSIONS

The presented problem concerns the issue of making decisions in a business system. As decision-making requires to be accelerated in order to initiate the business process, the way of optimising by means of combining the best approaches detected in five identical business systems is shown in detail. The structure of the decision-making system describes a two-way flow of decisions. The issue of making decisions does not only concern supply chain units but also the transfer of decisions between units. If the decision is not made in a timely manner, oversized costs are generated, which ultimately increase the cost of the contract for the final recipient. Therefore, it is extremely important to eliminate delays associated with making decisions. The escalation method used in the decision-making process definitely contributed to the minimization of costs not only for individual sets of input data but most of all to the achievement of the compilation result of the minimum results obtained from each result data set. In real business environment, each system is de facto autonomous, even if there are significant similarities between systems. Therefore, it becomes important, in addition to using standard optimization methods, to search for solutions that are better than those currently implemented. This study provides the theoretical foundations, supported by a simulation study analysis, for the creation of an automatic system that can facilitate decision-making or accelerate them in the real conditions of operating a business system. It is assumed that further work should be carried out towards the expansion of the system suggested in this study in terms of the elimination of unacceptable values from a practical point of view taking into account the specificity of a given business system.

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