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ENTERPRISE RISK ARISING FROM LEGACY PRODUCTION SYSTEMS: A PROBABILISTIC PERSPECTIVE

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Abstract

The model of estimation of effective minimization of strategic risks arising at modernization of the software of legacy production systems is presented. It is shown that incompatible hypotheses of strategic risks of the enterprise in the digital economy form a complete group of pairwise incompatible independent events, and their probabilities are found by mathematical methods of processing an inversely symmetric matrix, made by experts in pairwise comparison on a 5-point scale of relative importance errors of calculations of the constructed matrix (no more than 15 %). For these matrices, solutions of characteristic equations are found to determine the maximum values of the eigenvalues of matrices, which appear in the assessment of the adequacy of composite expert matrices together with the corresponding orders of matrices.

To substantiate the statistical measurement under the condition of quantitative or qualitative assessment of the risk of occurrence of events, the a priori value of the probabilities of occurrence of risk in the occurrence of events is taken. The full probability formula is the formula for the probability of occurrence of an event of effective minimization of strategic risks. It is shown that to determine the a priori values of conditional probabilities of hypotheses of effective minimization of strategic risks of the enterprise it is necessary to make statistically significant sections of these hypotheses at selected enterprises for several periods, which may be subject to statistical distribution laws. Thus, the presented model for quantitative measurement, comprehensive analysis of the level of software modernization of legacy production systems of the enterprise is the initial theoretical basis for improving the system of strategic management of the enterprise in terms of digitalization.

Keywords: project risk, expert matrix, full group of events, conditional probabilities, reengineering, business processes.

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1. Introduction

Today, digital technologies are the basis for innovation. Digital transformation creates opportunities for growth and value creation. However, none of the opportunities can be realized without addressing the associated risks. Thus, risk management is important for the stability of the enterprise in the digital age [1].

In the context of digital transformation, companies need to manage the risks that affect the existing ecosystem of the enterprise, to achieve the optimal state of the newly introduced digital initiatives. Therefore, assessing the effectiveness of minimizing strategic risks in the process of implementing information technology in the enterprise, as the main basis for reengineering is relevant and requires new methodological approaches and comprehensive coverage of strategic risks [2].

Although few universally-acceptable definitions of a legacy system exist in the literature, let's use the following criteria of a legacy software system [3, 4] instrumental in informing our work. The system is often considered legacy by practitioner consensus if it meets most of the following criteria: (1) old – a project must exist for a time as it accumulates entropy and becomes further removed from the intentions and knowledge of its original creators/maintainers, (2) large – thus creating additional difficulty in identifying bugs, (3) inherited – passed down generations of maintainers, being very far removed from its original creators, (4) poorly documented – in real-world settings, quality of available documentation often degrades over time. This creates and multiplies enterprise risks that are hard to quantify and manage, such as schedule, budget, operational, technical, and programmatic risks [3, 5]. In particular, it is possible to note that a survey of 1,400 cloud-computing users by the MIT Technology Review [3, 4] found that 58 % considered the risk arising from legacy computer systems to be significant or worse.

Therefore, it is necessary to develop reasonable measures to neutralize strategic risks. The development of such measures ensures a fairly accurate assessment not only of the number of potential losses and the probability of their occurrence but also of the impact of individual factors on the overall project risk [3–5].

In particular, software development is an activity that uses a variety of technological tools and requires a high level of knowledge. Therefore, the software development project contains elements of uncertainty – project risk [6, 7]. The implementation of a software development project depends on the amount of risk that corresponds to the project activity. To achieve a successful outcome, it is necessary to identify, assess priorities and manage risks. Let's note that current trends in production are determined by the small batch size, high variability of products, and changes in product range during the life cycle of the automated production system [8–10]. These trends provide more complex indicators for automation, which leads to updates to automation software. The share of system functionality implemented with the help of software is growing, which requires innovative support concepts [11]. Let's note that the software, as well as the software engineering, must meet the specific requirements of real-time and reliability.

Therefore, the assessment of strategic risks of the enterprise, especially those that arise during the modernization of software for legacy production systems is an urgent problem. In the process of software development, risk reduction is a central activity of management [12–14]. Risk is the possibility of incurring losses, and the overall risk for a particular project will consider both the probability and the amount of potential loss [15–18].

Risk identification and aggregation is the only method of forecasting to determine the probability that unforeseen or unacceptable events will occur in a software development project [19]. These include termination, breaks, schedule delays, understatement, and overspending of project resources [20].

Risk management means deterring and reducing risk. Most software programs use new technologies. Always changing tools, methods, protocols, standards, and development systems increase the likelihood that technological risks will arise in almost all aspects of software development [21–23]. Learning and knowledge are crucial, and the misuse of new technology often leads directly to the implementation of the project.

In [24] the application and architecture of legacy production systems in the conditions of digitalization are considered. It is emphasized that the wrong direction of the platform, component, or architecture can have catastrophic consequences, so the team must include experts who understand the architecture and have the opportunity to make informed design choices [25].

In terms of performance, it is important to make sure that any risk management plan covers the expectations of users and partners. Therefore, there is a need to consider benchmarks and threshold tests throughout the project to ensure the movement of working products in the right direction [26]. At the same time, organizational problems can harm project results. Project management should plan the effective implementation of the project and find a balance between the needs of the development team and the expectations of customers [27–29].

The risk management plan after their typical cataloging for software development should be crucial in the reengineering process because as part of the master plan of the project, the risk management plan determines the responses that will be accepted for each risk in its implementation [30, 31]. Note that program risk monitoring should be an integral part of most project activities, including project status reports and risk management issues; elimination of risks with the least probability; readiness for potentially new risks [32–34].

Human thinking about software risk is prone to cognitive biases [35], which is an obstacle to the enterprise's long-term success. Thus, let's arrive at a mathematical framework for more rationally considering enterprise risk arising from the legacy software production systems which we hope will improve real-world outcomes when thinking about risks in managing schedule, budget, operational, technical, and programmatic risks [35] is helpful. However, further research is required. Particularly, it is concerned about the limitations of human applications of the mathematical model we devised in the field. This paper is devoted to the practical development of a proof-of-concept model for evaluating risk during the modernization of the software of legacy production systems. Authors have limited only the risk assessment theoretical base.

2. Materials and methods

Let's consider the incompatible hypotheses of strategic risks of the enterprise, which arise during the modernization of software for legacy production systems (**Table 1**).

Table 1
Evaluation of effective minimization of strategic risks that arise during the modernization of software of legacy production systems

Assessment of effective minimization of strategic risks	The main incompatible hypotheses of strategic risks of the enterprise (denoting their probabilities)
Strategic risks that arise when upgrading the software of legacy production systems (*P(A)*)	Assessment of the current state of obsolete systems $P(A_1)$.
	The probability of effective approaches to software upgrades, which will provide value as soon as possible $P(A_2)$.
	Probability of rethinking architecture (functionality) and setting priorities for software simplification $P(A_3)$.
	The probability of choosing reengineering to ensure optimal performance $P(A_4)$.
	The probability of creating a code document on the future growth of the system $P(A_5)$.
	The probability of creating a separate schedule for maintenance and disposal of the legacy system $P(A_6)$.
	The probability of creating an effective budget for training and updating the system $P(A_7)$

Let's denote incompatible hypotheses by $A_i, i=\overline{1,7}$ and they form a complete group of pairwise incompatible independent events, and by definition, there is:

$$P(A)=\sum_{i=1}^{7}P(A_i)=1,\ \ \bigcap A_i\cdot A_j=\varnothing,\ \ i\neq j. \tag{1}$$

Let's note that in **Table 1** the sum of the probabilities of pairwise incompatible events is equal to one:

$$P(A_1)+P(A_2)+P(A_3)+P(A_4)+P(A_5)+P(A_6)+P(A_7)=1. \tag{2}$$

Henceforth, Doctor Bludova shall proceed to use the IBM SPSS software to probabilistically model the risk-analysis of the business processes as a compilation of a matrix of expert pairwise comparisons according to the importance of each event from the complete group of events $A_i, i=\overline{1,7}$ (**Table 1**), which is shown in **Table 2** and has an inversely symmetric form.

Table 2

Matrix of expert pairwise comparisons by the importance of each event according to **Table 1**

Actions	A_1	A_2	A_3	A_4	A_5	A_6	A_7
A_1	1	2	2	3	2	3	2
A_2	0.5	1	2	4	1	4	3
A_3	0.5	0.5	1	2	3	1	2
A_4	0.33	0.25	0.5	1	4	2	1
A_5	0.5	1	0.33	0.25	1	4	3
A_6	0.33	0.25	1	0.5	0.25	1	2
A_7	0.5	0.33	0.5	1	0.33	0.5	1

Let's compose a characteristic equation for finding the eigenvalues of the matrix of **Table 2**:

$$-x^7 + 6.99x^6 - 0.0049x^5 + 70.545x^4 + 35.678x^3 + 109.616x^2 + 44.364x + 26.803 = 0. \quad (3)$$

According to the online calculator complex eigenvalues of the matrix:

$$\{-0.27-0.68i; -0.27+0.38i; -0.27-2.67i; -0.25+0.49i; -0.05+0.77i;$$
$$-0.25-0.49i; -0.048+1.22i; -0.048-1.215i\}, \quad (4)$$

and the only real eigenvalue: {8.148}, which is the maximum real eigenvalue of the matrix of **Table 2**.

To reconcile the acceptable calculation error, the analysis was generated by the random number generator, random matrices. The normative value of the index of consistency of expert judgments for the matrix of the 7th order is equal to the value of 1.32. The level of agreement with inversely symmetric random matrices of the 7th order is checked (3):

$$\frac{\lambda_n - n}{(n-1)\cdot\zeta_n}\cdot 100\,\% \le 10 \div 15\,\%, \quad (5)$$

where λ_n is the maximum eigenvalue of the expert matrix, n is the order of the expert matrix of pairwise comparisons of expert judgments, ζ_n is the normative value of the consistency index for the generated random inversely symmetric matrices of the nth order.

In our case (5):

$$\frac{\lambda_n - n}{(n-1)\cdot\zeta_n} = \frac{\lambda_{\max} - 7}{6\cdot 1.32} = \frac{8.148-7}{7.92} < 0.1449 < 0.15. \quad (6)$$

Let's determine the probabilities of full group events $A_i, i = \overline{1,7}$ using mathematical methods of processing the inversely symmetric matrix, which are experts in pairwise comparison on a 5-point scale of relative importance [25]. Thus, a matrix of expert pairwise comparisons is true with an error of 14.49 %. Let's find the weights using the geometric mean of the rows. Thus, the probabilities of events of the full group of the main hypotheses of strategic risks of the enterprise under the condition of (6) are calculated in the form:

$$P(A_1) = 0.260228,\ P(A_2) = 0.22243,\ P(A_3) = 0.149684,\ P(A_4) = 0.109203,$$
$$P(A_5) = 0.115715,\ P(A_6) = 0.073488,\ P(A_7) = 0.069253. \quad (7)$$

Let's apply the theoretical-probabilistic approach to the establishment of the main hypotheses and their conditional probabilities of strategic risks in the reengineering of the enterprise. **Table 3** presents the main hypotheses and their conditional probabilities of strategic risks in the reengineering of the enterprise, which arise during the modernization of the software of legacy production systems.

Table 3

The main hypotheses and their conditional probabilities of strategic risks

Basic hypotheses (denoting their probabilities)	Conditional probabilities of hypotheses of strategic risks $P(A_{ij}/A_i)$, $i=1,\dots,7$ of the enterprise and their designations which for each value i form full groups of events
1. Assessment of the current state of obsolete systems. $P(A_1)$	1. 1. The probability of current and potential problems of the enterprise for software upgrades. $P(A_{11}/A_1)$. 1. 2. Probability of uninterrupted operation of all aspects of technology, considering business plans to ensure product growth. $P(A_{12}/A_1)$. $P(A_{11}/A_1)+P(A_{12}/A_1)=1,\ (A_{11}/A_1)\cap(A_{12}/A_1)=\varnothing.$
2. The probability of the effectiveness of the counterfeits to the modernization of software, which is likely to provide value. $P(A_2)$	2. 1. Probability of providing special product development services. $P(A_{21}/A_2)$. 2. 2. Probability of using accelerated software development methods (speed up the process and provide value quickly). $P(A_{22}/A_2)$. $P(A_{21}/A_2)+P(A_{22}/A_2)=1,\ (A_{21}/A_2)\cap(A_{22}/A_2)=\varnothing.$
3. Probability of rethinking architecture (functionality) and setting priorities for software simplification. $P(A_3)$	3. 1. The probability of applying a micro-service architecture approach to product scalability. $P(A_{31}/A_3)$. 3. 2. Chances are that the released program will work well with the rest of the tools used in the default business. $P(A_{32}/A_3)$. 3. 3. The probability of considering the requirements of the tools when changing them when creating a program. $P(A_{33}/A_3)$. $P(A_{31}/A_3)+P(A_{32}/A_3)+P(A_{33}/A_3)=1,\ (A_{31}/A_3)\cap(A_{32}/A_3)=\varnothing,$ $(A_{31}/A_3)\cap(A_{33}/A_3)=\varnothing,\ (A_{32}/A_3)\cap(A_{33}/A_3)=\varnothing.$
4. The probability of choosing reengineering to ensure optimal performance. $P(A_4)$	4. 1. The probability of choosing the right technology, which depends entirely on the specifics of the product and its ease of use. $P(A_{41}/A_4)$. 4. 2. The probability of ensuring optimal performance under the choice of technology. $P(A_{42}/A_4)$. $P(A_{41}/A_4)+P(A_{42}/A_4)=1,\ (A_{41}/A_4)\cap(A_{42}/A_4)=\varnothing.$
5. The probability of creating a document code for the future growth of the system. $P(A_5)$	5. 1. Probability of proper documentation and clean code, which makes the software easy to understand. $P(A_{51}/A_5)$. 5. 2. Probability of expanding the set of coding standards and internal processes. $P(A_{52}/A_5)$. $P(A_{51}/A_5)+P(A_{52}/A_5)=1,\ (A_{51}/A_5)\cap(A_{52}/A_5)=\varnothing.$
6. The probability of creating a separate schedule for maintenance and disposal of the legacy system. $P(A_6)$	6. 1. Probability of easy access and access to archived solutions. $P(A_{61}/A_6)$. 6. 2. Probability of maintenance and utilization of the legacy system under the condition of introduction of a new product. $P(A_{62}/A_6)$. $P(A_{61}/A_6)+P(A_{62}/A_6)=1,\ (A_{61}/A_6)\cap(A_{62}/A_6)=\varnothing.$
7. The probability of creating an effective budget for training and updating the system. $P(A_7)$	7. 1. Probability of time to learn new software. $P(A_{71}/A_7)$. 7. 2. Probability of willingness to invest in staff training for better performance and efficiency. $P(A_{72}/A_7)$. 7. 3. Probability of planning regular system updates. $P(A_{73}/A_7)$. 7. 4. Probability of occurrence of an event of timely preparation for modernization. $P(A_{74}/A_7)$. $P(A_{71}/A_7)+P(A_{72}/A_7)+P(A_{73}/A_7)+P(A_{74}/A_7)=1,$ $(A_{71}/A_7)\cap(A_{72}/A_7)=\varnothing,\ (A_{71}/A_7)\cap(A_{73}/A_7)=\varnothing,$ $(A_{72}/A_7)\cap(A_{73}/A_7)=\varnothing,\ (A_{71}/A_7)\cap(A_{74}/A_7)=\varnothing,$ $(A_{72}/A_7)\cap(A_{74}/A_7)=\varnothing,\ (A_{73}/A_7)\cap(A_{74}/A_7)=\varnothing.$

The statistical measurement under the condition of quantitative or qualitative assessment of risk in the occurrence of events $P(A_{ij}/A_i)$, $i=1,\dots,7$ will be taken as an a priori value of the probabilities of risk in the occurrence of these events in the notation, which is presented in **Table 4**.

According to the developed **Table 4** and the formula of total probability, there is the formula of the probability of occurrence of the event and effective minimization of strategic risks at reengineering of the enterprise, which arise at modernization of the software of legacy production systems in the form:

$$P(A)=\sum_{i=1}^{7}P(A_i)\cdot\left(\sum_{j=1}^{m}P(A_{ij}/A_i)\cdot P\left(A_{ij}^{*}/\left(A_{ij}/A_i\right)\right)\right), \tag{8}$$

where the index m is equal to:

$$m=\begin{cases}2, & \text{if } i=1;\\ 2, & \text{if } i=2;\\ 3, & \text{if } i=3;\\ 2, & \text{if } i=4;\\ 2, & \text{if } i=5;\\ 2, & \text{if } i=6;\\ 4, & \text{if } i=7.\end{cases} \quad (9)$$

To determine the a priori values of conditional probabilities of hypotheses of effective minimization of strategic risks of the enterprise when reengineering the enterprise, which arise during the modernization of software of legacy production systems, it is necessary to make statistically significant sections of these hypotheses at the selected enterprise for several periods. Let's take the value of conditional probabilities.

Table 4

Designation of risk probabilities in conditional probabilities of strategic risks at software reengineering of the enterprise

Conditional probabilities of hypotheses of strategic risks $P(A_{ij}/A_i)$, $i=1,\ldots,7$ of the enterprise and their designations, for all i form full groups of events	**A priori values of probabilities of occurrence of risk in conditional probabilities of strategic risks at enterprise reengineering**
$P(A_{11}/A_1)$	$P(A_{11}^{*}/A_{11}/A_1)$
$P(A_{12}/A_1)$	$P(A_{12}^{*}/A_{12}/A_1)$
$P(A_{21}/A_2)$	$P(A_{21}^{*}/A_{21}/A_2)$
$P(A_{22}/A_2)$	$P(A_{22}^{*}/A_{22}/A_2)$
$P(A_{31}/A_3)$	$P(A_{31}^{*}/A_{31}/A_3)$
$P(A_{32}/A_3)$	$P(A_{32}^{*}/A_{32}/A_3)$
$P(A_{33}/A_3)$	$P(A_{33}^{*}/A_{33}/A_3)$
$P(A_{41}/A_4)$	$P(A_{41}^{*}/A_{41}/A_4)$
$P(A_{42}/A_4)$	$P(A_{42}^{*}/A_{42}/A_4)$
$P(A_{51}/A_5)$	$P(A_{51}^{*}/A_{51}/A_5)$
$P(A_{52}/A_5)$	$P(A_{52}^{*}/A_{52}/A_5)$
$P(A_{61}/A_6)$	$P(A_{61}^{*}/A_{61}/A_6)$
$P(A_{62}/A_6)$	$P(A_{62}^{*}/A_{62}/A_6)$
$P(A_{71}/A_7)$	$P(A_{71}^{*}/A_{71}/A_7)$
$P(A_{72}/A_7)$	$P(A_{72}^{*}/A_{72}/A_7)$
$P(A_{73}/A_7)$	$P(A_{73}^{*}/A_{73}/A_7)$
$P(A_{74}/A_7)$	$P(A_{74}^{*}/A_{74}/A_7)$

The matrices of expert pairwise comparisons on the importance of each event from the complete groups of events $\{(A_{11}/A_1); (A_{12}/A_1)\}$ and $\{(A_{21}/A_2); (A_{22}/A_2)\}$, – are the same, where, accordingly, the advantage of the first event in the group is two times more important than the appearance of the second event. The matrix of expert pairwise comparisons on the importance of each event from the complete groups $\{(A_{31}/A_3); (A_{32}/A_3); (A_{33}/A_3)\}$ of events is given in **Table 5**.

Let's note that, according to experts, the onset of the expansion of the set of coding standards and internal processes is three times more important than proper documentation and clean code, making software easy to understand. However, the maintenance and utilization of the legacy system in the case of the introduction of a new product are 3 times more important than easy access and access to archiving solutions.

Table 5

Expert matrix, the level of its consistency and conditional probabilities of the event A_3

Conditional probabilities	$P(A_{31}/A_3)$	$P(A_{32}/A_3)$	$P(A_{33}/A_3)$	Characteristic equation, eigenvalues	Con-sistency	Value
$P(A_{31}/A_3)$	1	2	1	$x^3+3x^2+2.25=0$	13.23 %	0.412599
$P(A_{32}/A_3)$	0.5	1	2	{3.217}		0.32748
$P(A_{33}/A_3)$	1	0.5	1	{−0.1086−0.8291i; −0.1086+0.8291i}		0.259921
Conditional probabilities	$P(A_{31}/A_3)$	$P(A_{32}/A_3)$	$P(A_{33}/A_3)$			

Similarly to **Table 5**, let's present matrices of expert pairwise comparisons according to the importance of each event from complete groups of events $\{(A_{41}/A_4); (A_{42}/A_4)\}$; $\{(A_{51}/A_5); (A_{52}/A_5)\}$; and $\{(A_{61}/A_6); (A_{62}/A_6)\}$ **(Table 6)**.

The matrix of expert pairwise comparisons of the 4th order according to the importance of each event from complete groups of events $\{(A_{71}/A_7); (A_{72}/A_7); (A_{73}/A_7); (A_{74}/A_7)\}$ is given in **Table 7**, which also presents the characteristic equation of the matrix and finds all its eigenvalues with the maximum eigenvalue to find the level of agreement with random matrices 4th order.

The level of consistency is 13.239<15 %, which indicates a correctly compiled matrix by experts.

Table 6

Expert matrices, levels of their consistency, and conditional probabilities of events A_4, A_5, A_6

Conditional probabilities	$P(A_{41}/A_4)$	$P(A_{42}/A_4)$	Characteristic equation, eigenvalues	Con-sistency	Value
$P(A_{41}/A_4)$	1	4	$x^2-2x=0$	1.5 %	0.8
$P(A_{42}/A_4)$	0.25	1	$\{0;2\}$ $\lambda_{max}=2$		0.2
Conditional probabilities	$P(A_{41}/A_4)$	$P(A_{42}/A_4)$			
Conditional probabilities	$P(A_{51}/A_5)$	$P(A_{52}/A_5)$	Characteristic equation, eigenvalues	Con-sistency	Value
$P(A_{51}/A_5)$	1	3	$x^2-2x+0.01=0$	2.5 %	0.75
$P(A_{52}/A_5)$	0.33	1	$\{0.005; 1.995\}$ $\lambda_{max}=1.995$		0.25
Conditional probabilities	$P(A_{51}/A_5)$	$P(A_{52}/A_5)$			
Conditional probabilities	$P(A_{61}/A_6)$	$P(A_{62}/A_6)$	Characteristic equation, eigenvalues	Con-sistency	Value
$P(A_{61}/A_6)$	1	0.33	$x^2-2x+0.01=0$	2.5 %	0.25
$P(A_{62}/A_6)$	3	1	$\{0.005; 1.995\}$ $\lambda_{max}=1.995$		0.75
Conditional probabilities	$P(A_{61}/A_6)$	$P(A_{62}/A_6)$			

Table 7

Expert matrix, the level of its consistency and conditional probabilities of the event A_7

Conditional probabilities	$P(A_{71}/A_7)$	$P(A_{72}/A_7)$	$P(A_{73}/A_7)$	$P(A_{74}/A_7)$	Value
$P(A_{71}/A_7)$	1	2	2	1	0.340657
$P(A_{72}/A_7)$	0.5	1	2	2	0.286458
$P(A_{73}/A_7)$	0.5	0.5	1	1	0.170329
$P(A_{74}/A_7)$	1	0.5	1	1	0.202556
Conditional probabilities	$P(A_{71}/A_7)$	$P(A_{72}/A_7)$	$P(A_{73}/A_7)$	$P(A_{74}/A_7)$	–
Characteristic equation	$-x^4+4x^3+3.25x=0$				
Eigenvalues	$\{0; 4.186\}$ $\lambda_{max}=4.186$, $\{-0.093-0.876i; -0.093+0.876i\}$				
Matrix consistency	13.239 %				

Thus, the study of expert matrices for conditional probabilities for events $A_i, i=\overline{1,7}$ presented in **Tables 5–7** completes the cycle of finding a priori values of conditional probabilities of strategic risk hypotheses that form complete groups of events and correspond to the strategic risks that arise when upgrading legacy production software. The scheme of the cycle related to event A is shown in **Table 8**.

Table 8

The cycle of finding a priori probability values corresponding to event A

A priori value of the probability of strategic risks that arise during the modernization of software for legacy production systems	A priori values of probabilities of strategic risk hypotheses $P(A_i)$, $i = 1,\ldots,7$ that form complete groups of events	A priori values of conditional probabilities of strategic risk hypotheses $P(A_{ij}/A_i)$, $i = 1,\ldots,7$ that form complete groups of events
$P(A) = 0{,}315996$	$P(A_1) = 0.260228$	$P(A_{11}/A_1) = 0.(6)$
		$P(A_{12}/A_1) = 0.(3)$
	$P(A_2) = 0.22243$	$P(A_{21}/A_2) = 0.750941$
		$P(A_{22}/A_2) = 0.249059$
	$P(A_3) = 0.149684$	$P(A_{31}/A_3) = 0.412599$
		$P(A_{32}/A_3) = 0.32748$
		$P(A_{33}/A_3) = 0.259921$
	$P(A_4) = 0.109203$	$P(A_{41}/A_4) = 0.8$
		$P(A_{42}/A_4) = 0.2$
	$P(A_5) = 0.115715$	$P(A_{51}/A_5) = 0.75$
		$P(A_{52}/A_5) = 0.25$
	$P(A_6) = 0.073488$	$P(A_{61}/A_6) = 0.25$
		$P(A_{62}/A_6) = 0.75$
	$P(A_7) = 0.069253$	$P(A_{71}/A_7) = 0.340657$
		$P(A_{72}/A_7) = 0.286458$
		$P(A_{73}/A_7) = 0.170329$
		$P(A_{74}/A_7) = 0.202556$

Note that current trends in production are determined by the small batch size, high variability of products, and changes in product range during the life cycle of the automated production system. In a modern enterprise, the share of system functionality implemented using software is growing, which requires innovative support concepts [7, 11, 23].

3. Results and discussion

Table 9 presents the dynamics of $P(A)$ probabilities of strategic risks for event A for the 4th quarter of 2019: 1.01.2019–31.03.2019; 1.04.2019–30.06.2019; 1.07.2019–30.09.2019; 1.10.2019–31.12.2019 for two companies LLC «HIPRO-Engineering» (Kyiv, Ukraine) (Enterprise 1) and LLC «MONOLIT-Service» (Enterprise 2) at the specified level of risk.

From **Table 9** it can be concluded that concerning the occurrence of event A, the company LLC «HIPRO-Engineering» (Enterprise 1) is in the zone of medium risk, and the company LLC «MONOLIT-Service» (Enterprise 2) – in the zone of high risk. This can be explained the results for the fourth quarter showing that the second company began to increase the pace of software implementation, which is an objective necessity today.

It should be noted that the company LLC «HIPRO-Engineering» software upgrade required a quality assessment of the software used by staff to successfully perform functional and job responsibilities. The transition to new modern versions of software products and the installation of new programs for successful financial and economic activities required the modernization of the hardware component and the renewal of the fleet of computers, servers, and local computer networks.

Table 9
Dynamics of $P(A)$ probabilities of strategic risks for event A for the 4th quarter of 2019 for two enterprises: LLC «HIPRO-Engineering» (Enterprise 1) and LLC «MONOLIT-Service» (Enterprise 2)

Enterprise	The likelihood of strategic risks that arise when upgrading the software of legacy production systems $P(A)$ (level of risk)			
	1.01.2019–31.03.2019	1.04.2019–30.06.2019	1.07.2019–30.09.2019	1.10.2019–31.12.2019
Enterprise 1	0.729559 (Average level of risk)	0.725191 (Average level of risk)	0.731315 (Average level of risk)	0.757243 (Average level of risk)
Enterprise 2	0.681618 (High level of risk)	0.678584 (High level of risk)	0.682887 (High level of risk)	0.690305 (High level of risk)

At the same time, the main requirements for the software at LLC «Rubicon Form» were ease of operation, flexibility to technological changes in production, the efficiency of processing operations, high-quality documentation, as well as reliability and safety in emergencies.

The software upgrade required a reassessment of the current state of the software used by the company. The introduction of new versions of software products for doing business has led to the modernization of hardware, upgrades of computers, servers, and local area networks.

Thus, regarding the assessment of strategic risks of LLC «HIPRO-Engineering», LLC «MONOLIT-Service», which arise during the modernization of software of legacy production systems, they were all assessed systematically and under the condition of stable uninterrupted operation of the company [25], which aids us in objective comparison of respective strategies of legacy software modernization projects at LLC «HIPRO-Engineering» and LLC «MONOLIT-Service» for better decision-making.

Business process reengineering involves redesigning key organizational processes to improve product quality and output or reduce costs. Development of a strategic basis for enterprise reengineering includes:

– development of consistent and practical methodology of enterprise reengineering;
– support for the formulation and implementation of operational strategies;
– development of the architecture for conceptual reengineering of the enterprise.

In this context, by using business process reengineering, companies can significantly improve their efficiency and the quality of their products and services. With this in mind, it is necessary to develop conceptual principles for improving the management system, management decision-making technology, aimed at the transition to a new concept and reforming the enterprise in a digital transformation.

Although the sheer size and complexity of the problem at hand make «fully solving it» impossible, let's believe that formulating an abstract mathematical framework is an excellent first step in preparing specific bias mitigation techniques. As noted by other authors, a lack of practical strategies software professionals could use to overcome the adverse effects of cognitive bias in managing software risk is a significant limitation of the field [35].

In particular, let's believe that by employing a mathematically rigorous framework to make decisions with objectivity could improve outcomes by reducing the influence of decision-making agents' irrationality and limiting the impact of cognitive bias on enterprise risk management outcomes. It is possible to limit the effects of the «human factor» during the early stages of software development according to the SDLC model, which is considered one of the most destructive risks in software development [36].

The main point of advancement of this paper is that, through the application of the cognitive framework presented in this paper, there is potential to limit the decision-making agent's irrationality and limit its impact on practical outcomes, as «developer's thought processes are a fundamental area of concern» [37].

However, the study has significant practical and theoretical limitations. Among them is the senior decision-makers' unwillingness to apply the mathematical frameworks consistently in the field [38]. Additionally, it furthers the research in the use of mathematical methods for risk analysis that minimize the need for subjective human input [38]. Furthermore, before the framework of this study becomes more practically applicable, further work is required. It would be beneficial to condense this mathematical model into a more practically appropriate form, such as a checklist, following previous successful applications of mathematical thinking to risk management [39].

4. Conclusions

The proposed assessment of strategic risks of the enterprise in the context of digitalization has found practical use in the activities of homogeneous in the space of market relations of enterprises LLC «HIPRO-Engineering» and LLC «Rubicon Form». Thus, the study conducted at Ukrainian enterprises revealed several significant shortcomings in enterprise management, the elimination of which in the future using the proposed approach will increase the efficiency of enterprise management.

Thus, the concept of quantitative risk analysis is considered, which allows to analytically determine the most effective strategies for responding to strategic risks of the enterprise, which arise during the modernization of software of legacy production systems – and minimize the impact of risk on the enterprise. This is of fundamental importance when it comes to the need for measures taken by the management of the enterprise at the beginning of the implemented process to determine the potential level of risk that may exist concerning the introduction of this process in the enterprise.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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