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Business Informatics is a peer reviewed interdisciplinary academic journal published since 2007 by National Research University Higher School of Economics (HSE), Moscow, Russian Federation. The journal is administered by HSE Graduate School of Business. The journal is published quarterly.

The mission of the journal is to develop business informatics as a new field within both information technologies and management. It provides dissemination of latest technical and methodological developments, promotes new competences and provides a framework for discussion in the field of application of modern IT solutions in business, management and economics.

The journal publishes papers in the areas of, but not limited to: modeling of social and economic systems, digital transformation of business, innovation management, information systems and technologies in business, data analysis and business intelligence systems, mathematical methods and algorithms of business informatics, business processes modeling and analysis, decision support in management.

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Digital plant: methods of discrete-event modeling and optimization of production characteristics

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Abstract

This article presents a new approach to the development of a 'digital twin' of a manufacturing enterprise, using a television manufacturing plant as the case study. The feature of the proposed approach is the use of hybrid methods of agent-based modeling and discrete-event simulation in order to implement a simulation model of a complex production process for assembling final products from supplied components. The most important requirement for such a system is the integration of all key chains of a digital plant: conveyor lines, warehouses with components and final products (TVs), sorting and conveyor system, assembly unit, technical control department, packing unit, etc. The proposed simulation model is implemented in the AnyLogic system, which supports the possibility of using agent-based and discrete-event modeling methods within one model. The system also supports using

the built-in genetic algorithm to optimize the main parameters of the model: the most important production characteristics (for example, assembly time of a product, the number of employees involved in assembly, quality control and packaging processes). Optimization experiments were completed with the help of the developed model at various intensities of loading conveyor lines with components, various restrictions on labor resources, etc. Three scenarios of the production system behavior are investigated: the absence of the components deficit with the possibility of significantly increasing the labor resource involved, a components deficit while demand for final products is maintained, and the presence of hard restrictions on the number of employees who can be involved in the processes under conditions of components deficit.

Key words: digital plant; production processes; agent-based modeling; discrete-event simulation; genetic algorithm; AnyLogic.

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Introduction

Currently, the problem of rational management of production characteristics in a dynamically changing external environment is becoming highly timely for many industrial enterprises (e.g. in conditions of a sharp decrease in the supply of components, significant increase in the cost of raw materials, lack of labor resources). At the same time, the complexity of production and logistics processes often does not allow enterprises to quickly adapt due to the operational management of their own resources (e.g. to reduce the volume of production without reducing labor resources, change the structure of the production portfolio without significant capital investments). The reason of emerging problems, as a rule, is the unbalanced state of various parts of the production chain (e.g. the deficit of production capacity with a significant turnover rate of warehouse stock). Therefore, there is a need to develop decision-making systems (DMS) based on the construction of 'digital twins' of enterprises. Such twins help to determine the best values of the characteristics of the production process in various scenario conditions (e.g. with a sharp change in demand for final products when there are interruptions with supplies of raw materials and components).

The first works devoted to the problems of rational production planning date back to the mid-20th century. It is necessary to highlight the most important works on rational organization of production activities using the methods of system dynamics [1, 2]. Also, well-known developments of the application of queuing systems theory (QS) [3, 4] to control complex production and logistics processes [5, 6]. The central problem of such methods, developed within the framework of the well-known scientific field of operations research [7], is to optimize the characteristics of the chains for creating the final product. Examples include minimizing costs, maximizing the rate of turnover of stock, optimizing the number and structure of labor resources involved, as well as providing the required quality level and timeliness of finished goods delivery [8].

In modern times, we have methods of system dynamics [9–11], agent-based modeling [12–14], discrete-event modeling [15, 16], heuristic optimization methods for a class of genetic algo-

rithms [17–19] and others. For instance, a simulation model of a vertically integrated oil company, which includes the links of oil production, oil refining, transportation and sales, developed using the methods of system dynamics, is presented in [10]. The advantage of this model is the ability to maximize the shareholder value of an oil company under multiple constraints and take into account the influence of the feedback system arising in the value chain.

The next stage in the development of such intelligent production systems is the creation of so-called 'digital twins' [20–24] which are based on simulation models aggregated with databases, data warehouses, optimization modules, etc. For instance, a 'digital twin' of an organisation providing financial services is presented in [20], a simulation model of a mining enterprise is proposed in [21], implemented in the Powersim system.

This article develops a methodology for developing 'digital twins' of a manufacturing enterprise based on the methods of discrete-event and agent-based modeling with implementations in the AnyLogic system [25]. A new simulation model of the 'digital plant' type is proposed with the use of an enterprise that assembles TVs as the case study. The most important parameters of the production system are optimized according with the criteria of the value of the accumulated gross profit at the various scenario conditions.

1. Digital factory concept

Currently, TVs are assembled with the use of ready-made components, the production of which is done at other enterprises using an imported electronic component base (e.g. microprocessors, LCD displays, etc.) at most Russian plants. Despite certain disadvantages (such as complete dependence on the supply of imported components), such an organization of the production process can significantly reduce operating costs, mainly by attracting less expensive (local) labor, minimizing transport and tax costs.

The conceptual model of a 'digital plant' is based on the creation of a number of interacting subsystems, among which the most important are the following:

✦ **simulation modeling subsystem**, providing the ability to calculate the production and financial characteristics of the enterprise, taking into account the detailing of the entire chain of creating the final product for management at the micro level. The simulation model of an enterprise assembling TVs consists of the following important elements:

1. **sources of component supplies** required for the assembly of the final product (in particular, such components include housings, LCD screens, motherboards, video adapters, image processing units, power supplies, etc.) supplied to the factory in accordance with a given intensity;
2. **warehouses of components** which are intended for temporary storage of intermediate products (parts) and their delivery to conveyor lines;
3. **sorting and conveyor system,** designed for automatic synchronization of streams with components having different technical and operational characteristics, e.g. different size of the liquid crystal screen (in particular, varying from 20 to 90 inches), different body sizes, etc.;
4. **assembly unit** ensuring the assembly of final products using the attracted specialists (labor resources);
5. **technical control unit** providing quality control of the final product (testing devices);
6. **packing unit** performing the function of packing, picking and forming batches of final products;
7. **warehouse of final products** that is intended for temporary storage of TVs;
8. **shipping unit** providing the function of shipment of batches of final products by transferring it to a transport company;

- **data warehouse**, intended for storing the initial data required for simulation modeling and processing the results of optimization experiments;
- **optimization module** aggregated through objective functions with the simulation model of the enterprise and providing the ability to search for the best values of the characteristics of the production process in various scenario conditions.

An aggregated diagram of the 'digital twin' of an enterprise assembling TVs is shown in *Figure 1*.

Note that an important feature of the system under consideration (*Figure 1*) is the presence of agents involved in the production process:

- **agents-components** with their own individual characteristics;
- **agents-products** variated by their functional characteristics (e.g. TV model, matrix size, cost, etc.);
- **agents-batches** of final products, which are a grouping of agents-products (by TV-models) for transportation.
- **agents-resources (humans)** involved in various processes (e.g. assemblers, quality control specialists, packers, etc.).

At the same time, the production system provides a mechanism for automatic transformation of agents-components into final agents-products, as well as grouping of agents-products in the form of batches of final products (TVs).

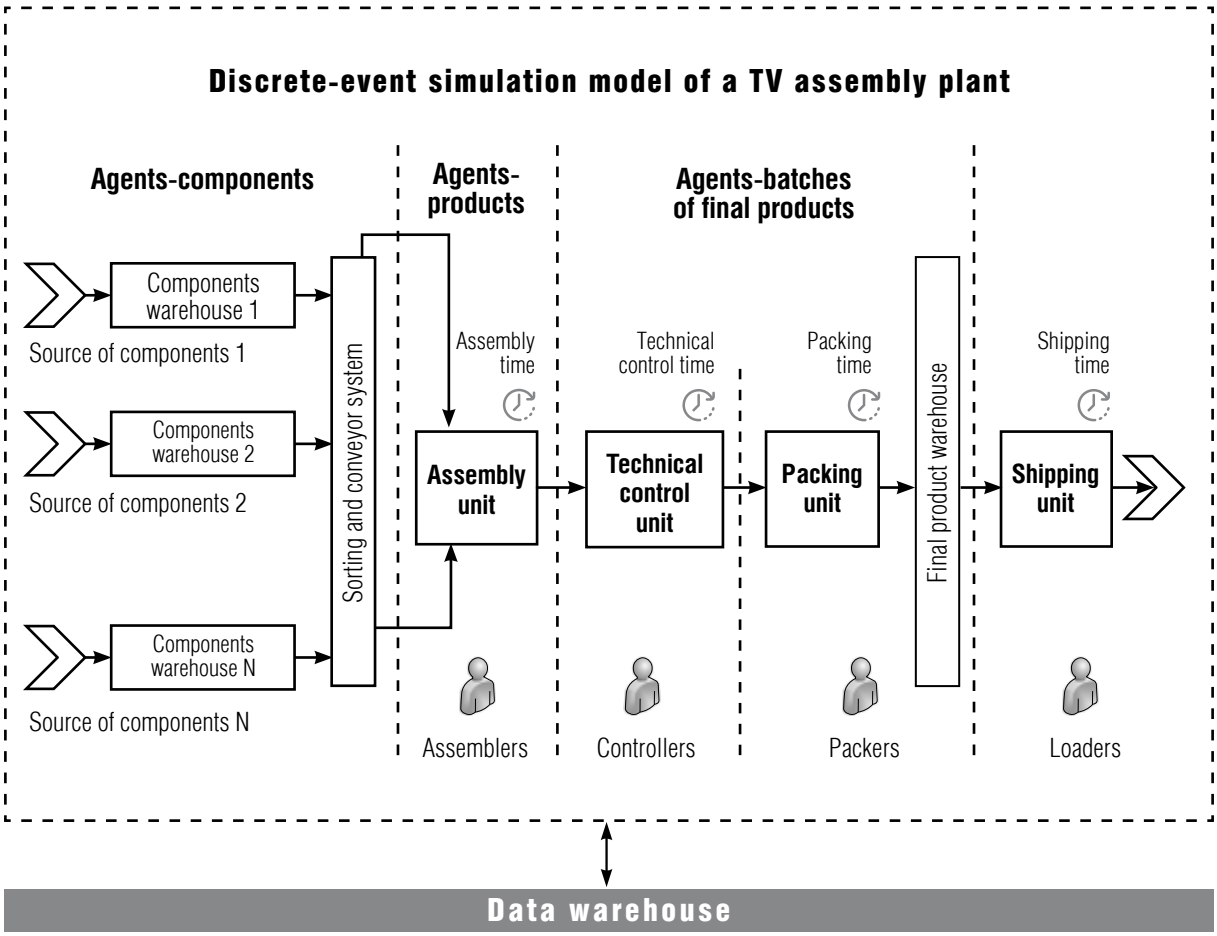

Fig. 1. Aggregated diagram of the 'digital twin' of a manufacturing enterprise

2. Simulation model

Earlier, a simulation model of an assembly unit implemented in the AnyLogic system was presented in [21]. Such a model can be considered as a prototype when creating a more complex model of a hybrid type which simultaneously uses the methods of system dynamics, agent-based and discrete-event modeling. Another important difference of the model proposed here is a more complex structure and dynamics of supply of components, characterized by the presence of multiple time gaps. At the same time, the main service characteristics of the production process (in particular, the time of assembly, technical control, shipment, etc.), which significantly affect its effectiveness, are stochastic. As a result, the performance metric of such a system (profit dynamics) belongs to the class of multimodal objective functions with multiple break points, the maximization of which cannot be performed by known analytical methods. Therefore, in order to create a 'digital twin' of a production enterprise that assembles TVs, an original simulation model is being developed, aggregated by target functionality with a built-in genetic algorithm that provides the search for the best solutions based on heuristics.

Further, a brief problem statement of optimizing main characteristics of the considered manufacturing enterprise is given.

Here:

- $t_r \in T$ – is the discrete model time; $T = \{t_1, t_2, ..., t_{|T|},\}$ – a set of moments of model time; $|T|$ – the total number of moments of model time;
- $I = \{i_1, i_2, ..., i_{|I|},\}$ – is the set of indices of models of the assembled TVs (variable by the screen size, different functional characteristics, etc.); $|I|$ – is the total number of assembled TV-models;
- $J_i = \{j_{i_1}, j_{i_2}, ..., j_{|J_i|}\}$, $i \in I$ – is the set of indices of components required for assembly i-th television model (e.g. bodies, LCD screens, system boards, etc.); $|J_i|$ – is the total number of components that are necessary for assembling TV sets of i-th type;
- $\{n_1, n_2, ..., n_N\}$ – is the number of specialists of various categories (e.g. assemblers of the first and second qualification levels, QM-specialists, packers and loaders) involved in production processes, humans; N is the total number of qualification categories of employees; $\xi = \{1, 2, ..., N\}$ – is index of the category of employees and the types of processes in which they are involved;
- $\{w_1(t_r), w_2(t_r), ..., w_N(t_r)\}$, $t_r \in T$ – are the daily salaries of specialists of various categories involved in production processes, rubles;
- $c_{j_i}(t_r)$, $j_i \in J_i$, $i \in I$, $t_r \in T$ – is the cost of components required for assembly the i-th TV model at the moment t_r, rubles;
- $p_i(t_r), i \in I, t_r \in T$ – is the price of a final product (TV) at the moment t_r, rubles;
- $\{\tau_1, \tau_2, ..., \tau_N\}$ – the average time for assembling a final product from main and auxiliary parts, technical control time, packing and shipping times per employee involved in the relevant operations;
- $\delta_{j_i}(t_r)$, $j_i \in J_i$, $i \in I$, $t_r \in T$ – is the endogenous structure of supply of components at the moment t_r, specified using a unit impulse function with random arguments, items;
- $v_i(t_r)$, $i \in I$, $t_r \in T$ – is the endogenous structure of final product output at the moment determined as a result of simulation and depending on the sets of control parameters $\{n_1, n_2, ..., n_N\}$, $\{\tau_1, \tau_2, ..., \tau_N\}$, as well as the dynamics of supply of components $\delta_{j_i}(t_r)$, items.

Daily gross profit of the enterprise at the moment t_r, $t_r \in T$:

$$\pi(t_r) = \sum_{i=1}^{|I|} \left(\left(v_i(t_r)\, p_i \right)(t_r) - \sum_{j_i=1}^{|J_i|} \delta_{j_i}(t_r) c_{j_i}(t_r) \right) - \sum_{\xi=1}^{N} w_\xi(t_r) n_\xi. \quad (1)$$

Now we can formulate the central task of the manufacturing enterprise to maximize the accumulated gross profit.

The problem. The need to maximize the accumulated gross profit by sets of control parameters $\{n_1, n_2, ..., n_N\}$and $\{\tau_1, \tau_2, ..., \tau_N\}$:

$$\sum_{t_r=1}^{|T|} \pi(t_r) \to \max_{\{n_1,n_2,...,n_5\},\{\tau_1,\tau_2,...,\tau_5\}}, \quad (2)$$

s.t.

$$\underline{n}_\xi \le n_\xi \le \overline{n}_\xi,\ \underline{\tau}_\xi \le \tau_\xi \le \overline{\tau}_\xi.$$

Here $\left\{\underline{n}_\xi, \overline{n}_\xi\right\}, \left\{\underline{\tau}_\xi, \overline{\tau}_\xi\right\}$ are known boundary values of control parameters (upper and lower limits).

The proposed simulation model that provides the computation of the objective function (1)–(2) was implemented in the AnyLogic system (*Figure 2*). The main feature of the model is the high dimensionality of initial data flows (tens thousands of components involved in the assembly of TVs with their individual characteristics). In particular, it is determined by the presence of a large number of elements of a 'warehouse' type used for storing intermediate and final products, and also the use of sorting and conveyor systems for synchronizing the flows of agents-components (*Figure 2*).

Another important feature of the model shown in *Figure 2* is the integration of the module of computing financial and economic indicators with operational sub-models. These sub-models implement the processes of receiving and distributing components through sorting and conveyor systems, assembly unit, technical control unit, packaging and formation of batch units vary-

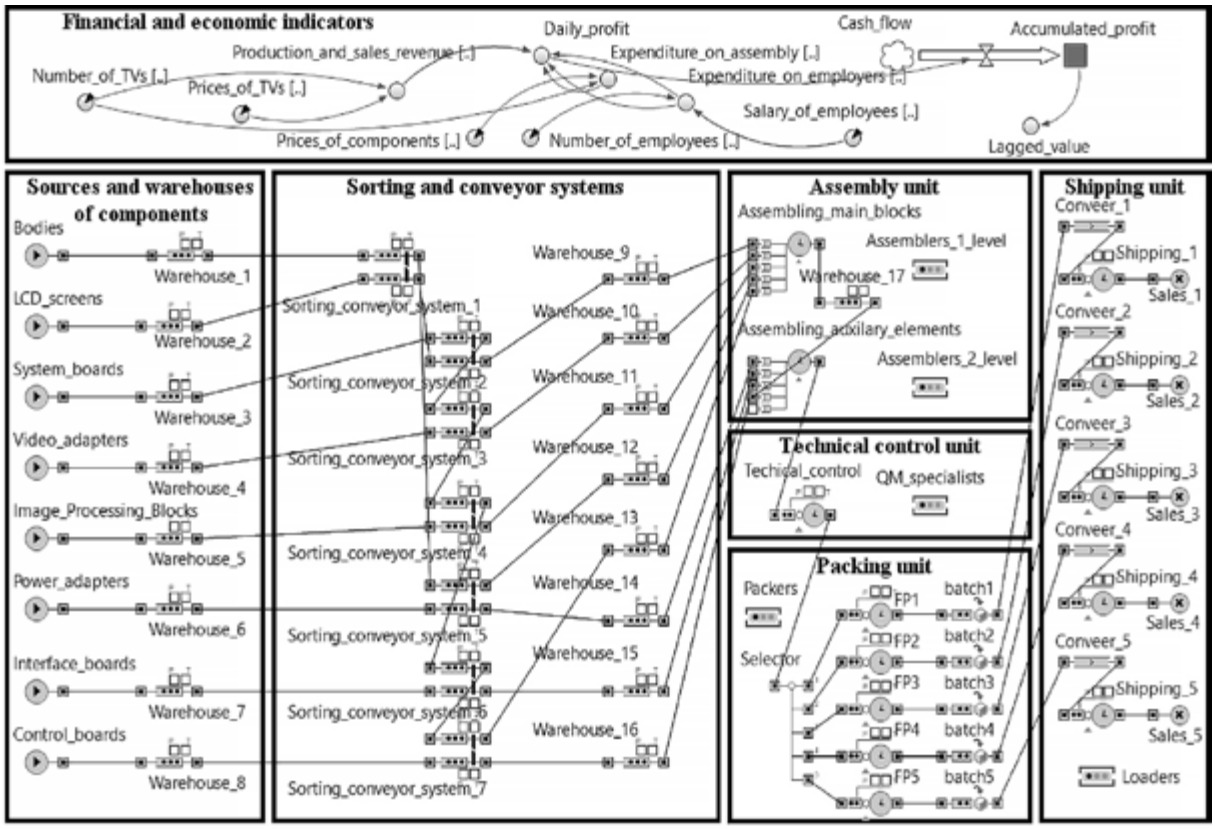

Fig. 2. Simulation model of TV equipment manufacturing plant in AnyLogic

ing by a product type (e.g. depending on the size of the LCD screen and the specified set of functions). The initial data of component (characteristics of elements) are loaded from the system database taking into account a variable number of each type elements, simultaneously arriving in accordance with a given intensity. The software implementation of the simulation model was performed using the Java programming language supported in the AnyLogic system.

To start sequential processing of components in the model, a special object of the **source** type (component source) is used in which the characteristics of each generated agent belonging to the **Components_X** class (components of type **X**) are redefined in a special field – **'Actions when approaching the exit'**:

```
((Components_X) entity) .parameter = components_X.get
(index_X) .parameter;
index_X = index_X ++;
```

Here, **Components_X** is a population of component agents of type **X** with characteristics whose values are dynamically loaded from the data warehouse (MS SQL Server), **parameter** is one of the possible parameters of the component agent ((**Components_X) entity**), e.g. the overall size of the body, **index_X** is the global variable used as an iterator to access the next member of the **Components_X** population (i.e. the agent-component). Note that starting with the AnyLogic of version 8, the simpler form of access to data of an agent participating in the process chain is supported using the **agent** attribute instead of the (**(Components_X) entity**). At the same time, when creating multiple requests, the '**Actions when approaching the exit**' method is also performed multiple times for each component agent outgoing from the source (*Figure 3*). The number of agents-components generated at any given time is set by means of a single impulse function with random arguments determining the expected number of details that will arrive in the case of the arrival of a given batch:

```
(int) pulse(uniform(0, 100), uniform(0, 100))*uniform_
discr(1000, 1500);
```

Also, one of the most important elements of the proposed model is the formation of batches of final products by distributing the flow of TVs that have passed technical control into groups depending on the type of an agent-product (i.e. a model of TV) (*Figure 4*).

Because of the prices of the final products depend on the model range of the assembled TVs, computing the revenue and expenditure is possible to use indicators whose values are calculated in the elements of the process diagram (*Figure 2*), e.g. the number of assembled TVs of various types can be set as follows:

```
Number_TV.set (Implementation1.count () * batch1_
size, M);
```

Here, **Implementation1.count ()** is the function that computes the number of elements (agents-products of the first type) at the exit from the production process, **batch1_size** is the number of products in a batch, **M** is the index of TV-model.

3. Experimental results

As mentioned earlier, the sources of suppling agents-components provide the generation of the components required for assembly using a single impulse function with stochastic arguments. *Figure 5* shows the dynamics of such deliveries over the model time interval from 1 to 100 days.

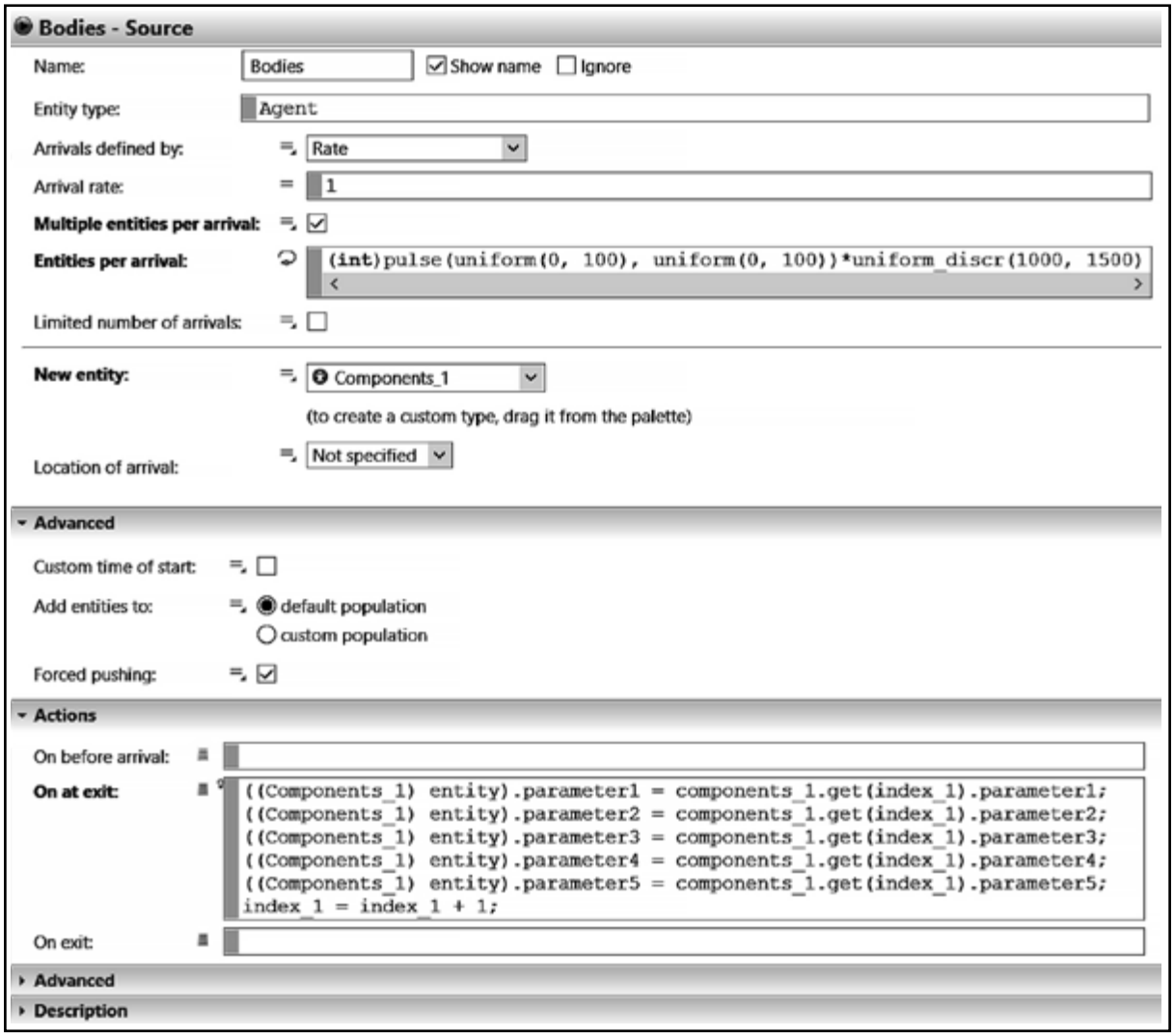

Fig. 3. Properties of a typical source of supply of agent–components

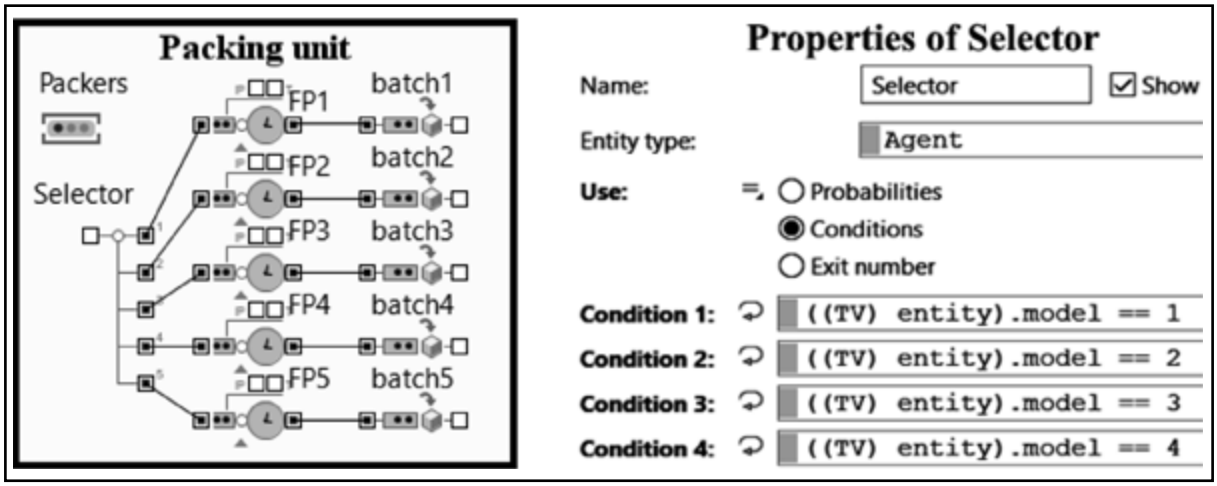

Fig. 4. Distribution of the flow of final products when forming batches

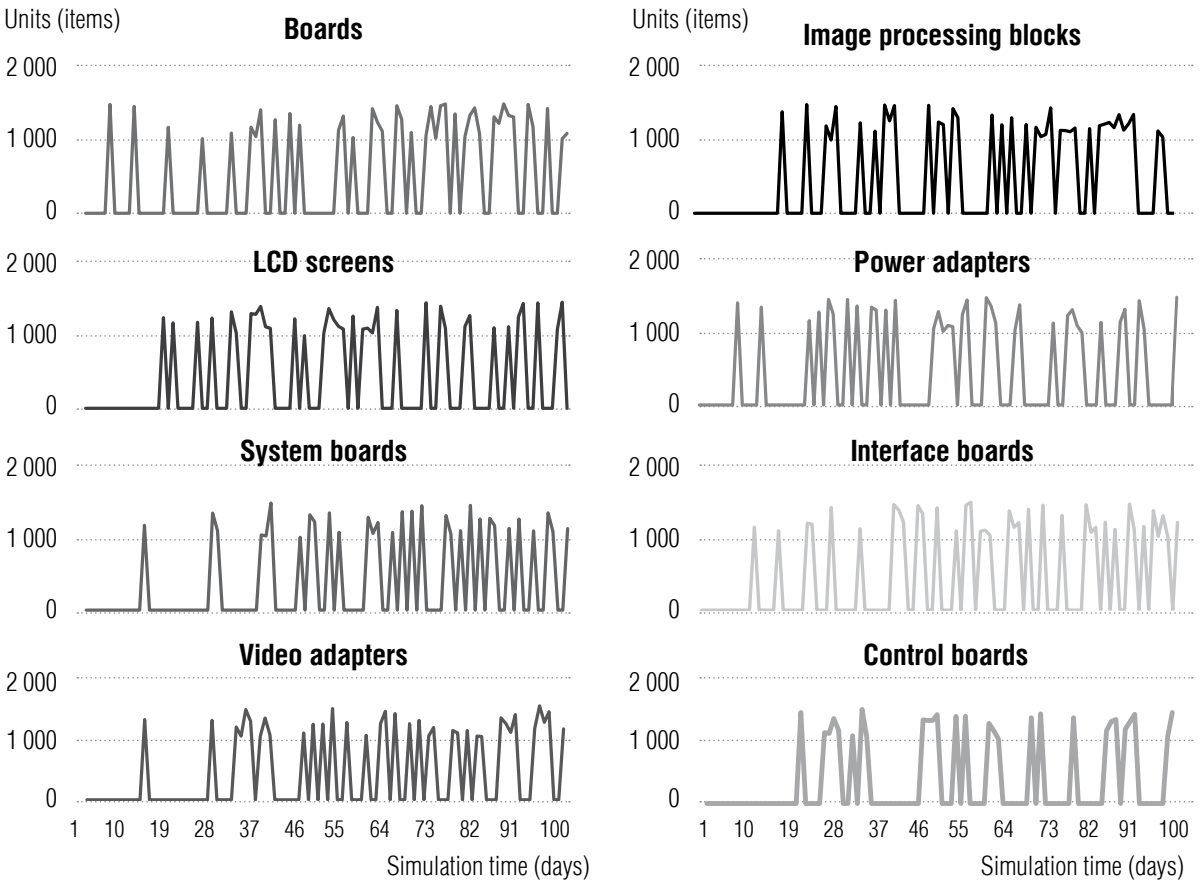

Fig. 5. Model dynamics of supplying the components

As follows from *Figure 5*, there are time gaps between component supplies due to natural logistic disruptions. Therefore, the model provides automatic synchronization of input flows through sorting and conveyor systems that redirect selected and mutually matched elements to the assembly unit.

Figure 6 shows the model dynamics of warehouse stocks of main and auxiliary assemblies, as well as finished products (TVs).

Further, optimization experiments were carried out aimed at maximizing the profit generated because of the assembly and sale of TVs. Optimization experiments were performed using the genetic algorithm embedded in the AnyLogic. At the same time, the following control parameters of the model were selected as decision variables:

- **number of agents-assemblers** (humans) of various categories involved in the assembly of main and auxiliary parts;
- **number of quality control agents** responsible for performing technical control of final products (TVs);
- **number of agents-packers and agents-loaders** involved in the processes of packaging and shipment of final products, respectively;
- **average (median) values of assembly time, technical control time, packaging and shipment (sale) times** affecting the speed of execution of the corresponding processes.

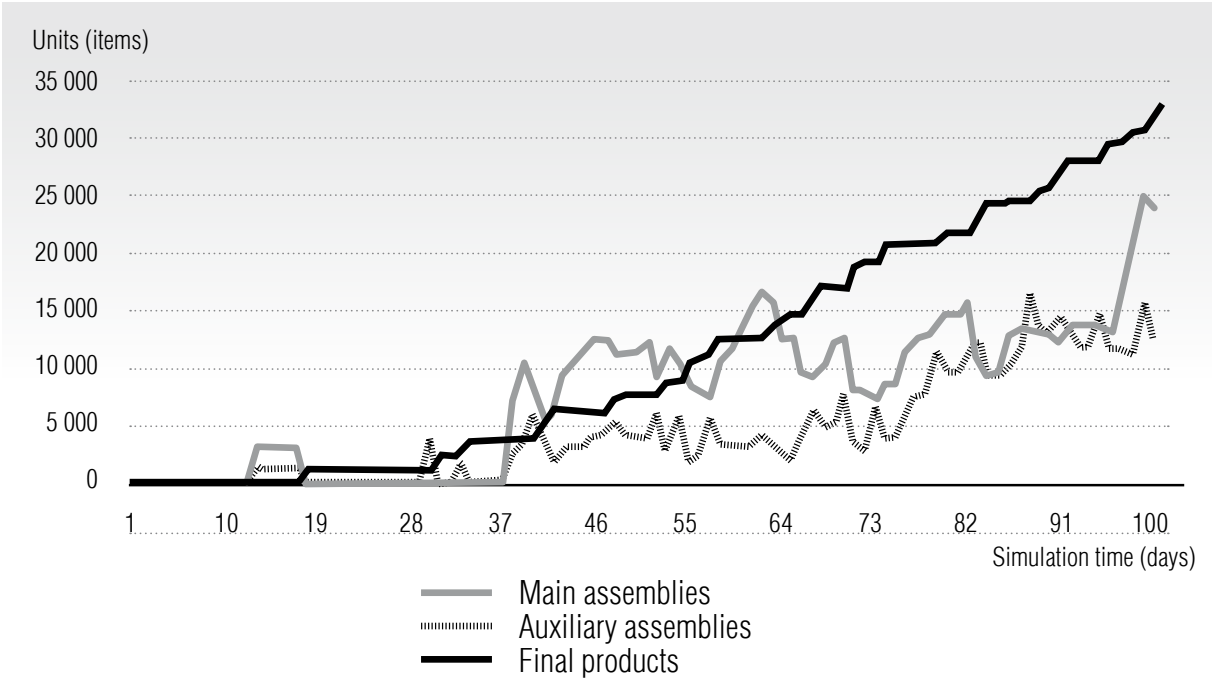

Fig. 6. Model dynamics of warehouse stocks

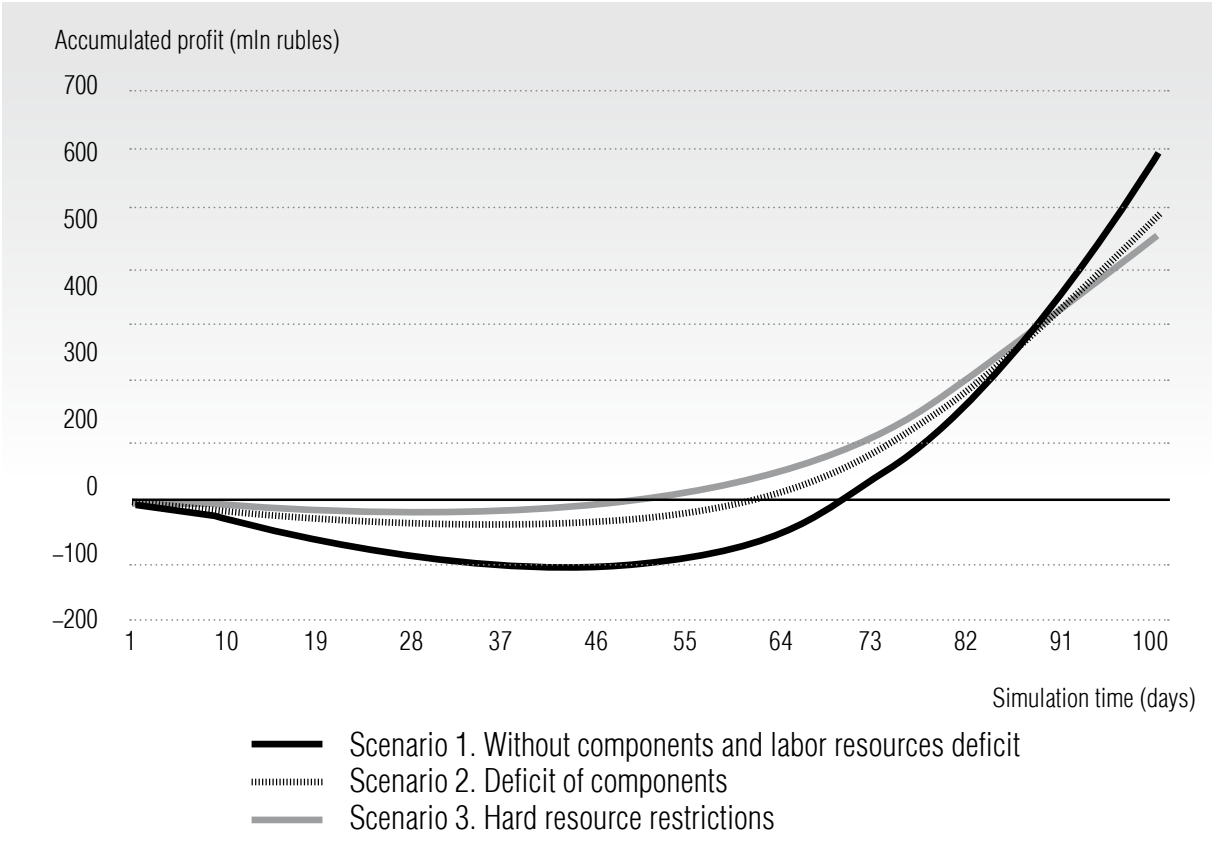

Fig. 7. Results of optimization experiments (accumulated profit)

Table 1.

Values of the sought variables and optimization results

Model parameter	Scenario 1: Without deficit of components and labor resources	Scenario 2: Deficit of components	Scenario 3: Hard resource restrictions
Number of agents–assemblers of the 1st category, people	1000	430	125
Number of agents–assemblers of the 2nd category, people	500	225	84
Number of agents– specialists belong to technical control department, people	100	30	15
Number of agents– packers, people	100	27	13
Number of agents–loaders, people	50	20	10
Average assembly time, days	0.1	0.05	0.03
Average technical control time, days	0.01	0.01	0.008
Average packing time, days	0.01	0.07	0.05
Average shipping time, days	7	5	4
Accumulated gross profit at time T = 100, million rubles	619	494	468

At the same time, three scenarios of the behavior of the considered production system were considered:

Scenario 1. Without any deficit of components and with the possibility of a significant increase in the involved labor resources.

Scenario 2. A deficit of components while demand for final products is maintained

Scenario 3. The presence of hard resource restrictions on the number of employees involved in the processes while many of the needed components are missing.

In *Figure 7* the results of optimization experiments are shown.

Table 1 shows the numerical values of the sought variables obtained because of optimization for the three considered scenarios of the behavior of the investigated production system.

As follows from *Figure 7* and *Table 1*, the use of a genetic algorithm to optimize the characteristics of the developed discrete-event simulation model made it possible to determine the best (suboptimal) values of the decision-variables corresponding to three fundamentally different scenarios of the production system

behavior. At the same time, the dynamics of the accumulated gross profit is generally stable in relation to the scenarios under study. Thus, for instance, in conditions of components deficit (Scenario 2) due to a significant reduction in the number of involved labor resources with a simultaneous decrease in the execution time of production operations (i.e. due to increasing labor productivity), a significant level of accumulated profit can be ensured. In addition, the same financial result can be obtained in conditions of hard resources restrictions and the absence of the components deficit (Scenario 3).

Conclusion

This article presents a new approach to the development of a 'digital twin' of a manufacturing enterprise (using a TVs assembly plant as the case study) based on the combined use of discrete-event and agent-based simulation methods. A conceptual model of a digital plant is proposed with subsequent software implementation in the AnyLogic simulation system. We formulated and solved the most important problem of maximising the gross accumulated profit of a manufacturing enterprise taking into account the contribution of the operational component, including the dynamics of the volume of finished products, the number of employees involved in various processes, the execution time of production operations, etc. Numerical studies were completed, in particular, optimization experiments which confirm the possibility of determining the best solutions that ensure the stability of the accumulated gross profit of the enterprise in relation to various characteristics of the external environment (e.g. in conditions of the components deficit and hard resource restrictions).

The simulation results demonstrate the possibility of obtaining an accumulated gross profit of the manufacturing plant that is stable in relation to the scenario characteristics of environment. Thus, for instance, in the appearance of the components deficit (Scenario 2), as well as in conditions of hard resource constraints and the absence of the components deficit (Scenario 3), it is possible to provide a level of accumulated profit close to the financial result of the first scenario with the absence of such restrictions.

Further research will focus on the development of methods for the creating 'digital twins' of manufacturing enterprises with a more complex organizational structure and nested (hierarchical, multilevel) processes. ■

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Valuating the position of the control object based on a universal complex indicator using structured and unstructured data

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Abstract

Valuating the position of a controlled object using indicators which are management and control tools is widely used in many areas of the economy. Usually such indicators are based on internal data, however, as the volume of available open information grows, algorithms for valuation of the position of certain control objects and on open structured data are appearing. The disadvantage of these models is their narrow specialization and binding only to structured, and sometimes strictly official data, which, as a rule, have a rare publication frequency. This does not allow you to track the change in the position of the object at different times. The authors have proposed a concept for constructing a universal complex indicator (UCI) for express valuation of the position of a controlled object in various types of activity: banking, educational, industrial, etc. Another difference in the construction of the UCI is that the concept presented in the article assumes, as a reference point, to take into account the requirements of regulatory authorities, while in most Russian and foreign studies, indicators are built for the needs of investors. It is also proposed to use, along with structured and unstructured data, tracking the dynamics of changes in the position of the control object. To determine the UCI values on the basis of various econometric models and methods, the components that characterize the requirements of the control bodies to the control object are calculated; using them the UCI value is determined from

the truth table. The concept proposed was tested to build an express valuation of the financial position of 108 banks for the period from 1 January 2018 to 1 February 2020. In accordance with the requirements of the Central Bank of the Russian Federation, the values of the three UCI components were obtained, and the value was calculated for each bank. The predictive ability of the constructed model, tested on three banks of the test sample, was confirmed by the consistency of the express valuation with their actual position in March 2020.

Key words: express valuation; universal complex indicator; logical function; truth table; control object; commercial bank; requirements of regulatory authorities; financial position; structured data; unstructured data; econometric model.

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Introduction

In the current economic environment, the role of competent management in the activities of an organization of any level cannot be underestimated. Optimal management saves resources, increases the efficiency of activities, accelerates the repayment of funds, and reduces the risk of financial losses. In recent years there has been a great deal of attention to the ways and methods of management, as well as to the information on the basis of which decisions are made. The more detailed and qualitative the information used, the more accurate the management decisions made on its basis will be. Control does not exist without monitoring and controlling the state of the control object [1]. Quite a lot has been written about the problem of managing economic objects in recent years, both by Russian and foreign researchers [2].

The problems of improving the management of various objects have been touched upon in many scientific publications of the last 10 years. For example, the article [3] is focused on the issues of improving the tools for planning socio-economic development and evaluation of control objects under the conditions of active formation of the information society infrastructure. The author also assessed the impact of digital technologies on the content of control tasks – in the process of variability of control objects and subjects in large-scale organizational systems. There is an underdeveloped level of involvement of big data in management at the tactical level [4]. The author proposes the standardization of technologies for collecting, transmitting, storing and processing big data, the construction of computer mathematical models to provide a multilevel system of state strategic planning [5, 6].

In [7] the author, analyzing the research in the field of management and control, notes that under the conditions of tightening competition, an effective tool for survival and adaptation at present is internal control. At the same time, the poorly developed system of internal control of the majority of today's enterprises is considered. The author draws the conclusion that heads of the majority of firms consider introduction of internal control as expensive and labor-consuming, thus they underestimate the importance of this system.

In [1] the author identifies a number of significant management problems concerning the control functions of the organization. Thus, when carrying out control, the accent of inspection bodies is made, as a rule, only on audit of financial and economic activity; control acti-

vity turns into rechecking of accounting operations, including arithmetic recalculation. At the same time, assessment of external non-quantitative indicators, such as the level of popularity, customer loyalty, the quality of the object of management, etc. remains outside the attention of the control authorities.

From analysis of the methods and models proposed both by Russian and foreign researchers, the advantage relies on the information coming with a certain periodicity, often with a significant lag relative to the current moment. At the same time, the controlling bodies need to obtain a reliable assessment of the state of the object of management for the current moment in time, which will allow taking the necessary measures in time to prevent negative developments.

This problem can be solved by conducting an express-analysis of the current state of the control object based on the use of formalized and non-formalized, structured and unstructured information. The result of express-analysis is to obtain an express valuation of the state of the control object. Express valuation of the state of the control object is a preliminary study, which largely determines the feasibility of further, more in-depth analysis.

Considering the above, the authors of this article set the following research goal and objectives. The aim of the study is to develop a universal complex indicator for express valuation of the compliance of the economic object of management with the stated requirements on the part of regulators or relevant services on the basis of structured and unstructured data from the internet.

The main objectives of the study are:

- ✦ developing the concept of express valuation of the compliance of the state of the object of management with the stated requirements of current controlling;
- ✦ development of an algorithm for constructing a universal complex indicator for express valuation of the compliance of the state of the control object with the stated requirements;
- ✦ approbation of the concept developed on the example of calculating the universal complex indicator for express valuation of the state of a Russian commercial bank.

The relevance of the study is explained by the following factors:

- ✦ the need to develop a tool of economic and mathematical modeling based on open data for current monitoring, analysis and forecast of the state of the control object;
- ✦ the need for a current assessment model, which does not depend on the moment of the release of statistical reports;
- ✦ conducting an express valuation of the state of the control object (for example, a bank) using open data;
- ✦ the need to track the dynamics of the state of the control object on the basis of structured and unstructured data.

1. Statement of the research problem

The proposed approach will provide a solution to the problem of transformation of the existing management and control system and the development of internal control system in the context of digitalization of the economy [7, 8]. As a rule, official statistical reports are published in the public domain with a certain periodicity and an appropriate lag, which makes it difficult to respond promptly in force majeure situations.

An approach to the construction of a complex indicator based on the use of open structured data on the control object at the current moment in time to assess the degree of coastal zone deterioration is proposed in [9]. The work formulates a model for calculating a complex indicator based on structured information collected from public maps and communities about the use by the population of the territory as undeveloped wild beaches, mini hotels or places of public assembly.

One of the problems raised by the authors of this article is the problem of ongoing monitoring of control objects, with official statistical reporting coming out with great frequency and a long time lag. For example, in the banking sphere current control by the Central Bank over other commercial banks is difficult because of the delay in the receipt of information about the state of bank finances. This problem is considered in [10]. We suggest involving open sources of information and, on the basis of a mathematical model, forming a complex indicator using such data [2, 11]. The approach outlined in the article makes it possible to obtain, on the basis of open data, operational information about the state of the bank as an object of management, and to accelerate decision-making in relation to it. The result of the application of the mathematical model is the probability of license revocation (as one of the components of the reliable bank assessment model) on the basis of public financial statements and taking into account the volatility of the external environment (changes in currency exchange rates, the cost of a barrel of oil, etc.) [12–14].

A distinctive feature of this paper is the authors' proposal to use, in addition to structured and unstructured data from "open" sources of information, such as: qualitative and express valuation of the overall condition of the bank from the point of view of independent Russian rating agencies, the tone of published news mentioning the bank.

The unstructured data can be presented in different forms – text, news reports, comments, photos [15]. With the development of internet technologies, their volume is growing, and information based on such data can help in express valuation of the state of the control object.

In contrast to the works discussed above, we offer the concept of building a universal complex indicator of express valuation of the state of the control object on the basis of open structured and unstructured data obtained from official and unofficial sites. The data are collected both from statistical resources, where they are published periodically, and from internet resources regularly updated with different periodicity. In contrast to the structured data used for many years, unstructured data is an amalgamation of disparate information. This allows end-users to monitor the consequences of their decisions at an early stage, thus minimizing risks. Consideration of unstructured data in the evaluation of control objects allows for operational monitoring of the current state of the control object, taking into account qualitative characteristics (reputation, feedback, trends) based on data obtained in a non-contact method from open sources.

For processing by methods of machine learning, mathematical statistics and mathematical models, the unstructured information is pre-structured in the form of a set of some indicators by methods of mathematical statistics, machine learning or econometrics [16–18].

For example, in the conference proceedings [19] we proposed using one of the components calculated on the basis of unstructured data indicating probability of instability of a bank's position (text content of the news highlighting the negative references to the bank's name), as an attribute for constructing a complex indicator. This indicator can be used for evaluating the bank's position that is different from the stable one.

2. The concept of constructing a universal complex indicator for express valuation of the state of the control object

The proposed concept of forming a universal complex indicator (UCI) of express valuation of the state of the control object makes it possible to assess not only the current, but also to predict the future state of such a control object [19–21].

The constructed universal complex indicator (UCI) can be used for the following purposes:

- ✦ to assess the proximity of the state of the control object to the critical level set by the controlling body;
- ✦ to analyze trends in the state of the controlled object on the basis of structured and unstructured data;
- ✦ to collect and analyze operational information about the state of the control object;
- ✦ to assess the reliability of reporting data on the state of the control object;
- ✦ to compare the state of different-scale control objects;
- ✦ to take into account the external in relation to the object of management characteristics of its activity (the presence of actual mini-hotels on the coast, the tone of the news about the director of the bank, the comfort of the infrastructure of the educational institution, the activity of the use of social networks by the respondent, etc.) [22–24].

The advantage of the use of open data is the possibility to receive information with any periodicity (not being restricted by the regularity of updating of officially published statistical information), to expand and check the correspondence of the actual state of the control object to the official data.

The conceptual scheme of building UCI express valuation of the state of the objectt for monitoring and control to prevent the development of negative events is presented in *Figure 1.*

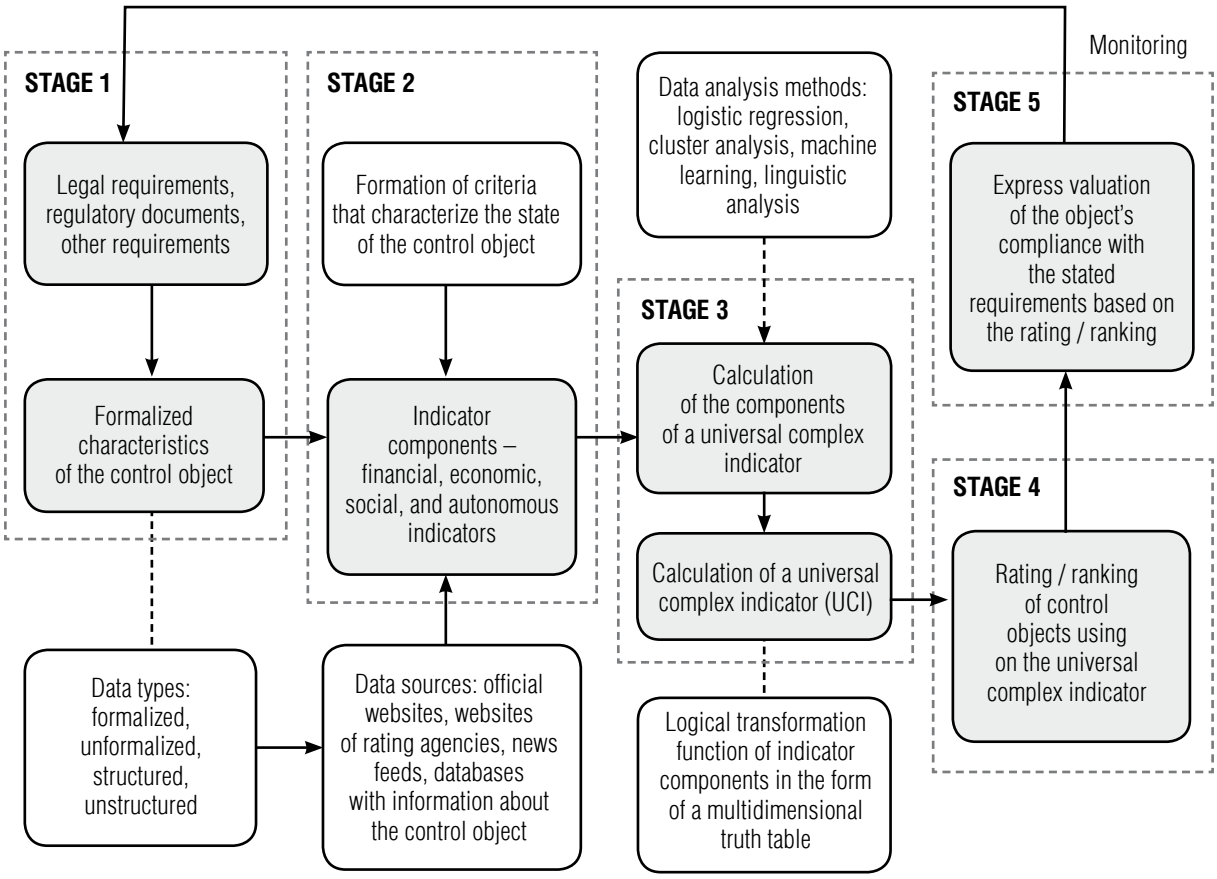

Fig. 1. Conceptual scheme of the construction of a universal complex indicator (UCI)

The construction of a universal complex indicator involves the following stages.

Stage 1. The first (initial) first stage is determining the components of UCI on the basis of information about the requirements from the supervisory body regarding the state of the control object. Such information can be obtained from decrees, orders, laws and other regulatory acts. Such a body may be either an external organization (the Central Bank, the Ministry) or an internal control body of the organization itself.

As a result of implementing the algorithm, a universal complex indicator (UCI) is formed, the values of which can be an integer representing binary or categorical values. These values reflect the state of the control object relative to the satisfactory state determined by the controlling body. So an example of binary values of the universal complex indicator is: 0 – no signs of illegal activities of the organization, 1 – there are signs of illegal activities of the organization. Most often, a categorical scale with three categories is used, for example, where: 1 means stable condition, 2 – unstable condition and 3 – condition requiring closer examination.

Stage 2. After the formation of criteria characterizing the state of the control object, which in their totality should be described by the UCI, the components of the indicator are defined. They make it possible to evaluate the state of various characteristics of the control object: economic state, the probability of an object state other than stable, media activity associated with the object, characteristics of the object's location, financial or economic state forecast of the object, etc. Then a list of UCI components is formed, and data from public sources are identified from which information can be obtained for mathematical modeling and calculation of the components. Unstructured data are pre-processed for their possible use as calculated indicators.

Stage 3. Using mathematical methods (logistic regression, cluster analysis, regression analysis, statistical analysis) based on the available data, the UCI components are calculated. They represent numerical values used to rank all the control objects.

Relying on the obtained UCI component values, the value of the universal complex indicator of express valuation of compliance of the state of the control object with the stated requirements is determined. For this purpose, the component values are substituted as arguments in the logic function that aggregates the various UCI component values.

Let us consider such a logical function. Let n requirements formulated in n criteria be received from the controlling authority and k components I_j, $j = 1, ..., k$, be formed for the universal complex indicator. The values of the components form the set X (as usual, $X \in \mathbf{R}$).

In this case, a particular control object state requirement received from a controlling entity can be described by a few UCI components, i.e. $k \geq n$. The values of the universal complex indicator (UCI) take values from some given discrete set Y, i.e. $y_i \in Y$, where $i = 1, ..., p$.

The logic function $\Psi(I_1, I_2, ..., I_k)$ is specified by the truth table (*Table 1*), based on the importance of the criteria received from the controlling body (*Figure 2*).

Each component I_j can take Q_j values. The values of the component $I_j^{q_j} \in X_j$, where $j = 1, ..., k$; $q_j = 1, ..., Q_j$; $X_j \in X$.

The total number of combinations M of all possible values of all k components is determined as follows:

$$M = \prod_{j=1}^{k} Q_j. \quad (1)$$

In the general case, the table is a matrix of the dimension $M \times k$. The first row of the matrix (combination s_1) is represented by the first values of each of the k components I_j^1. The last row of the matrix is represented by the maximum values of each of the k components $I_j^{(Q_j)}$. The rows between the first and the last rows can be formed in different ways, but so that a com-

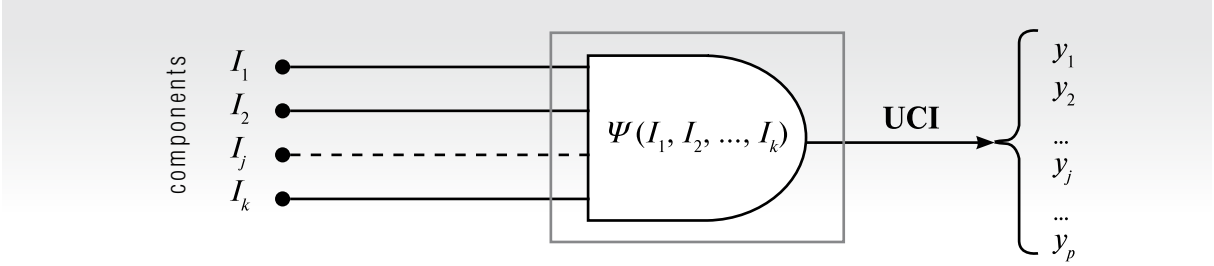

Fig. 2. UCI formation using a logic function

Table 1.

General form of the UCI multidimensional truth table

s_m – combination number, $s_m = 1, ..., M$	Components of the universal complex indicator (UCI)					The value of the universal complex indicator (UCI)
	I_1	...	I_j	...	I_k	
s_1	I_1^1	...	I_j^1	...	I_k^1	$y_{s_1} = \psi(I_1^1, ..., I_j^1, ..., I_k^1);\ y_{s_1} \in Y$
s_2	I_1^2	...	I_j^1	...	I_k^1	$y_{s_2} = \psi(I_1^2, ..., I_j^1, ..., I_k^1);\ y_{s_2} \in Y$
...	...	...	...	...	...	...
s_m	$I_1^{q_1}$	...	$I_j^{q_j}$	...	$I_k^{q_k}$	$y_{s_m} = \psi(I_1^{q_1}, ..., I_j^{q_j}, ..., I_k^{q_k});\ y_{s_m} \in Y$
...	...	...	...	...	...	...
s_M	$I_1^{Q_1}$	...	$I_j^{Q_j}$	...	$I_k^{Q_k}$	$y_{s_M} = \psi(I_1^{Q_1}, ..., I_j^{Q_j}, ..., I_k^{Q_k});\ y_{s_M} \in Y$

plete enumeration of all possible combinations of values taken by each of the I_j components is carried out.

Stage 4. In the next stage, after calculating the UCI value, the ranking of the control objects is performed.

Stage 5. After the ranking stage, an assessment is made of the compliance of the control object with the stated requirements in accordance with the obtained ranks (ratings). Based on the values obtained at the moment, recommendations for the supervisory authorities regarding the control objects are developed. As new information emerges during the monitoring period for a group of control facilities, data from public sources is updated regularly and the model is re-evaluated on the basis of the updated data.

3. Calculation of the universal complex indicator of express valuation of the commercial bank state

The proposed concept of constructing UCI express valuation of compliance of the state of the control object with the stated requirements on the part of regulators has been tested to obtain an express valuation of the state of a commercial bank. The controlling body for the solution of this problem is the Central Bank of Russia – the supervisory body in the banking sphere.

The construction of the UCI mathematical model of the express valuation of the commercial bank's condition in accordance with the above concept consists of five stages.

Stage 1. Formation of target measures of a bank's state based on requirements for liquidity and reliability indices derived from standards and legislative acts of the Central Bank of the Russian Federation. In accordance with the standards and requirements established by the Central Bank of the Russian Federation for commercial banks, the following characteristics were formed:

- probability of financial bankruptcy of the commercial bank;
- financial stability of the commercial bank;
- qualitative valuation of the commercial bank's activities by experts
- market participants.

To assess the formed characteristics, the values of the UCI components are calculated.

Stage 2. Determination of UCI components of the express valuation of the bank's condition:

- **probability of financial bankruptcy of a commercial bank (stated by the Central Bank of the Russian Federation).** To determine this characteristic, the component 1 is calculated. This component represents the forecasted probability of a commercial bank bankruptcy; it is estimated by means of logistic regression, using financial and economic factors;
- **financial stability of a commercial bank (stated by the Central Bank of the Russian Federation).** To determine this characteristic, the component 2 is calculated. This component is an indirect sign of instability of a commercial bank obtained on the basis of the assessment of the bank's belonging to the "troubled" group. Homogeneous groups of banks on the signs of stability are identified by the clustering method [25];
- **qualitative valuation of the commercial bank by experts – market participants (stated by the Central Bank of the Russian Federation).** To determine this characteristic, the component 3 is calculated. This component represents the availability of a negative valuation of the general state of the bank by a market participant – the expert agency "Expert RA". The indicator is constructed using a qualitative valuation based on semantic analysis of news texts mentioning the bank.

Stage 3. Construction of the UCI express valuation of the commercial bank's state. To construct the UCI, we used a training sample of 108 operating commercial banks. Information was obtained from eight external sources including the site of the Central Bank of Russia, rating agencies, reference books and information-analytical portals. The requirements relative to the bank's condition were taken from the norms of the regulator – the Central Bank of the Russian Federation.

To characterize the stability of the financial condition of a commercial bank and its market behavior, the significance of fluctuations in the dynamics of changes in bank rates without visible reasons was assessed. The main indicators characterizing the rates of banks on deposits were taken for the period from January 1, 2018 to February 1, 2020. Ratings agency indicators are from 2017 to 2020. General characteristics

of commercial banks according to the Bank of Russia website and other public sources were taken as of February 2020.

The UCI calculation model used more than 60 initial indicators of the following type:

✦ rates of each of the commercial banks on deposits for different terms;

✦ indicators characterizing the state of the bank: its assets and values of the statutory indicators ($H_1 - H_7$);

✦ macroeconomic indicators of the external environment: key rate, average rates for all banks of the Russian Federation and for the 30 largest banks of the Russian Federation;

✦ indicators of rating agencies for the period from 2017 to 2020;

✦ semantic (textual) information about the mention of each bank in the news feed of the rating agency.

The following central tendency and dispersion indicators were calculated based on these raw data:

✦ median, dispersion of deviations of deposit rates for each commercial bank relative to macroeconomic indicators: the key rate, the average bank rate for all banks, for the 30 largest banks in Russia;

✦ relative indicators of the rates dynamics, their medians and dispersion;

✦ relative and absolute place of the bank in the rating of banks;

✦ negative mention of the bank in the news feed on the website of the rating agency.

The criterion for checking the quality of the model was the status of the commercial bank at the time of information collection, i.e. whether it was operating or liquidated.

To obtain the UCI values, the components I_1, I_2 and I_3 were calculated as follows.

The component 1 (I_1) – predicted probability of a commercial bank going bankrupt. To obtain an estimate of the probability of revocation of the commercial bank's license, a logistic regression model was built on the basis of initial data and estimated indicators. These indicators include: the bank's position in the rating, the volatility of bank rates, a qualitative calculation indicator that characterizes the perception of the expert community of the activities of a commercial bank based on the processing of unstructured text data – mention of the downgrade of a commercial bank in the news feed on the rating agency's website. The dependent variable Y is a binary variable taking two values – 0 if the current status of the bank is "active" and 1 if it is liquidated.

The estimated logistic regression model has the form:

$$P(Y=1) = \frac{1}{1+e^{-z}}, \quad (2)$$

$$z = -16.7 + 1.4955 \cdot x_1 + 0.024 \cdot x_2 + 1.128 \cdot x_3 + 0.389 \cdot x_4, \quad (3)$$

where x_1 – descending in the ranking;

x_2 – ranking position;

x_3 – median deposit rates;

x_4 –median deviation of demand deposit rates from the market average rate.

All model coefficients are significant at the 5% level, the sensitivity (i.e. the share of liquidated banks) and specificity (the share of operating banks) indicators of the model are high, respectively 85.9% and 73.3%.

Relying on the results of the model's work, by dividing all the values obtained into three intervals, a UCI component 1 was formed. This component characterizes the probability of license revocation within six months of the time of the model's estimation:

✦ low: $P(Y=1) \le 0.25$;

✦ medium: $0.25 < P(Y=1) < 0.35$;

✦ high: $P(Y=1) \ge 0.35$.

The cutoff limits were chosen based on sensitivity and specificity optimization as follows. The upper limit, equal to 0.35, was obtained

when the maximum values of sensitivity and specificity of the model were achieved simultaneously (85.9% and 73.3%). The lower limit, equal to 0.25, corresponds to a specificity value of 80%.

The component 2 (I_2) – Valuation of the bank's membership in the "disadvantaged" cluster. When clustering the training sample by the BIRCH method (two-step method) on the main financial indicators of a commercial bank, the data on the value of the seven basic standards of banks ($H_1 - H_7$), the position of a commercial bank in the banking rating developed by the rating agency and the change in this rating in the retrospective five homogeneous clusters were obtained.

The most interesting is the first cluster, accounting for 14% of the training sample. This cluster contained 30% of the liquidated banks. All banks in this cluster ranked below 200. There was also a decrease in the median of the norms of each commercial bank for the retrospective period, a decrease in the median of the dispersion of deposit rates for the previous period.

According to the results of the model, the component 2 UCI was formed – belonging to the first cluster, as a sign of "disadvantage" of a commercial bank.

The component 3 (I_3) – availability of a negative valuation of the bank's activity by a market participant – expert agency. This component is formed as a binary indicator of belonging to one of two sets. Component 3 takes value 1, if there is at least one negative reference to the name of a commercial bank in the newsfeed on the site of rating agency for the current year, and value 0, if there is no negative reference.

The values of universal complex indicator (UCI) for training and test samples were calculated from UCI components with the help of truth table (*Table 1*). The results are presented in *Table 2*.

Stage 4. Ranking the commercial banks of the training sample on the basis of the calculated UCI values. The result of this stage is a list of commercial banks sorted by decreasing UCI values.

Stage 5. Testing the developed model of UCI calculation was carried out on a test sample of three commercial banks. The results of modeling and recommendations for commercial banks from the test sample are shown in *Table 3*.

The results of approbation of the developed model on the test sample of three commercial banks, as shown in *Table 4*, are confirmed by the current status of commercial banks as of March 2020.

Thus, the concept of express valuation of commercial bank's state proposed on the basis of the analysis of open structured and unstructured data, allows us to get the probability of the bank having an unsatisfactory state. The results obtained allow us to apply preventive measures of support or protection of depositors' interests by the supervisory body (the Central Bank of the Russian Federation).

Conclusion

This paper proposes a concept and algorithm for constructing a universal complex indicator. This allows us to get an express valuation of the state of the object of control by the supervisory authorities to prevent the development of negative events.

The novelty of the proposed approach is the possibility of using the universal complex indicator (UCI) for express valuation of the control objects in various subject areas and activities using as input information structured and unstructured data from open sources.

The information base of the study for the express valuation of the state of the Russian commercial bank, including 111 banks and 79 financial and non-financial indicators from 1.01.2018 to 01.02.2020 was formed.

Table 2.

UCI values of the valuation of the bank's condition

Components of the universal complex indicator (UCI)			The value (y_j) of the universal complex indicator (UCI)
Component 1 (I_1): Probability of license revocation	**Component 2 (I_2):** Cluster membership	**Component 3 (I_3):** Availability of negative references on the rating agency's website	
High (more than 0.35)	Cluster membership is not relevant	Availability of negative references is not relevant	3: Close attention is required
Medium (0.25–0.35)	Belongs to the Cluster 1	1 (availability of negative references)	
Medium (0.25–0.35)	Belongs to the Cluster 1	0 (absence of negative references)	2: Attention is required
Medium (0.25–0.35)	Does not belong to the Cluster 1	1 (availability of negative references)	
Low (less than 0.25)	Cluster membership is not relevant	1 (availability of negative references)	
Low (less than 0.25)	Cluster membership is not relevant	0 (absence of negative references)	1: Attention is not required
Medium (0.25–0.35)	Does not belong to the Cluster 1	0 (absence of negative references)	

Table 3.

UCI values for test sample banks

Bank	Component 1 (I_1): Probability of license revocation	Component 2 (I_2): Cluster membership	Component 3 (I_3): Availability of negative references on the rating agency's website	The value of the universal complex indicator (UCI)
PFS–Bank	High (0.844)	Does not belong to the Cluster 1	0	3: Close attention is required
Peresvet Bank	Low (0.01)	Belongs to the Cluster 1	1	2: Attention is required
Citibank	Low (0.007)	Does not belong to the Cluster 1	0	1: Attention is not required

Table 4.

Comparison of the calculated UCI value and the current status of the commercial bank

Bank	The value of the universal complex indicator (UCI)	Current status of the bank
PFS–Bank	3: Close attention is required	The license was revoked in March 2020
Peresvet Bank	2: Attention is required	Active. Repeated violations of the regulator's mandatory ratios in the process of the bank's rehabilitation are observed
Citibank	1: Attention is not required	Active

The concept developed for building a universal complex indicator (UCI) for express valuation of the state of three Russian commercial banks was tested and a bank with a state that does not meet the requirements for banks imposed by the Central Bank of the Russian Federation was identified. Conclusions about the status of three commercial banks as of March 2020 from the test sample obtained on the basis of the analysis of UCI values were further confirmed by information on the website of the Central Bank of Russia. ■

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Improving customer experience with artificial intelligence by adhering to ethical principles

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Abstract

The intensive development and application of artificial intelligence technologies in organizing interaction with clients is accompanied by such difficulties as: the client's unwillingness to communicate with the robot, distrust, fear, negative experience of the clients. Such problems can be solved by adhering to ethical principles of using artificial intelligence. In scientific and practical research on this topic, there are many general recommendations that are difficult to apply in practice, or, on the contrary, that describe the methods for solving a highly specialized technical or management problem. The purpose of this article is to determine the ethical principles and methods, the observance and implementation of which would increase confidence in artificial intelligence systems among client of a particular organization. As a result of the analysis and synthesis of the scientific and practical investigations, as well as the empirical experience of Russian and foreign companies, the main areas of application of artificial intelligence technologies affecting the customer experience were identified. The ethical principles recommended to be followed by business have been formulated and systematized. The main methods have been also identified to enable implementation of these principles in practice, and so to reduce the negative effects of customer interaction with artificial intelligence and increase their confidence in the company.

Key words: ethics; artificial intelligence (AI); ethical AI; customer experience; ethical principles; machine learning; trust; robot.

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Introduction

Using the artificial intelligence (AI) technologies when interacting with customers provides significant economic potential, but requires solving problems with data security, transparency of algorithms for machine behavior, and trust in such tools on the customer side. This is a reason for the increasing interest in the issues of digital ethics both in scientific literature and in practice. Searching for publications in the Web of Science and Scopus with the keyword "AI Ethics" shows that over 57% (483) papers found in Web of Science and 61% (587) of papers found in Scopus have been published in 2019 and 2020. Until 2019, on average about 30 papers on this topic were published each year on this topic, with more than 40% of the articles written by authors from the United States and Great Britain. Also among the leaders are authors from Australia, Italy, the Netherlands and Canada. Authors from the United States have published 528 papers, and Russian scientists have published only 14. It is also important to note that only half of all published papers are related to computer and social sciences, business and economics.

This trend is also observed in practice-oriented publications, as well as in the materials of state and international committees and expert councils [1–5]. They suggest high-level approaches, principles and methods for solving the problems of AI technologies implementation, which are difficult to apply in practice at the company level. At the same time, more than half of CEOs of companies using AI technologies emphasize the importance of ensuring their ethics and transparency [6]. Gartner also notes that in the coming years, the issues of digital ethics will remain at the peak of popularity as an element of corporate architecture [7].

In marketing, sales and after-sales processes, artificial intelligence can be used to solve a variety of problems. Examples include improving speech recognition and analyzing the emotional state of a customer, routing calls, handling requests, providing an individual approach to every customer, and finding new customers.

The term "artificial intelligence" does not have a single, well-established definition. Many researchers believe that the concept of AI refers to the programs, algorithms and systems that demonstrate intelligence [8]. However, such a formulation raises a lot of discussion on the subject of how to determine that a machine is demonstrating intelligence, and what are its actions which prove its intelligence. Therefore, in this work we will adhere to a slightly different point of view, implying that information systems with AI are built on the basis of machine learning technologies and they can use tools for robotic process automation, natural language processing, neural networks and deep learning methods [9–11]. Such software solutions allow interpretation of the available data, learning from it and adapting it to the current needs of the user [12].

The use of such advanced digital technologies is associated with ethical problems [11, 13, 14]. Clients are not inclined to confide in artificial intelligence. From the point of view of compliance with ethical standards, they expect more from such information systems than is regulated by the current legal norms [15]. It is also important for many people that interaction with them is carried out honestly and transparently; only in this case do they begin to trust the seller [16]. It is trust that acts as the most powerful factor influencing customer loyalty [17–19]. It arises from the company's consistent behavior, demonstrating its integrity and reliability. The importance of these aspects in building the relationship between the seller and the consumer is increasing every year. This trend, in particular, is confirmed by the results of studies by KPMG in 2019–2020 [17, 20].

The issues of improving the customer experience are thoroughly considered by research-

ers from the point of view of marketing, sales automation and after-sales service, including the use of artificial intelligence technologies [21, 22]. However, their use raises ethical problems. Therefore, there is an urgent need to study these issues and identify possible ways to reduce the negative consequences.

The goal of this paper is to identify ethical principles and approaches to improve the customer experience of interacting with AI during sales and the after-sales phases. As a result of the study, we intend to answer the following questions:

- What ethical principles need to be followed to improve the AI customer experience?
- What steps would reduce the negative attitude of buyers and consumers to the use of AI technologies by the company in management and implementation processes?

As part of the study, we carried out an analysis of scientific and practical publications, frameworks, "white papers" and analytical reports related to the questions raised from the point of view of marketing, business, psychology, ethics and information technology.

Based on the classification of artificial intelligence systems used in customer service [23], two scenarios of their application can be distinguished: 1) a robot as an assistant to a person who serves a client and 2) a robot as a replacement for a person serving the customer. In this paper, the second option is mainly considered. This will allow narrowing the research area and focusing on the problems that arise with this type of customer interaction.

1. Scope of artificial intelligence technologies when implemented for interaction with customers

In thefield of managing and implementing customer interactions, artificial intelligence technologies can be used to solve such issues as automating sales processes, processing requests and complaints, finding and attracting new customers, increasing loyalty and retaining existing customers. Among the tasks most frequently implemented with the support of AI, one can single out the management of incoming content, the implementation of simple sales processes, the analysis of information about the client and the formation of personalized offers for him.

Artificial intelligence tools, together with robotic process automation (RPA) technologies, capture customer messages and letters, identify them, recognize them, extract the necessary and useful information about the customer and his request, verify the received data with those already available in the company and then transfer them for processing and making decisions on a specific question.

Artificial intelligence is largely used in simple sales processes on marketplaces such as eBay and Amazon, Facebook and WeChat. Yamato Transport, one of Japan's largest courier companies, uses a chatbot to schedule deliveries and answer queries on the parcel's location [24]. Domino's Pizza uses a chatbot that accepts orders for online delivery.

To implement behavioral targeting in real time, based on the analysis of customer transactions, personalized offers are generated based on the buyer's behavior and sales experience in the company. For example, similar solutions are used in Netflix, Amazon, Outbrain, Taboola [22].

The determination of an individual trajectory of interaction with a client can also be implemented using AI systems, which are based on natural language processing and machine learning technologies. For example, the Stitch Fix company has created an online clothing store, where customers are invited to define their unique style (instead of choosing from the proposed template options), and choose items that suit this style, thus taking into account the individual characteristics of a person [25].

Artificial intelligence helps to improve communication and increase customer loyalty, sell him a product, by analyzing his emotional state by voice or text of the message. Such solutions allow predicting the client's behavior, his desires, and building interaction with him in the best possible way.

Robotization and the use of artificial intelligence technologies, like many other innovations, make it possible to satisfy customer needs in terms of the quality and speed of processing their requests [26–28]. Sometimes it even succeeds in surpassing the expectations of buyers and consumers, reducing their efforts to interact with the company.

A 2020 KPMG study [22] showed that the number of consumers willing to use digital technologies (social networks, web chats, instant messengers) to interact with sellers has recently tripled. According to McKinsey [29], the use of AI for deeper (in comparison with traditional solutions) data analytics allows a company to increase its value by 30–128%, while retailers increase their sales by only 1–2%. Therefore, to strengthen their competitiveness, increase profits and improve customer experience, companies are actively implementing IT solutions based on machine learning methods.

Companies are beginning to actively use artificial intelligence to interact directly with customers. The study [21] showed that using hidden chat bots (when customers think they are talking to a person) is four times more effective than the employment of an inexperienced salesperson. In addition, in some situations such solutions help to turn the negative experience of a client into a positive one by promptly and transparently resolving emerging problems.

2. Problems of using artificial intelligence technologies to interact with customers

Behavioral economics points to such a feature of a person as the formation of a trusting relationship with those we like. Many companies have been aware of this for a long time and are taking appropriate steps so that the buyer feels sympathy to the employees he communicates with. However, the question of how to make the buyer comfortable to communicate with the AI, which replaces the contact person from the company, remains unresolved. Capgemini [6] estimates that roughly two out of five companies that are encountering ethical issues in using AI have opted to abandon its use completely.

Empathy and personalization are other important aspects of a positive customer experience and increased customer loyalty, which are difficult to achieve with artificial intelligence technologies. Theoretically, when designing an algorithm for the functioning of a robot, one can try to build the logic of its interaction with a client in such a way that it takes into account the client's circumstances and shows a deep understanding of his problems, doubts, fears. However, a person communicating with, for example, a bot, most likely will not feel interest in himself from the AI, will not feel himself valuable and unique, since he will understand that he is not communicating with a person, but with a machine. Customers are especially reluctant to interact with a robot if they need subjective assessment, help in choosing a product, if they expect complicity and empathy [29–31].

There is a large category of customers who believe that a company that uses an artificial intelligence system to interact with them is in some way deceiving a buyer or consumer of services [24]. This seriously reduces the customer's confidence in the brand. So, after the disclosure of information that a bot and not a person is working in the sale process in the company, the frequency of interruption of the current contact increases, and the number of purchases decreases by almost 80% [21].

The studies described in [28] show that the introduction of innovative solutions based on

AI from potential customers and consumers is more likely to cause a negative reaction than a positive one; this especially affects the perception of the ethical side of a company's reputation.

Customers are very concerned about the confidentiality and security of interaction with the robot [32]. When interacting with a living person, in contrast to artificial intelligence systems, the feeling remains that the conversation may not be recorded, not all information that is communicated to the seller or manager will get into the accounting system and will be used for further contacts or for any other purposes. In addition, due to the opacity of the algorithms for the functioning of AI, the client feels insecure when transferring personal data about himself to the robot.

In the course of applying artificial intelligence, for example, in the analysis of customer experience and interaction with the consumer, a question of the ethical use of customer information arises. The principles of determining the ethics of the company's behavior in this case can also be an important criterion for the transparency of interaction and the honesty of the organization. In order to provide customers with a personalized service, many firms overuse personal data, which can negatively affect the customer experience. It may seem to a person that the seller violates acceptable boundaries and reaches into his personal life.

The exchange of personal data between companies of the same ecosystem is prohibited by the legislation of the Russian Federation. However, it is possible to transfer aggregated, anonymized data to each other as a service. This allows using the customer experience of ecosystem participants without violating basic ethical standards. This is what the companies Megafon and Mail.ru are doing [33]. Despite the fact that this does not violate the rights of customers, many of them would like to know what kind of personal data is used, by whom and for what purposes.

Thus, solutions based on artificial intelligence are perceived by many people as innovative, but having an incomprehensible functioning algorithm. This has a number of ethical implications that can negatively impact customer experience as well.

3. Ethical principles of using artificial intelligence technologies to interact with customers

The concept of "ethical" is very multifaceted, it can refer to both a process and a result or a value [18]. When considering the ethics of the process, we will talk about the internal procedures and actions that the company implements. The ethical values dimension refers to a set of parameters of organization interaction with its customers. In this case, we are talking about the transparency of information interaction, fairness of pricing, confidentiality of personal data, etc. The ethics of the results is related to the properties of the output of the AI system, non-discrimination, fairness and objectivity. It is important to consider the ethics of AI from all of the above points of view, as it addresses the ethical issues of design, development, implementation and use of appropriate technologies in practice.

People have begun to pay more attention to how well brands are behaving in relation to their ethical and social obligations. Many researchers [11, 13, 14] note that this contributes to the long-term success of the company in maintaining customer loyalty.

Fear, misunderstanding of the mechanisms of functioning of systems in which AI technologies are embedded can significantly reduce the potential positive effects of their use. Some companies that are actively testing various AI technologies (for example, Walmart Inc.) are concerned about the attitude of customers towards the robots they encounter during the purchase [34]. This is mainly due to the ethical aspect. In particular, the following risks apply:

- the client feels that a decision is made for him, that is, the possibility of self-realization decreases and the person's ability to research and choose a product that will satisfy his needs is devalued;
- opacity of areas of responsibility for decisions or conclusions made by artificial intelligence. For example, when a call center operator advises a caller of something, the responsibility for the recommendation lies with a specific employee or person. If the recommendations are made by a robot, who will be responsible for them?
- control over the actions of artificial intelligence. If the system is self-learning, then a situation may arise when conclusions from the analyzed information, behavior and AI decisions may turn out to be unpredictable not only for the user, but also for the developer.

Leading organizations working in the field of the formation of ethical norms and rules for the use of AI have formulated a large number of different approaches and tools to comply with the above principles [1, 2, 4, 5]. Almost all of them adhere to similar views and do not contradict but complement each other.

The Atomium – European Institute for Science, Media and Democracy white paper on AI ethics outlines five principles of AI ethics: 1) promoting human well-being; 2) harmlessness (confidentiality, security and "attention to opportunities"); 3) autonomy (the right of people to make their own decisions); 4) fairness (respect for the interests of all parties that can be influenced by the actions of the system with AI, the absence of discrimination, the possibility of eliminating errors); 5) explainability (transparency of the logic of artificial intelligence, accountability) [3]. These principles represent the quintessence of those set forth in codes, regulations and other advisory and regulatory documents issued by the expert and regulatory authorities of the European Union countries.

The Japanese Society for Artificial Intelligence (JSAI) identifies the following ethical principles to be followed by developers of artificial intelligence systems [35]: 1) respect for human rights and respect for cultural diversity; 2) compliance with laws and regulations, as well as not harming others; 3) respect for privacy; 4) justice; 5) security; 6) good faith; 7) accountability and social responsibility; 8) self-development and promotion of understanding of AI by society. It is also important to note that in contrast to the European principles of AI, here special attention is paid to the development of AI in such a way that it also observes the above principles in the course of its functioning.

Google has also formulated seven principles of artificial intelligence that the company is following in creating and using such technologies. These include [36]: 1) AI should be socially useful; 2) it is necessary to strive to avoid unfair influence on people; 3) application of best security practices; 4) responsibility for the actions of AI in front of people; 5) ensuring guarantees of confidentiality, proper transparency and control over the use of data; 6) maintaining standards of excellence; 7) limiting the use of potentially harmful and offensive software products. A feature of this list of principles is indication to the importance of the qualifications of people who create and manage systems with AI.

The Russian code of ethics for the use of data, which was developed at the initiative of the Big Data Association and the Institute for the Development of the Internet, states that it is necessary "to be based on the fundamental principles of protecting human rights and freedoms, to prevent discrimination and harm" as the basic principles for the use of AI. They must also comply with Russian and international legislation in the field of information security and data protection from illegal use [37].

The Capgemini Research Institute has also formulated the core characteristics of ethi-

cal AI. These include [6]: 1) ethical actions from design to application; 2) transparency; 3) explainability of the functioning of AI; 4) the interpretability of the results; 5) fairness, lack of bias; 6) the ability to audit.

Table 1 shows the results of comparison of the sets of principles that are recommended by the scientific and expert communities [3, 6, 35], principles used by the leading IT company Google [36], as well as those formulated in the Russian code of ethics for the use of data [37].

As noted earlier, the main challenge for a company in this area is to build trust with the customer. At the company level, it is important to adhere to ethical principles related to various aspects of trust. IBM distinguishes among them fairness, reliability, transparency, accountability, explainability and equalization of values (compliance with rules, business processes, norms, laws, ethics and morality) [38].

An analysis of the recommendations for the formation of ethical principles allows us to

Table 1.

Comparative characteristics of different sets of principles of ethics of artificial intelligence

Principles	Source of the body of principles				
	JSAI [35]	Atomium – EISMD [3]	Capgemini [6]	Google [36]	ABD*) [37]
Equality and fairness	+	+	+	+	+
Benefit, harmlessness	+	+		+	+
Respect for cultural diversity and pluralism	+				+
Non–discrimination and lack of stigma	+	+	+	+	+
Individual responsibility and accountability	+	+	+	+	
Autonomy and consent		+			
Confidentiality, respect for privacy	+	+		+	+
Data protection and control of their use	+	+		+	+
Promoting public understanding of AI	+				
Good faith	+			+	
Social responsibility	+				
High skill, self–development	+			+	

*) Big Data Association and Internet Development Institute

conclude that two categories can be distinguished as the key principles of artificial intelligence ethics that commercial companies need to comply with:

- category "trust": fairness, reliability, transparency, accountability, explainability;
- compliance category: data protection, data control, confidentiality.

Organizational measures taken by business to ensure adherence to these principles also play a significant role in improving the customer experience. Examples are the development of joint industry regulation and self-regulation in AI, the development and implementation of moral values for the company, and the definition for the degree of transparency of artificial intelligence functioning in advertising, marketing, sales and after-sales management systems.

4. Methods to reduce negative customer experience of interaction with artificial intelligence

The ethical use of AI increases customer loyalty, trust and sales. Unethical behavior can lead to reputational risks, court trials, and the loss of up to 30% of clients [6].

To improve the customer experience with AI technologies, it is important to ensure that the above categories of principles are adhered to, and enable people to help the company to improve the algorithms and methods for using artificial intelligence. In this way, the company will demonstrate adherence to the basic principles of AI ethics.

One of the main ways to increase the degree of trust when interacting with artificial intelligence is to inform the client about the fact that he or she is communicating with a robot. It is important to note that it is advisable to convey this information at the end of the communication process, when a person has placed an order, or submitted an application complaint that has been processed, or even a decision has already been made. Thus, the company adheres to ethical standards to ensure transparency in the use of AI in communication, and also allows the client to have a positive experience of communicating with the machine. If the client is informed about this at the beginning of communication, there is a high probability of interruption of this contact at the initiative of the client [21]. Because of this, the company loses customer loyalty, and the client, in turn, will not be able to form his own opinion (possibly positive) about the functioning of the robot.

Another tool is to inform the client about the algorithm for generating proposals for him. As a rule, this is done on demand, rather than being imposed on every person on a regular basis. For example, the special option "Why do I see this?" in Facebook shows the criteria that worked for the selection of personalized advertising [22]. Also, at the request of the user, a newsletter can be created which provides information about the digital policy, the data used, the purpose of collection and processing the data, risks, results of verification for compliance with the company's ethical principles. In this way, the principles of explainability and accountability are adhered to, and the user's trust in Facebook is maintained.

If a company does not disclose the algorithm for forming an individual price for a product or service, personal discounts and promotional offers, then there is a feeling of deception or discrimination. Today there are already many examples of such unethical use of AI. As an example, the insurance company Allstate in Maryland can be mentioned, which formed the cost of insurance depending on the client's ability to pay. To estimate this ability, the company was referring to external sources of information [18]. Such secret behavior is already alarming the buyer today.

Therefore, similar to the disclosure of financial statements, public companies should make publicly available the information about the data they collect and the policy of their use by AI systems. This will ensure compliance with the principles of transparency and accountability. At the same time it will ensure the protection of trade secrets, since details are not disclosed, and information of general nature is provided instead.

It is also advisable to use open source tools that reveal bias and discrimination in artificial intelligence algorithms. An example is AI Fairness 360 (AIF360), a set of tools that provides the means for identifying and eliminating bias in machine learning models [39]. Such mechanisms allow the company to follow ethical principles, tactical and strategic goals. An example is the practice of identifying and reducing the age discrimination when issuing a loan from German Credit using a solution from IBM [40].

The General Data Protection Regulation (GDPR) of the European Union provides for reporting on the applied AI algorithms to ensure compliance with individual rights and systemic co-management [41]. This includes a Data Protection Impact Assessment (DPIA). When this assessment is executed in accordance with the concept of "multilevel explanation" [42] of algorithmic systems, it makes possible to ensure the implementation of client rights to explain the principle of functioning of the AI with which they interact.

In addition, it is important to communicate information about AI to customers in such a way that people understand it, can appreciate the importance and safety of collecting information about them. It is also recommended to inform clients about the risks that accompany the operation of systems based on artificial intelligence, about possible misuse or incorrect interpretation of the received data.

Hence, another method of increasing the client's confidence follows – the transfer to the client of part of the functions to control and manage the area of functioning of the artificial intelligence system. The participant in the interaction should be able to ask for help from a real employee of the company, or report incorrect actions of the robot. Moreover, this option must be known to him and easily accessible. The client can be delegated the authority to determine the categories of personal data available to AI for processing, as well as the list of online services that he would like to receive in the course of contact with the company. For example, in the Beeline company [43] as a criterion for ethical behavior, the client's ability to indicate the level of personalization of interaction is highlighted. This allows a person to feel that he or she is in control of the conditions of interaction and feel the informational security.

A person will become more confident in artificial intelligence if the corresponding system will provide up-to-date statistics on successfully completed work, as well as demonstrate the connection of its recommendations with the goals of the person it interacts with [44]. Here, different indicators of productivity and effectiveness can be defined, for example, the number of customers satisfied with the service with a particular robot, the proportion of successfully solved problems, or the average processing time of application.

The afore-mentioned methods are aimed at forming trust, almost partnership relations between the company and its customers. Their implementation may not achieve the desired effects if these actions are only formal and do not become an element of the corporate culture of the company. In ensuring flexibility and openness in building relationships with customers, especially when it comes to the use of artificial intelligence, an

important role is played by the digital culture which should be formed and developed in the company [45]. The organization must create conditions for the development of ethical thinking among its employees, so that they want to act correctly at all stages of creating and managing an artificial intelligence system. Such events are mainly aimed at creating an atmosphere of effective and ethical use of advanced information technologies. But it is above all to strengthen the client's trust that they shall be convincingly demonstrated in the external environment. It seems expedient to inform the public about the principles and methods of developing the corporate culture, about the goals that the company wants to achieve in this direction, and what steps it is taking for this. It is also important to show the client that this is not only a declaration of intent, but also a real action. An example for such a real action is the active use of benchmarking and conducting research in this area, employee training and creating internal centers of excellence for ethics, and also participating in various communities and associations dealing with AI ethics.

Despite the fact that the goal of introducing such technologies is to reduce personnel costs, in order to form trust relationships at the first stage of AI implementation, as part of the after-sales service process, a company employee must contact the client and inquire about his experience. One of the tasks of such a contact will be to demonstrate to the client the intentions to provide him with the comfort and safety of interacting with the AI, taking into account his doubts and wishes.

The application of the proposed list of methods and approaches to improving the interaction with AI allows almost any organization to comply with key ethical principles and thereby preserve the client's trust in the company.

Conclusion

With the active use of AI technologies in the organization and implementation of processes of promotion, sales and after-sales service, the problem arises of ensuring a positive customer experience. This is due to the fact that many people fear and distrust robots and artificial intelligence. In order to reduce negative attitudes towards such systems, it is important to convey to the client the ethical application of these solutions, to ensure the transparency and accountability of their operation.

This article considers the main areas of application of artificial intelligence technologies in the processes of interaction with the client. The necessity is demonstrated for defining and formulating the ethical principles for the development, implementation and application of AI in practice. The analysis of recommendations of international and local expert commissions, scientific research and leading IT companies allows formulating two categories of basic principles of artificial intelligence ethics which are recommended to be followed by commercial organizations.

These principles, scientific and practical experiments and the experience of companies that are actively using AI technologies represent the basis for key methods of improving the customer experience of interacting with IT solutions.

The guidelines presented in this article may be useful for organizations planning or already using AI-powered systems. The results obtained can also serve as a starting point for further research. For example, it is interesting to identify changes in the significance of certain ethical principles depending on the industry affiliation of the company, as well as to study the impact of each of the described methods on changing the trust in AI of clients of Russian companies. ■

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IoT systems in the process of multidisciplinary training of personnel for the digital economy and their design

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Abstract

In the context of digitalization of the most knowledge-intensive sectors of the domestic economy, the development of an industrial training system in the field of electronic instrumentation is of great importance. The key areas of its development with the use of information and communication technologies include the development and improvement of the technological basis for training and retraining of personnel in engineering educational programs. One of the elements of this basis is the service of multi-user remote access via the internet to a high-tech experimental equipment laboratory as a service based on internet of things (IoT) systems. Within the framework of this service, an urgent problem is to increase the functional saturation of automated stands/installations, which is currently characterized by a paucity of scientific research. The purpose of the research is to expand the areas of experimental research carried out in the mode of multiuser remote access based on specialized IoT systems. As a result, a method of multidisciplinary application of specialized IoT systems was developed. This consists of the technical implementation of possibilities for additional research: research into technologies underlying both multi-user distributed measuring and control systems and IoT systems in general; research into technologies used in their end-to-end computer-aided design; research into

joint interaction of several geographically distributed automated stands/installations, implemented on the basis of a four level IoT reference architecture. A methodology for the design of multi-user distributed measuring and control systems as specialized IoT systems has also been developed, focused on solving multidisciplinary research problems in an interactive dialogue mode based on single sample of experimental equipment. The methodology mobilizes organizational, technical and methodological support for the process of creating such systems with specified target characteristics. In general, the method and methodology developed open up opportunities for systematically implementing the basic principles of the "Education 4.0" concept in the preparation and retraining of engineering personnel in the field of electronic instrumentation.

Key words: internet of things (IoT); IoT system; laboratory as a service; technical teaching tools; multiuser distributed measuring and control systems; design methodology.

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Introduction

The accelerated pace of digitization of various areas of human activity is reflected primarily in the meaningful, methodical and technological components of industry training systems (ITS). At the same time, a feature of the current situation in the world which imposes a number of restrictions on traditional approaches to education is the pandemic COVID-19 [1]. In these conditions, the relevance of the following current trends in ITS is increasing:

✦ system-based use in various types of information and communication technology (ICT) training;

✦ increased emphasis on personalization of learning, the introduction of flexible learning schedules and the abandonment of rigid binding of trainees to specific locations;

✦ modernization of the traditional infrastructure of educational institutions – the introduction of digital library systems, the widespread use of ICT tools and specialized systems for simultaneous lectures in many different locations for online and offline modes, the use of cyber-physical systems, as well as internet of things (IoT systems) systems, in particular, as means of conducting experiments in specialized distributed laboratories;

✦ ICT learning as a continuous process that accompanies a person throughout his life [2–10].

The Education 4.0 strategy highlights the following key aspects [11]:

✦ education on demand;

✦ personalization of education;

✦ learning at a convenient time anywhere;

✦ life-long learning.

The practical implementation of these aspects relies on the development and improvement of the ICT base for training and retraining in engineering education programs in the field of electronic instrumentation.

Thus, in the preparation and retraining of engineering personnel for the digital economy, the implementation of such aspects as "training at a convenient time anywhere" and "personalization of education" within digital educational environments are based on improving

the service of access to high-tech experimental equipment and modern specialized software – "laboratory as a service" [12–14]. This service allows trainees to perform in-kind and computational experimental research in remote access mode on the internet from any location. The relevance of the development of this service is associated with an increase in its efficiency. The main areas of service efficiency include increasing the capacity of laboratory equipment that is part of remote laboratories, as well as its functional saturation in terms of experimental research, both in the context of multidisciplinary and acquired in the course of training practices. Ways to solve the problem in terms of increasing the capacity of high-tech experimental equipment by the authors of this article have already been outlined in a number of works [14–15], and the approach to solving the problem of increasing the functional saturation of experimental equipment is the subject of this article.

1. Multidisciplinary use of remotely accessible experimental equipment

Remote laboratories are based on technical training tools (TTT) [16] developed using end-to-end digital technology, including internet of things technology [2–4, 17–19]. Other TTT include multiuser distributed measuring and control systems (DMCS) that implement high-tech equipment (measuring equipment, computing equipment, automated laboratory layouts/stands/installations) based on the concept of multi-tenancy [14]. The DMCS integration scheme into the IoT's four-tiered architecture is shown in *Figure 1* [20, 21].

The process of creating DMCS samples as relevant IoT systems is based on the integration of a whole pool of digital technologies, which in turn may be the subject of individual experimental studies in addition to targeted domain research determined by appropriate automated layouts/stands/installations (*Figure 1*). In addition, advanced design technologies for such IoT systems can also serve as a separate subject of laboratory research in the context of end-to-end cycles of automated design of both individual elements and these systems as a whole. Thus, the current technical means of training in the form of DMCS (as appropriate IoT systems) are characterized by the following areas of laboratory research:

✦ in-kind experimental research in the target subject area determined by a specific ALL or their totality (purpose of the DMCS);

✦ research into the technologies underlying the functioning of DMCS (in addition to the intended purpose);

✦ research into technologies used in the design of DMCS (addition to the intended purpose).

Each of these areas is characterized by a specific area of research and its own set of training practices in *Table 1.* For a more detailed analysis of the components of the experiment, *Table 1* introduces the following clarifications:

✦ a "learning experiment" is a natural experimental study provided by relevant training courses and/or discipline programs;

✦ the "scientific experiment" includes in-kind experimental studies aimed at obtaining information on new, previously unexplored processes and/or phenomena (as part of the educational process).

Taken together, these areas allow the appropriate DMCS to be used as TTT to develop multidisciplinary training courses. This, in turn, allows students to develop skills such as "systemic abilities," "cognitive abilities" and "solving complex problems" that are quite popular in the major sectors of the digital economy. In addition, a number of areas allow for contextual training, for example, in the field of research, such as end-to-end automated design technology. *Table 1.*

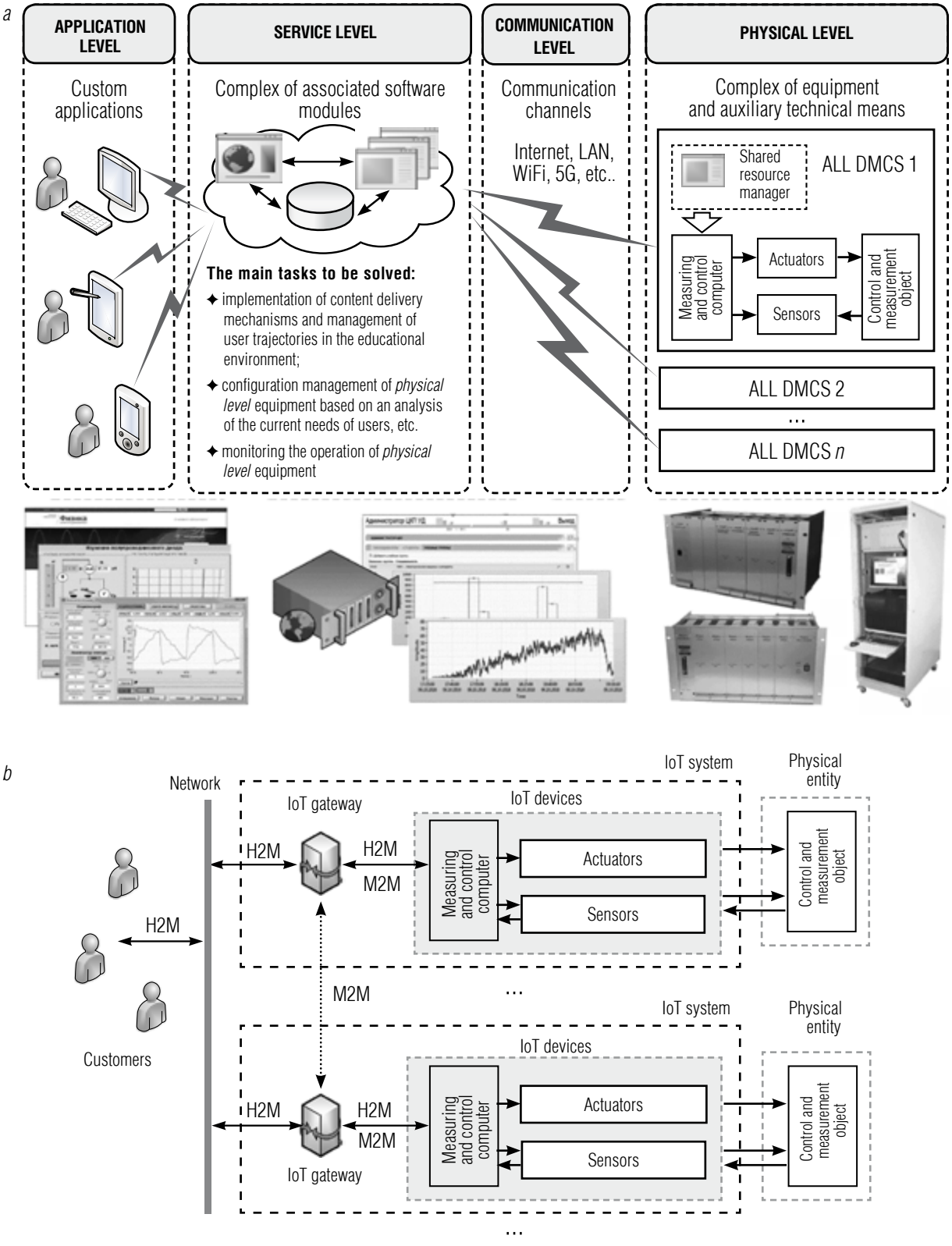

Fig. 1. DMCS as an IoT system with four–tier architecture:
a – IoT levels; *b* – DMCS as IoT system;
ALL – automated lab layout; H2M, M2M – how to organize an interaction (Human–to–Machine, Machine–to–Machine)

Table 1.

Directions of multidisciplinary research based on multiuser distributed measuring and control systems (DMCS)

No	Direction of research	Research area	Types of experimental research	Developed development/research practices
1.	The subject area defined by the TTT, as well as the properties of the DMCS as IoT systems as a whole	1.1. Physical processes or phenomena in individual functional nodes or electronic devices, as well as devices, complexes and electronic systems 1.2. Methods of organizing external (network) interaction between elements of IoT systems on the principle of M2M	Educational / Scientific	1. The use of modern information and communication technology tools to analyze the processes taking place in electronic devices. 2. Applying the principles of building IoT systems as one of the promising directions in instrumentation. 3. The use of DMCS to automate the educational and scientific experiment as a segment of the modern digital educational environment*). 4. The use of electronic pedagogy methods that improve the quality of engineering teaching*). 5. Managing individual educational trajectories in a digital educational environment*).
2.	The technologies behind the functioning of DMCS	2.1. Remote control of objects and processes over computing networks	Educational	The use of data technology in IoT systems
		2.2 Digital data technologies and protocols	Educational / Scientific	
		2.3. Statistical patterns of digital traffic transmission	Scientific	
		2.4. Operating principles and scheduling in DMCS as in interactive dialog systems (queueing systems)	Educational / Scientific	1. Applying query service disciplines with priorities in queueing systems. 2. Study of methods to increase the bandwidth of the DMCS as queueing systems. 3. The use of software to investigate the dynamics of the queueing systems.
		2.5. User behavior in ergatic (human–machine) systems	Scientific	Methods of formal description of the operator's patterns in human–machine systems.
		2.6 Functional GUI testing technologies	Educational / Scientific	Application of functional testing methods of the user GUI for human–machine systems (object control systems, virtual measuring systems, etc.)
		2.7. Methods for processing the results of experimental research	Educational	The use of specialized software for digital, statistical and other processing of experimental research results
		2.8. Computer measurement technology	Educational	The use of computer measurement technologies in the development of IoT systems

No	Direction of research	Research area	Types of experimental research	Developed development/research practices
3.	DMCS design technologies	3.1. End–to–end automated design technology / "Digital Twin"	Educational	1. Applying mathematical modeling techniques in the design process of IoT systems and cyber–physical systems in general 2. The use of methods of identification and verification of mathematical models of radio components in the process of researching electrical characteristics of electronic devices. 3. Applying methods to develop modern electronic design documentation. 4. Exploring the specifics of methodical support for end–to–end automated design of radio electronics based on CAE/CAD/CAM/PLM systems (conveyor, cyclical and iterative solution of design tasks based on specialized engineering procedures)
		3.2. Technology and tools for developing applied software (frontend / backend) of special–ized IoT systems	Educational	Application of technologies and tools for the development of applied software for automated systems (object management systems, virtual measuring systems, etc.)

*) Developing practices in the process of retraining teaching staff

As you know, the increasing functional complexity and cost of devices, complexes and systems make it difficult to properly equip training and research laboratories with modern samples as objects of appropriate experimental research [22–24]. At the same time, the use of the properties of DMCS, such as the IoT system (*Figure 1b*), namely the interaction of several DMCS, provides an opportunity to study on their basis several variants of the implementation of devices/complexes/systems in general. The organization of such research is as follows. Appropriate automated laboratory layouts which implement the variability of the performance of functional nodes/devices/complexes can be placed in one location and provide the possibility of connecting them at the physical level to organize their interaction, and can be distributed geographically across several locations. In this case, it is possible to "collect" them (to emulate the process of their joint operation) as part of a common device/complex/system at the service level (*Figure 1*) by organizing M2M interactions at the communication level. This type of interaction is realized by creating a digital "image" of relevant signals (digitization of their fragments) and then exchanging them between DMCS of different locations. In order to implement such interaction, certain instrument samples provide technical devices (means) to record digital counting of relevant signals and/or to generate signals on their digitized fragments.

As an example of such a system that implements this principle of interaction, *Figure 2* provides an example of an IoT supersystem structural scheme to ensure the process of training and retraining specialists for the aerospace industry. This system, based on the

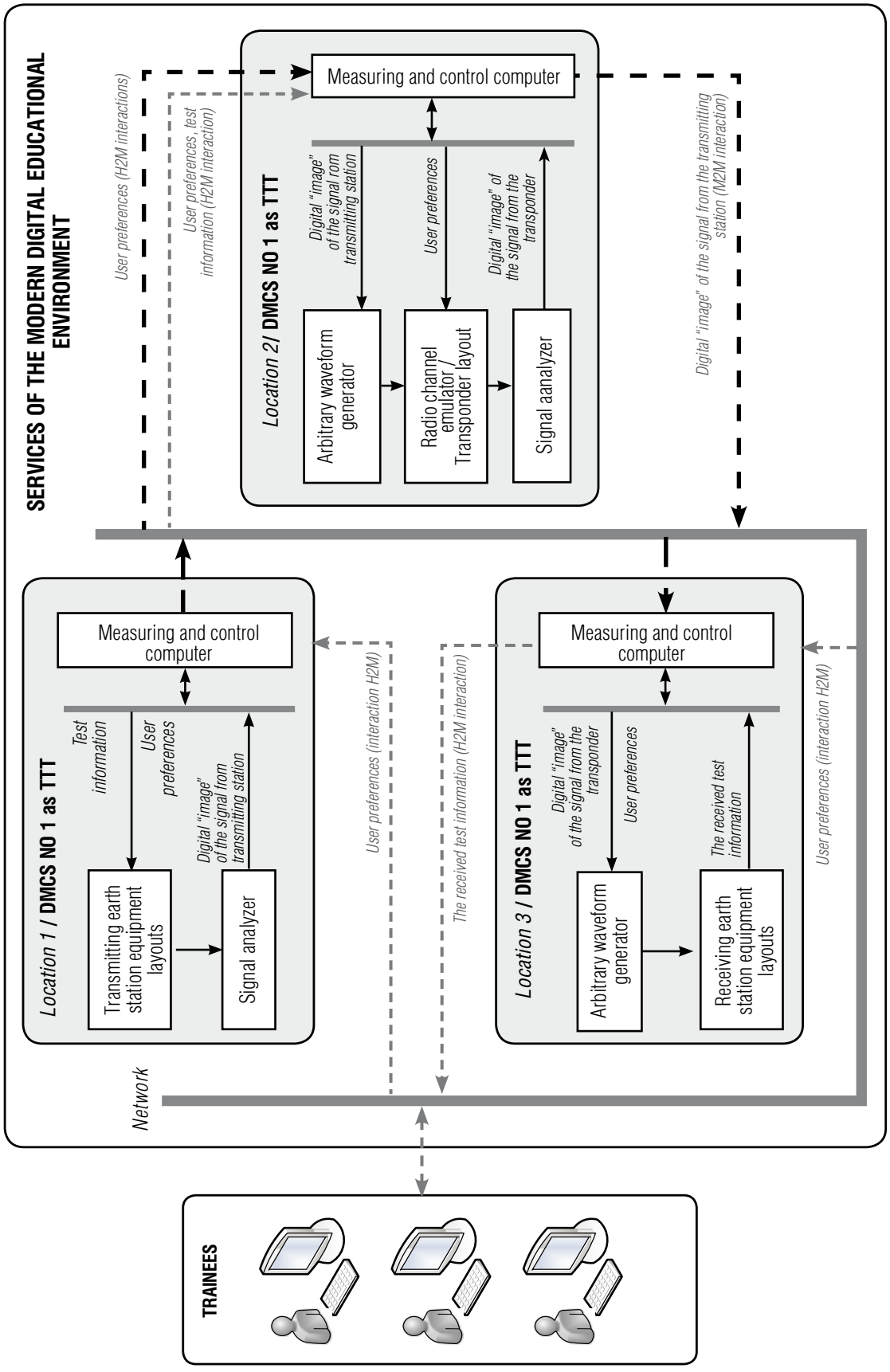

Fig. 2. An example of a research model of a satellite communications system in the form of an IoT supersystem, elements of which are individual instances of distributed location

combination of interactions H2M and M2M, implements a model of the satellite communication system through the on-board transponder of the satellite, elements of which are individual instances of distributed location DMCS.

As part of the experimental studies carried out on the basis of this system, the user is given the opportunity to form a high-frequency signal with specified parameters (the number of signals (carriers) in the band, the data transfer rate, the type of modulation used, etc.), for example, a fragment of a complex envelope which is digitized and transmitted over the computer network to location 2. In location 2, this signal is reproduced and sent to the entrance of the transponder or radio channel simulator, simulating the conditions of the signal passing in the space system, taking into account the uneven amplitude-frequency characteristics and group time delay of the transponder, the non-linearity of the amplitude characteristics of its amplifier, phase noise heterodyne and etc. A digitized signal fragment from the transponder is transmitted over the computer network to location 3. Using technical means in location 3, on the basis of the received digital "image," a signal can be formed at the entrance of the models of the equipment of the receiving station to assess the possibility of its detection, reception, processing, etc., or to evaluate the generalized qualitative characteristics of the communication system under study (bit error rate, error vector magnitude, etc.) [25].

It should also be noted that under this approach, the equipment layouts located in locations 1–3 continue to be subjects of full-fledged experimental research for each training site conducted as part of the relevant training courses.

Consider the systematic areas of experimental research in *Table 1*. The implementation of the research in accordance with items 2.1–2.2, 2.6 is based on the creation of a sample of the DMSC in the form of an open platform (with open software interfaces). Using this platform, the trainee can test and conduct functional testing of the self-developed and created user GUI to remotely control the automated laboratory layout on the basis of A pair of communication channels based on a personal computer, smartphone, laptop [26, 27] (using various software technologies and communication protocols based on various operating systems), as well as experimentally test the developed scheduling algorithms.

The study of statistical patterns and dynamics of the functioning of the DMCS as a queueing system (items 2.3–2.5) is carried out through processing the relevant statistical data. Such a given moment in time of sending and receiving the results of their implementation, the moment of arrival, beginning and end of the task on the measuring and control computer, the duration of the functional operations performed and other operations. Such data can be obtained during the operation of the DMCS, for example, by using the developed and tested software of the module which provides measurement and their centralized accumulation and storage [14].

Thus, the information content of DMCS as a TTT and their further multidisciplinary application within the designated areas should be laid down at the design stage through their implementation based on a pool of modern technologies, as well as using a scientific approach to their creation using modern computer-aided design tools. This approach should ensure the harmonization of the functional user tasks to be solved (in the corresponding subject area of ALL and the planned areas of interdisciplinary application) and the required technical characteristics of functioning as a queueing systems (average response time to user requests, the number of concurrent users, etc.).

2. Methodology for designing DMCS as specialized IoT systems

Based on the results of the research, a subject-oriented methodology for designing DMCS was developed, combining both well-known [28] and newly developed approaches:

✦ methods of increasing the efficiency of functioning (method of optimizing control operations, method of time division of multiple measurements, method of parallelizing functional operations);

✦ mathematical models of the dynamics of functioning, taking into account the heterogeneity of the behavior and service of users, the variability of the implemented scheduling algorithms, the dependence of the durations of the performed functional measurement and control operations on the parametric and functional content of tasks, etc., as well as adaptable software modules that implement them;

✦ procedures for solving particular design problems (designing hardware and software forming the boundary parameters of the dialogue scenario, calculating parametric sensitivity functions, etc.), which provide solutions to design problems in a formalized form;

✦ a set of technical solutions (a set of basic structures for hardware construction of DMCS, algorithms for scheduling a shared resource, algorithms for spectral measurement of signal parameters and software modules that implement them, basic unified virtual devices, basic design templates for a graphical user interface).

A generalized block diagram of the methodology is shown in *Figure 3*. Based on the built interaction of the components of the methodology and the complex application of modern computer-aided design tools within the DMCS design procedure as a specialized IoT system, a design solution with improved technical level indicators is sought. Additionally, in order to provide information support for the design process, the informational composition of the knowledge base of engineering solutions, accumulating and realizing the possibility of applying the experience of previous developments, is proposed.

The design results in the form of sets of electronic software and design documentation, the results of the analysis of various characteristics of DMCS, etc. are integrated as part of an interactive electronic technical manual [29]. Interactive electronic technical manual for corresponding samples of DMCS are also an auxiliary element of the educational process in the framework of the implementation of practices in the field of end-to-end computer-aided design technology. Maintenance of the process of pilot/industrial operation of industrial designs of DMCS is carried out on the basis of the proposed procedure for adapting to changing operating conditions (increase in the number of users, variability of users' thinking time, deployment of new access locations, etc.) [14].

Practical application of the proposed methodology and procedure for adapting DMCS helped to reduce the time of their design by 20–30%, allowed 3 to 6 times to expand the set of alternative design solutions synthesized in accordance with the specified requirements of the technical task, to increase in some cases the number of simultaneously served user terminals by 30% or more, as well as to create a number of industrial designs of DMCS in order to provide resources for the processes of field experimental studies of both ITS and production activities. The proposed methodology, in combination with the procedure for adaptation, makes it possible to ensure the effective use of DMCS as part of the "laboratory as a service" service while minimizing the cost of hardware and software through the implementation of the multi-tenancy concept. The high efficiency of such a service, implemented on the basis of DMCS, contributes to the wide possibilities of using the methods of electronic pedagogy in the preparation and retraining of engineering personnel for the digital economy.

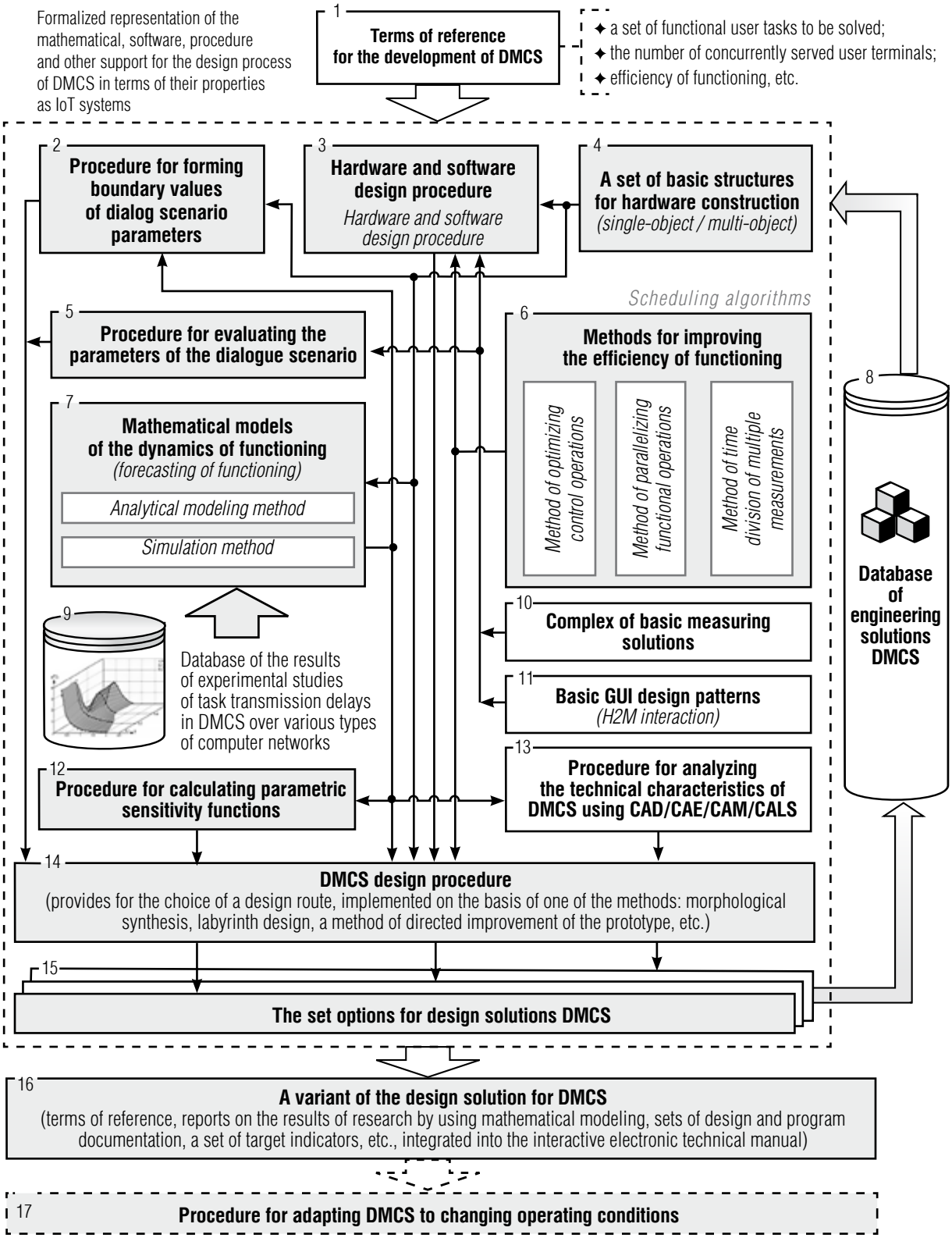

Fig. 3. Methodology for designing DMCS with specified technical characteristics:
blocks 2–7, 9–11 – solving design problems in research areas according to the items 2.1–2.8 of *Table 1*;
blocks 3, 8, 11, 13, 14, 16, 17 – solving design problems in research areas according to the items 3.1, 3.2 of *Table 1*

The "laboratory as a service" service allows several educational institutions or training centers (as operating organizations) to move from the deployment and maintenance of high-tech experimental equipment to its temporary lease and remote access via the internet (implementation of the economic model of sharing economy) [12–15, 30].

Conclusion

The directions of multidisciplinary research considered and the proposed approach to their implementation on the basis of DMCS are provided due to the following factors:

✦ a wide range of experimental laboratory studies as part of modern educational environments, allowing students to study various aspects of IoT systems (principles of operation, design methods, purpose), taking into account the key aspects of the Education 4.0 strategy and the development directions of electronic instrumentation;

✦ the development of students in the process of educational and scientific experiments, practices focused on solving a wide range of tasks in the field of digitalization of various spheres of human activity;

✦ development of students' skills within the framework of professional competencies, such as "systemic abilities," "cognitive abilities" and "solving complex problems" which are in demand in the main sectors of the digital economy;

✦ development of DMCS samples with specified characteristics (number of served users, response time) due to interrelated components of a domain-specific methodology which include the proposed methods, models, procedures and specialized software, and also ensure the effective use of modern computer-aided design systems;

✦ increasing the efficiency and functionality of the "laboratory as a service" service for the processes of training and retraining of personnel in the field of electronic instrumentation based on the methods of electronic pedagogy. ■

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The problem of loss of solutions in the task of searching similar documents: Applying terminology in the construction of a corpus vector model

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Abstract

This article considers the problem of finding text documents similar in meaning in the corpus. We investigate a problem arising when developing applied intelligent information systems that is non-detection of a part of solutions by the TF-IDF algorithm: one can lose some document pairs that are similar according to human assessment, but receive a low similarity assessment from the program. A modification of the algorithm, with the replacement of the complete vocabulary with a vocabulary of specific terms is proposed. The addition of thesauri when building a corpus vector model based on a ranking function has not been previously investigated; the use of thesauri has so far been studied only to improve topic models. The purpose of this work is to improve the quality of the solution by minimizing the loss of its significant part and not adding "false similar" pairs of documents. The improvement is provided by the use of a vocabulary of specific terms extracted from the text of the analyzed documents when calculating the TF-IDF values for corpus vector representation. The experiment was carried out on two corpora of structured normative and technical documents united by a subject: state standards related to information technology and to the field of railways.

The glossary of specific terms was compiled by automatic analysis of the text of the documents under consideration, and rule-based NER methods were used. It was demonstrated that the calculation of TF-IDF based on the terminology vocabulary gives more relevant results for the problem under study, which confirmed the hypothesis put forward. The proposed method is less dependent on the shortcomings of the text layer (such as recognition errors) than the calculation of the documents' proximity using the complete vocabulary of the corpus. We determined the factors that can affect the quality of the decision: the way of compiling a terminology vocabulary, the choice of the range of *n*-grams for the vocabulary, the correctness of the wording of specific terms and the validity of their inclusion in the glossary of the document. The findings can be used to solve applied problems related to the search for documents that are close in meaning, such as semantic search, taking into account the subject area, corporate search in multi-user mode, detection of hidden plagiarism, identification of contradictions in a collection of documents, determination of novelty in documents when building a knowledge base.

Key words: similarity of documents; semantic proximity; thesauri application; corpus vector model; applied intelligent information systems; algorithm explainability; similarity evaluation; text mining.

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Introduction

Among the tasks that distinguish intelligent applied information systems from systems for automating business processes, there is the task of discovering insights in a large amount of information, in particular, in a company's text documents. One of the goals is to find documents that are "close in meaning." To solve this problem, a semantic model of a text corpus is built within which the similarity of documents is defined as the distance between the vector representation of documents.

One of the problems is the possible partial loss of pairs of documents that are similar in human opinion but do not satisfy the condition of exceeding the similarity threshold value set in the applied intelligent information system. This leads to the task of detecting that part of the results that do not show a sufficient degree of similarity with the existing methods, but must be taken into account from the point of view of an expert who uses the system ("true similar" pairs of documents).

When calculating the vector model of the corpus of text documents, different vocabularies are used, and their characteristics and limitations affect the quality of the solution. In particular, focus of the vocabulary on the subject area of the corpus, the proportion of frequently used and rare words, the choice of the *n*-gram range and other parameters have an impact.

It should be noted that if the vocabulary is expanded too much or the similarity threshold is reduced too much in order to include the specified "true similar" pairs of documents in the set of solutions, then the result again deteriorates. This happens because together with the return of the lost part the solutions also include unnecessary, "false similar" pairs that reveal proximity due to an insignificant part of the vocabulary (words with low weight for semantics within the given corpus). One of the methods that allows us to achieve a balance

between the inclusion of unnecessary pairs of documents in the solution and the loss of a significant part of the results is the use of thesauri of the subject area when constructing a text corpus model.

Many applied problems require calculation of similarity indicators between text samples and their constituent parts – paragraphs or sentences. The most obvious example is when a user searches for information in the system and the search engine compares the query text with the texts of previously saved documents in order to find the most relevant document. The user's query is a short text, and the system displays the documents that are most similar to the query using the ranking function.

In addition to the semantic search components, the content similarity of documents is used in the following IT solutions:

- ✦ a recommendation system for authors that determines the most suitable journal for publication;
- ✦ incoming requests routing system that selects an expert in accordance with the documents previously processed by him;
- ✦ software for building project teams for a specific technical task;
- ✦ EDMS for determining an approval route for the document based on its content.

To construct a similarity matrix, it is necessary to use a vector representation of documents, which can be created using the TF-IDF statistical measure, which is often used as a ranking function. To calculate the TF-IDF values, the entire vocabulary of the corpus is taken into account; therefore, common vocabulary may have a dominant influence on the document similarity, while the industry specificity of documents may be lost. So there arises an additional task to identify documents that are close in meaning due to specific terminology. Modification of the method can be made by changing the set of terms which are used to determine the similarity of documents. In particular, the quantity and accuracy of the results obtained can be improved by adding the domain thesaurus to the algorithm for calculating the ranking function.

This modification of the algorithm improves the quality of recommendations in information systems and accelerates user decision-making. This is done by increasing the explainability of the algorithm, which is, reducing the time that the user needs to understand why the system recommends to him some pair of documents as similar [1]. Ultimately, this improvement contributes to the growth of user confidence in the system's recommendations and simplifies his analytical work with text documents, e.g. searching for information in corporate sources, checking for duplicates in the database, detecting intersections and inconsistencies. All of this together leads to a reduction in time spent by an employee to process large volumes of text data.

The aim of this work is to improve the model based on ranking function by using a vocabulary of domain-specific terms as a thesaurus. The authors focused on the corpora of structured text documents in a specific subject area. Such documents, for example, include the regulatory and technical base of organizations [2], income and expense contracts, CVs of candidates, state standards and many others. The applied problem of finding documents with similar meaning in the text corpus was considered.

The problem of the loss of a part of the solution was investigated when calculating the proximity of documents using a ranking function. The core of this problem is that some pairs of documents are similar according to human assessment, but the program does not define them as such, since they show a low degree of similarity according to the TF-IDF algorithm, even taking into account the optimization of the vocabulary by removing the most frequent and rare words. In practice, such a problem arises in the development of applied intelligent information systems: there is a task to find in

the corpus all documents that are close enough in meaning, i.e. those whose degree of similarity exceeds a certain threshold and, therefore, is significant for the user. This paper proposes a modification of the existing methods for calculating the proximity of documents using ranking functions, thereby avoiding the loss of the specified part of the results.

The hypothesis of the research is the following: when searching in a text corpus for pairs of documents similar in meaning and using the TF-IDF ranking function for calculating proximity, the part of the solution that is lost if vector representation is made with the complete corpus vocabulary can be found when constructing a vector model based on the vocabulary of specific terms from subject area. *Figure 1* shows the hypothesis schematically.

This article includes an overview of the available research in the field of thesauri applicability and the problems of their construction, a description of research methods and experimental confirmation of the research hypothesis, as well as an analysis of the results obtained.

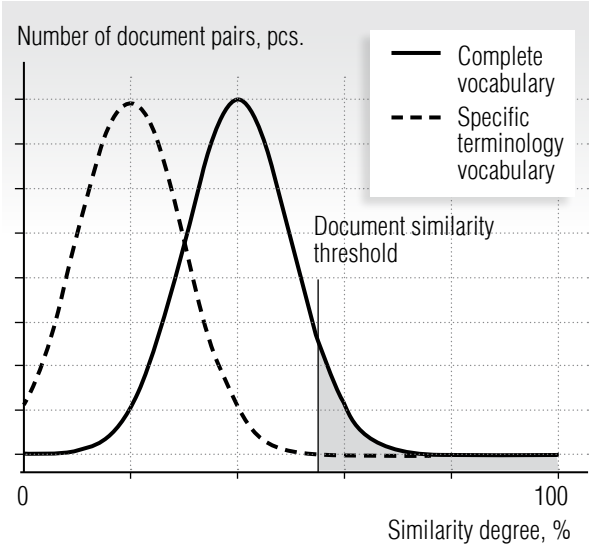

Fig. 1. Expected shift in the distribution of the degree of document similarity when replacing the complete vocabulary in the TF–IDF algorithm with a vocabulary of domain–specific terms

1. Using thesauri

For decades, computational linguistics investigated the possibility of using thesauri in text analysis to identify semantic relationships in the corpus, since the dictionaries of definitions of terms and concepts created by experts have high semantic accuracy.

The first methods proposed in the 1970s and 1980s were aimed at creating semantic language models through the analysis of computer dictionaries, which were considered as sources of taxonomic relations "hyponym – hyperonym." To extract relations from dictionaries, rule-based algorithms were used [3, 4]. The advantage of these methods was that they extracted semantic relations from reliable sources, which can be considered already partially structured, since dictionaries work as "implicit taxonomies." However, these methods inherited the problems of lexicographic data associated both with the unreliability of data due to incorrect updating of sources, and with incompleteness of dictionaries, since even today they are not always corpus.

Many studies have shown interest in finding co-hyponymic relationships, i.e. identifying groups of words that are defined using the same hyperonym, such as types of systems, equipment, nets [5, 6]. Such words are considered paradigmatically related. This means that they tend to repeat in similar syntagmatic contexts and presumably have common semantic features.

Another strategy for identifying semantic relations in the corpus is to create a language model based on the statistical analysis of texts without using any previously obtained knowledge about the dictionary relations. In [7], in order to identify pairs of hyponyms and hyperonyms, a directed graph of the coincidence of terms is constructed, and if terms are too rare, a bias is introduced into the frequency distribution: an analogy relation between hyponyms is introduced based on the composition and mor-

phological features of terms. For example, if it is statistically found that Asperger's syndrome and Carpenter's syndrome (hyponyms) are diseases (hyperonyms), then the term "Meretoya's syndrome" has the same hyperonym "disease"; the word "arthritis" can also be referred to it by analogy with "gastritis." The authors of [8] combined both strategies to create hypernymic chains using approaches based on distributive semantics.

A potential limitation of quantitative methods is the lack of accuracy, but this disadvantage can be overcome by increasing the volume of linguistic data. Therefore, this approach is considered effective and is quite popular. In addition, being language independent, it can be easily replicated and used to create multilingual resources.

Within the framework of the statistical approach, to solve many applied problems vector models of the document corpus are constructed based on ranking functions. The frequently used ranking function is TF-IDF, which is based on two concepts: the frequency of occurrence of a word (term) in a document (term frequency, TF) and the importance of this word for the entire set of documents – the inverse frequency of occurrence of a word in all documents of the corpus (inverse document frequency, IDF). This method was proposed in the 1970s [9–12] and is still widely used to analyze the similarity of texts, since it allows them to preserve certain features when projecting text data onto a numerical space. Similarity measurement can be done by calculating the proximity between TF-IDF vectors, for example in a cosine measure. The principle of comparison using TF-IDF can be called "word-by-word," since the number of components in the sparse TF-IDF vector corresponds to the number of terms in the vocabulary. However, the set of terms that determine the similarity of a document pair is formed by frequency discrimination, but not by the content analysis of these documents. TF-IDF ranking is used in various applications such as document clustering [13–16] and topic modeling [17, 18].

The use of thesauri in the text corpus analysis by the distributive semantics methods has been considered in a number of studies. In particular, various authors investigated the problem of working with the thesaurus at one of the steps of the text search algorithm. For example, the article [19] describes an approach to automatic indexing of abstracts using a subject area thesaurus. The authors of [20] presented a method for automatically extracting key phrases using semantic information about terms and phrases collected from a domain-specific thesaurus. In [21], a polythematic (i.e. covering many subjects) thesaurus is used for the purposes of semantic comparison of concepts.

A noticeable number of studies are devoted to improving the parameters of topic vector models of the corpus, in which the vector representation of documents is made on a set of topics identified as a result of text analysis on the entire corpus. For example, in [22], the improvement of the topic model is performed by artificially increasing the coincidence of synonyms, and the authors of [23] introduce information about synonyms into the prior Dirichlet distribution in order to enhance the coherence of the topics. The work [24] proposed such a concept as Thesaurus-Based Topic Model and compared various topic models. All of the above studies are united by the general result of the experiments: the elimination of hyponyms and an increase in the frequency of phrases improves human evaluation of the quality of the topics obtained, since this method gives more weight to more specific words and phrases that are better defined.

At the same time, the possibility of using thesauri to improve the semantic model of the text corpus, in which a proximity matrix is built on the basis of a ranking function (such as TF-IDF), has not yet been sufficiently studied.

2. Building thesauri

As defined by the International Organization for Standardization (ISO), a thesaurus is a vocabulary formally organized in order to establish explicit a priori relationships between concepts[1]. The elements of the thesaurus are lexical units and semantic relations (connections) between them. Thesaurus relations (genus – species, part – whole, complex – element, cause – effect) are imposed on the taxonomy structure, i.e. they are identified as the main taxonomies of the subject area.

The methodology for creating thesauri is defined in the Russian state standard "GOST R ISO 704-2010 Terminological work. Principles and methods" [25]. Historically, thesauri were created to manually index documents and were not meant for automatic indexing. The difficulty of constructing a thesaurus corresponding to the entire topic variety of indexed information makes the thesaurus a self-sufficient information product, but at the same time it is the main reason for unpopularity of thesauri in modern information systems.

As an outstanding example of specialized thesauri, the Russian thesaurus in the field of agriculture created by the Central Scientific Agricultural Library of Russia should be noted [26]. The thesaurus is built as an extension of the Russian GRNTI dictionary-classifier (state rubricator of scientific and technical information).

Labor intensity of the manual thesaurus compilation and the resulting problems can be seen on the example of such regulatory and technical documents as state standards (which are named particularly in Russia as "GOSTs"). Most of them are accompanied by a thesaurus – a section describing terms and definitions. Organizations responsible for the development of industry standards are faced with the fact that in different documents there are contradictions such as conflicting definitions of the same terms, different names for the same concept, or conflicts between the normative values of indicators. The reason for this phenomenon is that the GOST database consists of hundreds of thousands of documents and it has been accumulating over many decades. At the same time, due to the limited search capabilities, some statements of the standards were often duplicated, turning over time into contradictions due to the updating of documents without taking into account their topic links with others.

Example 1. Consider the various definitions and names of the concept of "acoustic (noise protection) screen" available in different regulatory and technical documents[2]:

1. GOST R 51943-2002. Acoustic screens for protection against traffic noise. Methods for experimental evaluation of efficiency (2002): "**Acoustic screen, screen:** Barrier (limited obstacle) installed in the path of the propagation of noise from a real source to the object to be protected from noise".

2. GOST 32957-2014. Automobile roads for general use. Acoustic screens. Technical requirements (2014): "**Acoustic screen**: An artificial barrier installed in the path of noise propagation from road transport to the object to be protected from noise. A typical acoustic baffle is a prefabricated structure consisting of the following main parts: a foundation (if provided for by the design documentation), a supporting structure (in particular, support posts) and panels. Seals, transverse profiled beams, fasteners, acoustic interconnections, canopies, wickets, gates, frames of breaks, etc. are used as additional elements".

3. GOST 33329-2015. Acoustic screens for railway transport. Technical requirements (2015): "**Acoustic screen**: An extended artificial barrier installed in the path of noise propagation from a real source (railway transport) to an object protected from noise".

[1] https://www.iso.org/standard/53657.html
[2] Translation from Russian

4. SP 338.1325800.2018. Noise protection for high speed rail lines. Design and construction rules (2018): "**Soundproof (acoustic) screen (screen)**; SS: Structures in the form of vertical or inclined extended artificial barriers of various designs, earth embankments, excavations, galleries, etc., installed along the railways on the path of traffic noise propagation to the protected object in order to reduce noise".

5. ODM 218.8.011-2018. Methodological recommendations for determining the characteristics and selection of noise protection structures for highways (2018): "**Noise protection screen (NPS)**: An extended artificial barrier installed on the path of noise propagation from road transport to an object protected from noise, the width (or thickness) of which is much less than its height consisting of a foundation and a soundproofing sheet fixed on it".

To avoid the influence of the indicated disadvantages of manually compiled thesauri on the results of searching for similar documents in applied information systems, it is necessary to use automatic methods of forming terminological dictionaries for the corpus of documents.

Existing pattern-based approaches to the extraction of semantic relations, similar to those described in the previous paragraph, are used in the field of computational terminology. For example, in [27], extraction methods are described that are focused on identifying the relations hyponym – hyperonym (particular and generalization), meronym – holonym (a part and a whole), synonyms and cause-and-effect relationships, which are collectively used to define terms and their relationships in within the data fusion pipeline approach. However, computational terminology focuses mainly on the study of the patterns of semantic relations themselves, their description, interpretation and formalization of their linguistic properties, as well as on the analysis of patterns beyond the limits of their detection. But for the problem under consideration, it is sufficient to obtain a set of specific terms that are used in the investigated corpus of documents without taking into account the semantic relationships of these terms.

3. Methods

To test the formulated hypothesis, an experiment was carried out to compare the results of solving the problem of searching for similar documents in the corpus obtained by two methods: the basic TF-IDF and its modification using the thesaurus.

In this study we considered a set of N_D structured text documents in Russian united by a subject.

As a thesaurus (as the most accessible its option), we used a dictionary T which is a vocabulary of specific terms of the subject area, obtained as a result of automatic texts analysis of the documents. To do this, all documents from the set were processed by the rule-based NER algorithm, which extracted terms from the special section of each document, where specific terms used and their descriptions are listed. Then all the obtained terms were aggregated in the domain terms vocabulary specific to this corpus.

The vocabulary included only terms consisting of one or two words. Words were brought to normal form, information about morphological features was added, numbers and English symbols were excluded.

The documents were converted to the following text format: a set of documents is presented as an array of strings M, in which one line corresponds to one document and the sequence of words was preserved.

To obtain the $\mathbf{S}_{TFIDF}$ matrix containing degrees of "word-by-word" similarity between text documents of the M corpus, the vector transformation TF-IDF was used in several variants, differing in vocabulary:

✦ All words from the corpus of documents were used as a vocabulary. Several options for constructing a complete vocabulary were con-

sidered, depending on the threshold frequency of word use within the entire corpus: if a word was encountered less than a certain number of times (parameter df_{min}), then it was excluded from the vocabulary;

✦ The vocabulary consisted of the set of specific terms *T*.

As a result, for each array, five variants of the $\mathbf{A}_{TFIDF}$ matrix of the "documents – terms" type were obtained with the dimension $N_D \times N_T$ (the number of words in the vocabulary). The vector proximity matrix (containing the degree of document similarity) $\mathbf{S}_{TFIDF}$ was calculated by the formula:

$$\mathbf{S}_{TFIDF} = \mathbf{A}_{TFIDF} \times \mathbf{A}^{T}_{TFIDF}.$$

Using the $\mathbf{A}_{TFIDF}$ matrix formed by a set of specific terms, a knowledge graph $\mathbf{G}_{TFIDF}$ for the text document corpus was built. The vertices of the graph (documents and terms) were connected by edges if the TF-IDF value for the corresponding document – term pair was higher than the threshold (the edge weight is equal to the corresponding value in the $\mathbf{A}_{TFIDF}$ matrix).

4. Experiment results

For the experiment, a set of normative documents from the GOST library was selected: $N_{D\_IT} = 667$ documents in docx format related to the field of information technology. After processing the documents in accordance with the selected methodology, an array of M_{IT} text strings was obtained. $T_{IT} = 4417$ terms were extracted from the text of the documents.

The calculation results for information technology documents are shown in *Figure 2*.

Table 1 shows the values of the mathematical expectation and standard deviation of the similarity degree of documents of pairs from M_{IT}.

The experiment confirmed the hypothesis put forward: replacing the general vocabulary with a set of specific terms in the algorithm based on the ranking function increases the number of solutions found. It can be seen from the graphs presented and from the data in the table that a model built on specific terms determines a larger number of similar documents pairs, and exclusion of words rarely found within the corpus do

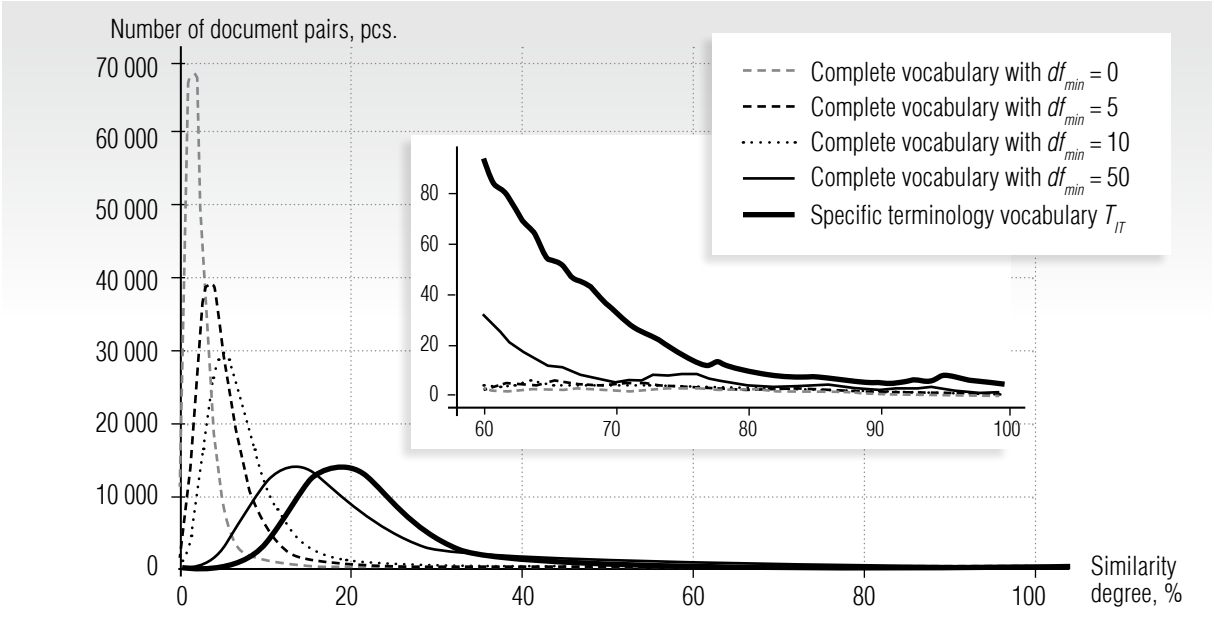

Fig. 2. The number of M_{IT} document pairs of different similarity degrees with different options of the vocabulary, incl. number of M_{IT} document pairs with similarity in the range 60–100% with different vocabulary options

not make significant differences. Therefore, for further comparison of the methods, including the analysis of the documents proximity distribution, from the first group of algorithms we chose the one with the calculation of the similarity by the complete vocabulary at $df_{min} = 5$.

For subject analysis, we consider a similarity range from 60% to 100%. The quantitative characteristics of the obtained result are presented in *Table 2*.

Example 2. *Table 3* shows examples of pairs of documents on information technology that have a high degree of TF-IDF similarity based on the vocabulary of specific terms and a low one by the complete vocabulary of the corpus.

Example 3. *Figure 3* shows one of the options for the graph of links between documents and $\mathbf{G}_{TFIDF}$ terms, namely, its fragment with the documents GOST 34.971-91 and GOST R ISO / IEC 9066-1-93 discussed above. For each of the documents, links with the five most "weighty" (significant) terms are shown.

The experiment has been repeated on another set of documents: $N_{D\_RW} = 218$ documents in docx format related to the field of railways. For these documents an array of M_{RW} text strings was generated and a set of T_{RW} terms was selected.

The results of the second experiment confirmed the conclusion that, despite the shift in the distribution curve of the number of document pairs by the similarity degree, the revealed tendency is preserved, namely: when calculating the proximity by the TF-IDF method based

Table 1.

Expected value and standard deviation of the similarity degree of M_{IT} document pairs with different vocabularies

Conditions	Expected value, %	Standard deviation, %
Complete vocabulary with $df_{min} = 0$	2.9	2.3
Complete vocabulary with $df_{min} = 5$	5.8	3.9
Complete vocabulary with $df_{min} = 10$	7.9	4.8
Complete vocabulary with $df_{min} = 50$	17.4	8.0
Specific terminology vocabulary	21.9	8.0

Table 2.

The number of pairs of M_{IT} documents in different intervals of similarity found by the TF-IDF algorithm with different vocabularies

The M_{IT} similarity degree	The number of similar document pairs determined by the complete vocabulary with $df_{min} = 5$	The number of similar document pairs determined by the specific terminology vocabulary
60% – 70%	42	459
70% – 80%	26	133
80% – 90%	25	55
90% – 100%	7	56

Table 3.

Examples of pairs of M_{IT} documents with high TF-IDF similarity based on specific terminology vocabulary and low similarity on the complete vocabulary of the corpus

No of pairs	Documents	The absolute value of TF-IDF similarity according to the specific terminology vocabulary	The absolute value of TF-IDF similarity according to the complete vocabulary
1	GOST 34.971–91 (ISO 8822–88) Information technology (IT). Open Systems Interconnection. Definition of connection–oriented presentation layer services	0.6944633	0.1744794
	GOST R ISO/IEC 9066–1–93 Information processing systems. Text transmission. Reliable transmission. Part 1. Service model and definition		
2	GOST 28147–89. Information processing systems. Cryptographic protection. Cryptographic Transformation Algorithm	0.6806692	0.17162557
	GOST R 34.13–2015 Information technology (IT). Cryptographic information protection. Modes of operation of block ciphers (with amendment)		
3	GOST R 34.964–92 (ISO 8602–87) Information technology (IT). Open Systems Interconnection. Connectionless transport protocol	0.7068537	0.1946876
	GOST R ISO/ IEC 10025–3–94 Information technology (IT). Data transfer and information exchange between systems. Connection–Mode Transport Layer Qualification Testing Using Connection–Mode Network Layer Services. Part 3. Test Management Protocol Specification		

on the specific terms vocabulary, more similar documents are found in the set than when considering the complete vocabulary of the corpus.

The difference between the document similarity matrix based on specific terms and the complete vocabulary similarity matrix is shown in *Figure 4*.

5. Discussion

The proposed algorithm gives a significant difference when searching for similar documents in the range of similarity of 60–80%. With a higher degree of document similarity, the distribution of proximity for specific terms does not differ much from the distribution of proximity for a complete vocabulary, since the concentration of terms in documents approaches the concentration of commonly used words.

From the graph in *Figure 2*, it can be seen that for a given set of documents, high proximity based on the complete vocabulary means also high proximity based on specific terminology. However, in the opposite case, searching

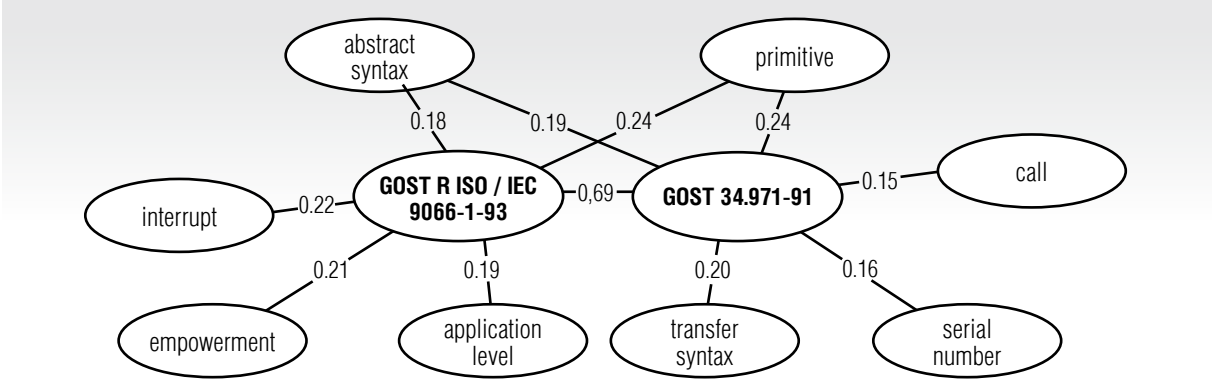

Fig. 3. Graph of a pair of documents GOST 34.971–91 and GOST R ISO/IEC 9066–1–93 and the five most significant terms for each of them

for similar documents by specific terms gives a higher degree of similarity.

The examples of documents given in *Table 3* demonstrate that the described method of calculating the similarity by the ranking function based on specific terms vocabulary can reduce the risk of losing that part of the solution where the similarity is below the threshold, but the documents are similar from the system user's point of view.

It should be noted that in the general case switching from the complete vocabulary to terminology when searching for similarity can in theory lead to the loss of that part of the solution where documents are similar according to human assessment. However, in real information systems, this loss is insignificant, since the user is primarily focused on identifying similarities within a certain topic, that is, similarities based on vocabulary specific to the subject area. Therefore, when moving from a complete vocabulary to specific terms, it is possible to lose only those pairs of similar documents that are close due to the common vocabulary. Quantitative indicators of such losses depend on the proportion of specific terms in the complete vocabulary, which varies from corpus to corpus. Various metrics can be used to calculate the contribution of common words to the overall similarity score, but their development is beyond the scope of this study.

In the experiment, no documents were found in which the similarity in the complete vocabulary was greater than the similarity in specific terms. On the graph showing the difference between the similarity based on the specific terms and on the complete vocabulary (*Figure 4*) the number of negative values is insignificant, and the difference between the similarity for such pairs of documents is hundredths of a percent.

Comparison of the results of two experiments (on the M_{IT} and M_{RW} arrays) made it possible to draw additional conclusions and highlight the factors affecting the quality of the result when searching for similar documents using vector decomposition in a vocabulary of specific terms, including one created automatically based on the same set of documents.

If documents were originally obtained as image files, then the data processing suffers from the uncertainty that appears at the stage of text recognition. This uncertainty is a key factor in the analysis of the corpus of documents. Insufficient recognition quality when part of the text is lost reduces the average similarity according to TF-IDF when using a complete vocabulary; however, according to the specific terms vocabulary such similarity of documents is still

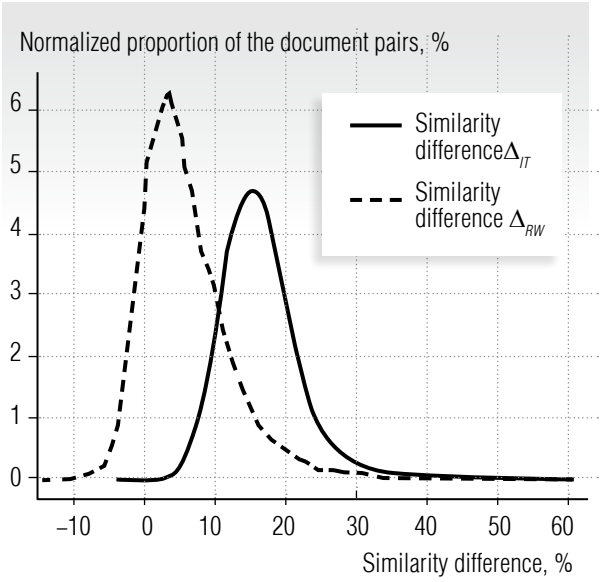

Fig. 4. Distribution of the difference in the similarity degree of document pairs calculated using two vocabularies: all words of the corpus without rare ones (complete vocabulary) and a vocabulary of specific terms (Δ_{IT} – difference in the M_{IT} corpus, Δ_{RW} – difference in the M_{RW})

detected. Thus, the proposed algorithm avoids the cost of preparing text for analysis – preliminary cleaning of the text layer and structuring the document to search for key sections.

The result also depends on the choice of the method for automatic compilation of the glossary of specific terms. The experiment showed that if these terms are separated from the text and listed in a special section of the analyzed documents, then the results are affected by the presence of the described terms in the content of the document: if the terms are only listed in the section, but are not used further, then the meaning of the similarity between the documents is distorted.

With automatic compilation of a vocabulary of specific terms, the similarity also depends on the number of errors in the terms description, since in this case part of the specific vocabulary may be lost: terms are used in the text of the document, but are not included in the vocabulary (which is used for vector representation of documents).

In the general case, the similarity of documents by specific terms depends on the choice of the range for *n*-grams when compiling a vocabulary: long terms consisting of several words probably will never be found in the text of the document entirely, when all words of the *n*-gram go in the right order and stand in a row.

Example 4. In the document from the M_{RW} set "GOST 33798.4-2016 (IEC 60077-4: 2003). Electrical equipment of railway rolling stock. Part 4. Automatic switches for alternating current. General technical conditions" the following terms are introduced among others:

- "**Manual On / Off Lever:** Lever for manually placing the circuit breaker on or off." The specified term is never used in the content of the text of this document.
- "**Indoor switch:** A switch designed for installation and use only with protection from adverse operating conditions (wind, rain, snow, increased dirt deposits, unusual environmental conditions, ice and frost)". This term is not found in the text in its full form, it is used only once and in a modified form: "Switches are classified: ... according to the type of construction, that is, switches for outdoor or indoor installation." This means that this trigram does not appear anywhere in the document, except for the very description of the term. Thus, in this case, TF value (the importance of the term for this document) changes. Therefore, when calculating the similarity of documents according to TF-IDF based on the specific terms vocabulary, it is advisable to include only unigrams and bigrams in it.

Finally, if there is an inversion in the term description (which is allowed in Russian and some other languages, for example: "protective shield" – "shield protective"), then there is also high probability that this term cannot be found in the text as the original *n*-gram.

Example 5. In the document GOST 33798.4-2016 discussed above, the term **"semiconductor switch"** is defined as "switch semiconduc-

tor." In accordance with the Russian language rules, collocations in their inversed form are often used in formal language, while in a coherent text the words of this term will most likely be reversed: the adjective will be placed before the noun. Indeed, in the main part of the document, this term is found only once, without inversion: "For each switch [there should be] indicated: the type of device (for example, an air switch, a vacuum switch, ..., a semiconductor switch ...".

The described experiment has been repeated on two text corpora of the same type. If it is carried out on any other set of documents, the result may be less expressive. This can be facilitated by both the above factors and other features of documents: their structure, stylistics of presentation, industry specificity. In addition, in the general case, the result can be influenced by the subject of the corpus, as well as etymological features of terminology, such as the use of common vocabulary as highly specialized terms. However, preliminary theoretical studies allow us to conclude that when considering any other corpus of documents united by a topic the tendency will remain the same: the number of similar documents found increases when their vector representation is based on the vocabulary of specific terms.

The approach proposed in this work has been implemented in practice within the framework of the Naumen LegalTech information system (the product is being developed with grant support of the Russian Fund for the Development of Information Technologies). It is a platform for analytical processing of a large flow of legal documents focused on users whose interests are far from the field of information technology and natural sciences: lawyers, methodologists, developers of corporate regulatory documents, authors of legislative initiatives, standardization specialists, representatives of legal expertise departments. The specificity of their work is that any mistake of the system in document processing can have legal consequences, but at the same time intelligent algorithms help a lot when applied in an advisory mode. For such users, it is especially important to trust the recommendations from the information system without plunging into the technical details of its implementation, and the explainability of decisions is one of the key factors.

Conclusion

In this work we consider the possibility of using a vocabulary of specific terms as a thesaurus in the vector representation of a text documents corpus using a ranking function.

We study the problem of a partial loss of the solution while searching in the text corpus for pairs of elements that are close in meaning, which is understood as "word-by-word" similarity of texts, taking into account the significance of terms.

The paper describes an experiment carried out on two sets of normative and technical documents. The results of the experiment showed that vector representation based on the vocabulary of specific terms allows us to reduce the loss of that part of solutions that do not meet the given condition of exceeding the threshold value of the similarity degree between two documents, but should be still recognized as significant according to human assessment.

We determined possible factors influencing the solution quality for the selected method of searching for similar documents in the corpus: the way of constructing a vocabulary of specific terms, limiting the length of an n-gram in the vocabulary, grammatical features of terms.

Document corpus models based on a specific terminology vocabulary are applicable in various IT solutions that take into account the similarity of texts: in recommendation systems, in semantic search components, when routing incoming requests. The proposed algorithm increases the accuracy and explainability of recommendations in information systems, which speeds up decision-making by users and increases the efficiency of their work with a large volume of text documents. ■

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How do information technology and knowledge management affect SMEs' responsiveness to the coronavirus crisis?

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Abstract

All organizations have been affected by the coronavirus pandemic in different ways. Small and medium-sized enterprises (SMEs) are more vulnerable to changes due to their limited resources. However, the capabilities of information technologies and processes of knowledge management can assist these enterprises to survive and respond appropriately to changes. Thus, this study aims to assess the extent to which information technology capabilities influence the responsiveness of SMEs to challenges that have emerged during the coronavirus crisis. It also investigates the degree to which knowledge management affects such a relationship in the context of Saudi Arabia. The study includes developing a survey as a data collection method. The responses from 136 SMEs were used to make an analysis and, consequently, draw a conclusion. It has been found that IT capabilities positively influence SMEs' responsiveness to changes brought by coronavirus, through supporting work flexibility and providing a wide range of options in the supply chain, processes, and sales. It further found that knowledge management mediates the relationship between IT capabilities and SMEs' responsiveness.

Key words: IT capabilities; small and medium-sized enterprises (SMEs); responsiveness; knowledge management; Saudi Arabia.

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Introduction

There are numerous ways that the coronavirus pandemic (COVID-19) affects the economy, particularly for Small and Medium-Sized Enterprises (SMEs). SMEs experience challenges such as limited resources can hinder the investment in top-notch information technology (IT) systems for efficient operations [1]. In terms of revenue, the abrupt and drastic loss of competition and profits for SMEs severely impacts their operating ability or generates a significant cash deficit. Also, the loss of jobs, concern about contagion, and increased insecurity are causing consumers to lower spending and consumption. This is compounded by the laying-off of employees and businesses unable to pay salaries. More commonly than other companies, SMEs are likely to suffer from social distancing [2].

SMEs contribute significantly to economic progress in any given country, particularly, the developing nations. In Saudi Arabia, the bulk of the companies are SMEs, with added value and employment. However, the prevalence of SMEs is more significant in some regions and sectors that have been impacted. The number of suppliers to SMEs also is lower. Furthermore, the vulnerability of SMEs increases by relying on suppliers from countries and regions with more COVID-19 [3]. Based on a decrease in global demand for their goods and services, businesses, including SMEs, will bear the brunt.

Moreover, it could be more difficult for SMEs to obtain information not only about steps to avoid the spread of the virus but also about potential business strategies to mitigate the shock and policy support initiatives. These are some severe challenges that SMEs are encountering in the midst of the pandemic, as well as in the post-coronavirus period. Since SMEs have different conditions, countries have adopted initiatives to support them. In particular, in this challenging period, several countries are urgently adopting policies to help SMEs and self-employed workers, with a heavy emphasis on short-term liquidity initiatives.

Research on the responses of SMEs to such a major and comprehensive pandemic remains limited. Thus, the need is still high to understand the behaviour of this type of organization, and how they use IT to survive during this crisis and minimize its effects. This research is considered a contribution on both theoretical and practical sides. In terms of theoretical contribution, it provides a framework that combines the effects of both IT and KM in enhancing SMEs' capabilities and responsiveness. Such a framework will be useful and adaptable in studying or explaining other capabilities of SMEs. The contribution of this research is represented by exploring the ability of SMEs in the Kingdom of Saudi Arabia to adapt and cope with the pressures of the coronavirus pandemic. Furthermore, the contribution is presented through developing and testing a framework that can:

- ✦ provide a better understanding of IT utilization among SMEs;
- ✦ explain the effect of IT and KM processes on SMEs responses to crises.

On the practical side, this framework can guide SMEs to the best way to handle crises through proper utilization of IT and good management of knowledge.

Understanding how IT can be utilized by SMEs to survive and respond to changes could contribute to both SMEs and IT literature. Moreover, Research on SMEs' utilization of IT and knowledge management is limited in the Saudi context. Thus, this research is an attempt to fill such a gap.

This research aims to investigate the relationship between IT capabilities and Saudi SMEs' responsiveness to the coronavirus crisis. It further explores the impacts of knowledge management (KM) processes as a mediating factor of such a relationship. This research is an attempt to answer the following questions:

✦ To what extent do IT capabilities influence SMEs' responsiveness to the coronavirus crisis?

✦ To what extent do KM processes mediate such influence?

1. Literature review

1.1. IT and responsiveness capabilities in SMEs

Research has made a significant contribution to understanding the impact of the environment on IT systems [4]. However, there are gaps in the approaches that organizations, specifically SMEs, use to respond to changes in the external environment. The difference consequently raises interest in the need to understand whether IT systems have any role in supporting the SMEs in addressing viable responses in critical moments, such as the presence of a coronavirus pandemic. The relationship between IT capabilities and the level of readiness to respond to various changes in the environment has leaned more on the large enterprises [5]. The understanding of SMEs' response to environmental changes is pertinent for the fact that SMEs are more vulnerable to environmental changes partly due to the limited resources [1]. In order to address such a gap, there is a need to assess how SMEs utilize their IT capabilities to minimize the impacts of environmental changes on them.

According to [6], "dynamic groups of ICT tools, competencies, and expertise, which are exercised through business processes, enable firms to organize activities and leverage ICT assets to achieve the desired results." IT-based capacity is "unique." Companies build capacity to react and organizational characteristics to environmental stimuli.

There are "internally-oriented" (IO) and "externally-oriented" (EO) capabilities [6]. IO technologies are focused on using IT applications for storing information about the internal activities of organizations, such as Enterprise Resource Planning (ERP) solutions. This method can help managers make short-term organizational choices and thereby increase performance and operational control by incorporating data through functions [7]. While technology such as ERP matures, statistics show that practices and IO-based resources among SMEs remain limited.

EO's ability relies on IT to encourage business model creativity, new product development operations, CRM processes, and e-commerce initiatives and to enable businesses to adapt to market changes. The ability to use IT to understand and process external business knowledge is also evident in EO's capacity, which allows companies to reconfigure their products, business models, and supply chain relationships more effectively [6]. More precisely, CRM systems support substantial market intelligence activities. IT supports the new product development, which is critical for customer participation in product innovation, and for supply chain partnership to shorten time-to-market. Because EO resources can also include the opportunity to manage e-commerce programs, the costs of reaching new business segments are controlled. Given the value of IT capabilities, even without the "weaving" of IT, SMEs will achieve strategic agility.

However, the role of these innovations in organizational processes and lowering entry costs in the new market segments can be crucial to their growth by supporting the capacities of the small companies. It can be challenging to implement ERP systems in SMEs, due to their lack of management experience in re-engineering the business process [8], and to their specific characteristics in production management, resulting in profound changes in their organizational routine and modules of standardized ERP software. Given the greater alignment in the concept of IT requirements that they must adopt with partners, IT programs helping EO companies are challenging to implement for SMEs. As such, it requires high levels of social sophistication to apply IT in EO organizational processes.

Furthermore, travel dependencies are more evident as the use of IT in product creation, and CRM requires a pre-existing build-up of IS supporting internal operations and customer profile and transaction information repositories [6].

1.2. IT and KM processes in SMEs

Through a reduction in lead times, reduction of overhead cost and product differentiation, KM aims to gain a competitive edge. Firstly, by assessing current circumstances and combining them with previous experience, KM allows companies to reduce their lead times rapidly by recognizing and responding to the evolving marketplace [9]. Secondly, by enhancing commodity quality, which eventually helps consumers, the organization aims to reduce its costs [10]. Third, KM is considered a critical enabler to improve decision making and product changes for organizational advancement [11]. To develop and sustain diverse capabilities, the productivity and effectiveness of information uprooted within an enterprise are essential [12].

KM systems are, therefore, built and implemented to achieve the above three objectives. Sher and Lee [13] have identified three issues in their previous work on KM systems, comprehensive IT design, the degree to which corporate information is built up and preserved, and search for awareness, development and dissemination of IT.

In acquiring and obtaining core expertise, IT is a vital element for organizations, whether adopting personalization or codification KM strategy. KM continues to emphasize both directly and tacitly the incorporation of core business expertise and its importance within the company. In addition to controlling and paying for private information as a central consideration for the KM system, KM takes into account the external aspect [14]. In order to ensure the convergence of the process and information gain, the internal administration role must be combined with external information through the KM system. In a KM report, the following concepts were identified: facilitation of the information, production and information acquisition, marketing knowledge production, marketing knowledge acquisition and alignment with company strategy [15].

The value of managing external knowledge is evident from literature as a specific challenge to achieve the sustainability of competitive advantage more efficiently and effectively than others [16]. It can be argued that the control of external knowledge through IT is indispensable. Furthermore, the management of external knowledge plays a significant role in achieving corporate performance and influencing the company's strategic path. To achieve such a goal, there is a need for an effective compilation of all needed information to design and execute organizational activities in alignment with corporate strategy.

1.3. KM and responsiveness capabilities of SMEs

Roach, Ryman and Makani [17] argue that for most national economies, SMEs and business enterprises are the leading segment drivers. The strategic advantage of capable SMEs is identical, allowing them to create a market niche by changing their product mix to suit the clients' needs [18]. In different parts of the world, SMEs are defined in different ways. Some define them as properties, while others use the criterion of employment, shareholder funds or sales. Some others use the hybrid criterion of a mix of income and jobs. Current literature indicates that SMEs can be distinguished by a variety of essential characteristics from larger firms. This view has now been illustrated by some international business and economic analysis, which proposes that more substantial organizations, for example, from foreign parents, may obtain less knowledge internally than from smaller organizations, because of their ability to produce information on their own [19].

Moreover, the findings discovered in Eastern Europe by Sinani and Meyer's [20] empirical research reveals that relatively smaller organi-

zations are more knowledgeable than larger entities. Rahayu and Day [21] state that SMEs are more likely than large companies to look for information through experiences with the know-how possessors. Their specific characteristics – management structures, markets, processes, community – are significant features that influence KM activities in SMEs that separate them from large organizations.

Various variables, such as the location of the customer order point, set-up times, manufacturing resources, and system configuration (equipment and workers), affect the responsiveness of a production system. In this regard, three aspects of responsiveness are identified: product, volume and process [22].

2. Conceptual model and research hypotheses

This research involves developing a framework that is used to explore how IT capabilities and KM affected SMEs' response to changes caused by the coronavirus pandemic. The hypotheses (*Figure 1*) indicate that SMEs' responsiveness to change is affected directly by IT (independent variable), and KM is a mediating factor for this effect.

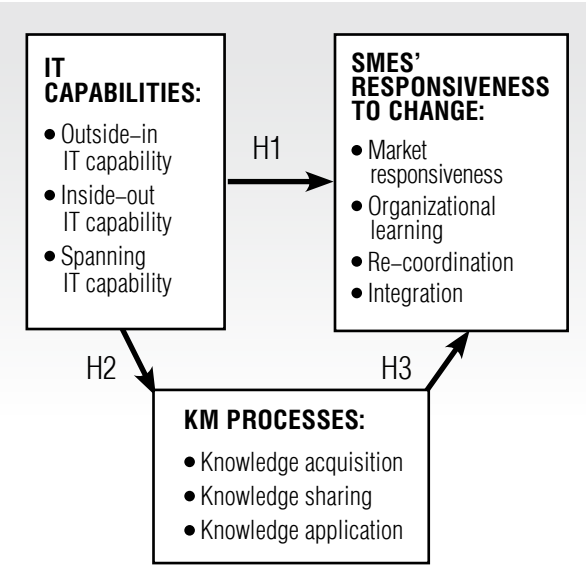

Fig. 1. Research model

The hypotheses of this research are listed below:

✦ **H1:** IT capabilities positively affect SMEs' responsiveness to change;

✦ **H2:** IT capabilities positively affect KM processes;

✦ **H3:** KM processes positively affect SMEs' responsiveness to change.

2.1. IT capabilities

Zhang and Ziegelmayer [23] assert that every organization that seeks to survive change must be responsive. Flexibility in the IT infrastructure provides the relevant framework to respond to various changes in contemporary society. A firm's responsiveness refers to its ability to react quickly to the possible variations within its environment to try and seize the available opportunities [23]. The effectiveness and efficiency is a reflection of an organization's capacity to sense, internalize and act on stimuli. This is one of the processes that ensure a competitive advantage. The firms with a high level of responsiveness can outperform their competitors by utilizing the available resources to satisfy the needs of customers.

IT capabilities refer to the ability of a firm to install, utilize, integrate and reconfigure the resources from IT systems to enhance the strategies of a business [24]. This kind of approach assists businesses to catalyse their processes and support their strategy. Various approaches can lead organizations to diverse outcomes. Three types of IT capabilities have been identified: outside-in, inside-out and spanning [25]. The three subcomponents (items) can be used to measure IT capabilities. Outside-in capabilities are the external orientation that represents the ability of the firm to develop IT-links with significant business partners. Inside-out IT capabilities refer to the ability of a firm to internally deploy data, networks, as well as relevant infrastructure for its services and applications [26]. Spanning IT capabilities are the ability to integrate both the external and internal IT related factors to gene-

rate the best performance for a firm [25]. The research adopted a parsimonious yet comprehensive view of the IT capabilities that include: outside-in, inside-out and spanning.

The level of preparing IT personnel for unexpected changes is linked directly to the firm's plans and experience in managing such changes. The competency of such skilled personnel creates a positive impact on the responsiveness of an organization [27].

The present study would consequently seek to bridge the gap by assessing the validity of the statement. This leads to formulating the following hypothesis:

H1: IT capabilities are positively related to SMEs' responsiveness to change.

2.2. KM processes

Companies with more significant KM potential are learning to improve their ability to minimize duplication, react rapidly to change, and generate new ideas and creativity [28]. KM processes are measured by three sub-components, which are knowledge acquisition, knowledge sharing and knowledge application.

Knowledge acquisition can be conceptualized as the process involved in gaining knowledge, or only "the method of gaining information" [29]. Information acquired can be implicit, explicit or both. External networks of an organization may be an effective means of acquiring knowledge. Also, formalized and undefined external sources of knowledge provide useful information and promote developments in knowledge [30]. Knowledge sharing is a culture of social interaction involving the exchange of information, experiences and skills between the entire department or organization. The exchange of knowledge involves several collective insights that enable employees to have access to information and to develop and use networks of knowledge inside organizations [31]. Knowledge application is the ability of employees to use the information to develop structures to resolve issues and address problems within an organization and can simply be described as information-application capabilities. Through effective use of information, individuals may make fewer errors or improve their effectiveness and minimize redundancies [12].

IT capabilities enhance the learning process by improving information acquisition, assimilation and implementation by processing contextual intelligence [32]. That is why this skill makes it possible to make the learning cycle in KM a company as an intellectual resource, which is the foundation for organizational responsiveness. IT ability may strengthen the response, as it encourages the assimilation of information in the process of learning. The IT capabilities of this sort reflect the company's ability to implement cross-functional IT frameworks, such as systems of KM and cross-company interpreting, to integrate external understanding into internal processes. This skill involves both internally and externally oriented emphasis on promoting the assimilation of information in an organization [33]. In order to test these concepts, the following hypothesis has been framed:

H2: IT capabilities positively affect KM processes.

2.3. SMEs' responsiveness to change

SMEs form an integral factor in modern economies. They form a large proportion of all the enterprises present in any given nation. However, they suffer from limitations of resources, which is imperative to respond to the various changes [34]. One of the precarious survival capabilities is responsiveness strategies. In light of the reported research study carried out by Sui and Baum [27] on the failure of more than half of enterprises, it is conceivable that SMEs' ability to adapt to changes is critical for their survival. Firms must always seek to learn from their partners that have more exceptional experiences in terms of responding to crises and mar-

ket changes [35]. Knowledge plays a crucial role in impacting efforts aimed at supporting an organization to respond to various changes within its environment [36]. KM stems from the effective use of strategies and mechanisms that can ensure the processing of information and data coupled with the utilization of IT and the capacity, in terms of innovation and creativity, from the human beings [37].

Firms usually establish strength to be competitive through finding access to external knowledge. Effective firms' learning processes can support firms' responsiveness. The acquisition of knowledge is likely to enable a firm to respond to prevailing changes, market demands, or changes. A close coordinative relationship with the various partners can also assist an organization to get in-depth, private and rich content that they are likely to use to learn how to respond to the multiple changes in the environment. Integration with other partners can assist an organization in learning collectively on how to handle pertinent changes [38]. Coordinating with different firms can help in creating collective cognitive values. This research investigates the SMEs' responsiveness based on four dimensions: Market Responsiveness, organizational learning, re-coordination and integration. Consequently, the following hypothesis has been articulated:

H3: KM processes positively affect SMEs' responsiveness to change.

3. Research methodology

The research adopted a quantitative method of study in which a survey has been used as a data collection instrument. As stated in the introduction section, research questions were formulated to investigate the relationship between IT capabilities, KM processes and Saudi SMEs' responsiveness to the coronavirus crisis. To develop the research framework and instrument, the related literature was reviewed and analysed. Then, the elements for each framework's construct were adopted from previous research. *Table 1* shows the main literature from which the survey items were adopted.

Table 1.

Sources of survey's items

Constructs	References
Knowledge management	Yee–Loong et al., 2014 [39]
Information technologies capabilities	Zhang and Ziegelmayer, 2008 [23]
SMEs' responsiveness	Nidumolu and Knots, 1998 [40] Pavlou and Elsawy, 2006 [41]

The questionnaire consists of 30 items distributed on three main constructs as shown in the *Table 2*.

The research was conducted in the Saudi context, and the parameter which was used in SMEs' definition in this research was the number of employees (organizations with less than 200 employees). Items were translated into clear Arabic to enable targeted participants to comprehend the meaning completely. The targeted participants were asked to show their level of agreement on a five-point Likert scale regarding three main constructs: IT capabilities, SMEs' responsiveness to change and KM processes. The five-point Likert was 1 "strongly disagree," and 5 "strongly agree." SME executives/owners are the main targeted participants. Due to coronavirus lockdown, an online survey method was used to contact the targeted SMEs and collect the required data. All contact details of SMEs were obtained from the Chamber of Commerce without any identifying data. There were 136 SMEs who responded out of 500 targeted SMEs, which counts for 27.2% as response rate.

The questionnaire elements were tested for their reliability and robustness before the key findings are expanded. Cronbach's Alpha value is calculated to determine the value of the items'

Table 2.

The survey's items

Main construct	Sub-constructs	Items
Knowledge management processes	Knowledge acquisition	**KA1:** Our organization has processes for generating new knowledge based on existing knowledge. **KA2:** Our organization has processes for acquiring customer knowledge. **KA3:** Our organization has processes for acquiring knowledge on developing new products/services.
	Knowledge sharing	**KS1:** Our organization has processes for sharing knowledge throughout the organization. **KS2:** Our organization has processes for transferring organizational knowledge to employees. **KS3:** Our organization has processes for sharing knowledge among business partners.
	Knowledge application	**KAP1:** Our organization has processes for integrating different sources and types of knowledge. **KAP2:** Our organization has processes for applying experiential knowledge. **KAP3:** Our organization has processes for applying knowledge to solve new problems.
IT capabilities	Outside–in IT capabilities	**OIT1:** Our organization has technology–based links with customers. **OIT2:** Our organization has technology–based links with suppliers. **OIT3:** Our organization has IT–based entrepreneurial collaborations with external partners.
	Inside–out IT capabilities	**IIT1:** Our organization has good appropriateness of the data architectures. **IIT2:** Our organization has good appropriateness of network architectures. **IIT3:** Our organization has good adequacy of architecture flexibility.
	Spanning IT capabilities	**SIT1:** Our organization restructure IT work processes to leverage opportunities. **SIT2:** Our organization has multidisciplinary teams to blend business and technology expertise. **SIT3:** Our organization has a climate that nurtures IT project championship.
SMEs' responsiveness	Market responsiveness	**MR1:** During the coronavirus crisis, our organization has the agility to respond to environmental changes. **MR2:** During the coronavirus crisis, our organization monitors the environment for the identification of new business opportunities. **MR3:** During the coronavirus crisis, our organization has the agility to develop new products and services.
	Organizational learning	**OL1:** Coronavirus crisis increases our organization's desire to improve the ability of employees. **OL2:** Coronavirus crisis encourages our organization to have a learning atmosphere. **OL3:** Coronavirus crisis encourages our organization to enhance the sharing of ideas.
	Re–coordination	**RE1:** During the coronavirus crisis, our organization has coordination between organizational processes and employees' abilities. **RE2:** During the coronavirus crisis, our organization allocates the assignment of activities to employees based on their abilities. **RE3:** During the coronavirus crisis, our organization engages in effective assignment of resources to projects and processes.
	Integration	**INT1:** During the coronavirus crisis, our organization engages in defining new activities based on new situations. **INT2:** During the coronavirus crisis, our organization enhances the reintegration of organizational processes. **INT3:** During the coronavirus crisis, there is sufficient cooperation of different departments or sections in our organization.

reliability. The factor analysis was carried out to find out the validity of each construct and to report the value of each factor loading. The critical analyses were designed to test the hypotheses and to construct the relationship between variables, mainly via Pearson product-moment correlation and multiple regressions. In the beginning, a general description of the data collected was given and descriptive statistics such as frequency distribution, central pattern and variability measurements were extracted from the use of the SPSS program.

From the data collected, 136 participants responded to the survey. Out of these, the respondents were 36% Chief Executive officers, 11.8% directors of accounting and finance, 14.7% directors of human resources, 17.6% were directors of IT while others were 19.9%. The data shows that majority of the participants are in managerial positions, which puts them in a better position to answer the research questions.

The demographic analysis (*Table 3*) shows that there is a wide diversity of participant SMEs in terms of sectors (18.4% retail firms, 14% in manufacturing firms, 21.3% restaurants and food industry, 10.3% IT services, 14.7% constructions, and 21.3% in others sectors). The majority of the firms have been in operation between two to five years, have between 50–249 employees, and with annual revenue of less than 3 million Saudi Arabian Riyals.

4. Results and analysis

This research intends to investigate the relationship between IT capabilities and the SMEs' responsiveness during the coronavirus pandemic. The study also aims to investigate whether KM mediates this relationship or not. To achieve these particular investigations, correlation and regression analysis were used. There were 136 SMEs' managers who participated in the survey. The collected data was inserted into SPSS statistics software, and the research hypotheses were examined.

Table 3.

Demographic analysis

SMEs' sector		Role of respondents	
Sector	**%**	**Role**	**%**
Retail	25 (18.4%)	Chief Executive Officer	49 (36%)
Manufacturing	19 (14%)	Director of Finance	16 (11.8%)
Restaurants and food industry	29 (21.3%)	Director of HR	20 (14.7%)
IT services	14 (10.3%)	Director of IT	24 (17.6%)
Constructions (real estate, engineers)	20 (14.7%)	Other	27 (19.9%)
Others	29 (21.3%)		

SMEs' age		Number of employees		Annual revenue	
Age	**%**	**No of employees**	**%**	**Revenue**	**%**
< 2 years	34 (25%)	1–5	42 (30.9%)	< 3 million	58 (42.6%)
2–5 years	41 (30.1%)	6–49	44 (32.4%)	3–40 million	40 (29.4%)
5–10 years	24 (17.6%)	50–249	50 (36.8%)	40–200 million	38 (27.9%)
> 10 years	37 (27.2%)				

4.1. KMO and Barlett's Test of Sphericity

KMO's test of sampling adequacy and Barlett's test of sphericity (*Table 4*) were carried out. KMO's value is 0.955, with a *p*-value of 0.000 (< 0.05). The Barlett's test of sphericity is also significant ($p = 0.000$; < 0.05). Principal component analysis can consequently be conducted. The factor loading for the various elements can be as shown in *Table 5*.

Table 4.

KMO's test of sampling adequacy and Barlett's test of sphericity

KMO and Bartlett's test		
Kaiser–Meyer–Olkin measure of sampling adequacy		.955
Bartlett's test of sphericity	Approx. Chi–Square	3583.843
	df	435
	Sig.	.000

Table 5.

Factor loading for the various items

Items	Factor Loading	Items	Factor Loading
KA1	0.753	SIT1	0.728
KA2	0.720	SIT2	0.780
KA3	0.785	SIT3	0.772
KS1	0.773	MR1	0.772
KS2	0.787	MR2	0.740
KS3	0.784	MR3	0.779
KAP1	0.750	OL1	0.699
KAP2	0.804	OL2	0.755
KAP3	0.810	OL3	0.748
OIT1	0.742	RE1	0.756
OIT2	0.765	RE2	0.721
OIT3	0.781	RE3	0.737
IIT1	0.757	INT1	0.763
IIT2	0.775	INT2	0.744
IIT3	0.769	INT3	0.714

Rahn [42] states that a factor loading of more than 0.4 is good, and a researcher can carry out further analysis. From the results in *Table 5*, all items have factor loadings of more than 0.4 and consequently qualify for further analysis.

Table 6.

Cronbach's Alpha for the variables

Variable	Number of items	Cronbach's Alpha
IT capabilities	9	0.937
KM processes	9	0.931
SMEs' responsiveness	12	0.943

4.2. Cronbach's Alpha

Cronbach's Alpha was used to measure the level of reliability of the items in the scale for every variable. It measures the level of interrelatedness or the homogeneity of the items [43]. It can be used to assess how a group of given items can measure a construct. The parameter would determine if the individual items would be relied on to measure the intended variables. According to Sharma [44], a reliability coefficient of ≥ 0.7 is acceptable. *Table 6* shows Cronbach's Alpha for the various items and their respective constructs.

The reliability of the various items was calculated using Cronbach's Alpha, as shown in *Table 6*. The values are higher than 0.7, which shows higher reliability. The internal consistency of the various research question items when one item is deleted is shown in *Table 7*. From the results, deleting either of the items would reduce Cronbach's Alpha. Consequently, all items contribute to a higher internal consistency and reliability and can all be used for further analysis.

4.3. Correlation analysis

Correlation analysis was carried out to test the identified hypotheses.

H1: IT capabilities positively affect SMEs' responsiveness to change (*Table 8*).

The analysis shows a strong positive correlation between KM processes and SMEs' responsiveness ($r = 0.838$; $p < 0.05$). The null hypothesis is, therefore, rejected.

Table 7.

Cronbach's Alpha if items deleted

KM processes		IT capabilities		SMEs' responsiveness	
Items	**Cronbach's Alpha if item deleted**	**Items**	**Cronbach's Alpha if item deleted**	**Items**	**Cronbach's Alpha if item deleted**
KA1	.926	OIT1	.930	MR1	.939
KA2	.923	OIT2	.932	MR2	.938
KA3	.923	OIT3	.931	MR3	.938
KS1	.923	IIT1	.929	OL1	.940
KS2	.921	IIT2	.927	OL2	.938
KS3	.922	IIT3	.930	OL3	.938
KAP1	.926	SIT1	.933	RE1	.937
KAP2	.921	SIT2	.931	RE2	.938
KAP3	.923	SIT3	.928	RE3	.939
				INT1	.938
				INT2	.938
				INT3	.939

Table 8.

Correlation analysis between KM and SMEs' responsiveness

		Knowledge management	**SMEs' responsiveness**
Knowledge management	Pearson Correlation	1	.838**
	Sig. (2–tailed)		.000
	N	136	136
SMEs' respon–siveness	Pearson Correlation	.838**	1
	Sig. (2–tailed)	.000	
	N	136	136

** Correlation is significant at the 0.01 level (2–tailed)

H2: IT capabilities positively affect KM processes (*Table 9*).

The analysis shows a strong positive correlation between IT capabilities and KM processes ($r = 0.882$; $p < 0.05$).

H3: KM processes positively affect SMEs' responsiveness to change (*Table 10*).

The results show that there is a strong positive correlation between IT capabilities and SMEs' responsiveness ($r = 0.832$; $p < 0.05$).

4.4. Regression analysis

A regression analysis was carried out to determine the extent of IT capabilities' influence on SMEs' responsiveness. The results of the analysis are shown in *Table 11*.

From the analysis shown in the *Table 11*, IT capabilities are proved to have a strong posi-

Table 9.

Correlation analysis between IT capabilities and knowledge management

		IT capabilities	KM processes
IT capabilities	Pearson Correlation	1	.882**
	Sig. (2–tailed)		.000
	N	136	136
KM processes	Pearson Correlation	.882**	1
	Sig. (2–tailed)	.000	
	N	136	136

** Correlation is significant at the 0.01 level (2–tailed)

Table 10.

Correlation between IT capabilities and SMEs' responsiveness

		IT capabilities	SMEs' responsiveness
IT capabilities	Pearson Correlation	1	.832**
	Sig. (2–tailed)		.000
	N	136	136
SMEs' responsiveness	Pearson Correlation	.832**	1
	Sig. (2–tailed)	.000	
	N	136	136

** Correlation is significant at the 0.01 level (2–tailed)

tive correlation between IT capabilities and SMEs' responsiveness (R-value 0.832; $P < 0.05$); $F(1,134) = 301.158$. The β-value is 0.832, $P = 0.000$, which is as well as a significant value. The R-squared value (0.692) implies that the IT capabilities can account for 69.2% of the variation in the SMEs' efforts to respond to the impacts instigated by the coronavirus pandemic. The other factors would only account for 31.8% of the variation. The prediction model for the analysis is the following:

$$\text{SMEs' responsiveness} = 0.772 \cdot \text{IT capabilities} + 0.931.$$

4.5. Mediation test using Andrew F. Hayes PROCESS method

From the results shown in *Figure 2* and *Tables 12 – 14*, IT is a significant predictor of knowledge management, $\beta = 0.83$; ($p = 0.000$). Multiple regression shows that IT and KM processes are significant predictors of SMEs' responsiveness; $p = 0.000$, respectively. IT is a significant predictor of SMEs' responsiveness ($\beta = 0.77$; $p = 0.000$). The results also prove that the indirect effect of IT capabilities is significantly greater than zero. For instance, in this case, the effect size is 0.38, with a 95% confidence interval, which does not include a zero. The effect is consequently greater than zero at $\alpha = 0.05$.

The first step aimed to assess if the predictor variable (IT) significantly predicts the mediator variable (KM processes). In comparison, the second step is examined if both IT and KM processes significantly predict SMEs' responsiveness. The last step is investigated if IT significantly predicts SMEs' responsiveness. The use of both the predictor and the mediator shows a significant decline in β-value, which proves a partial mediation from the intervening variable. Consequently, it can be argued that KM partially mediates the relationship between IT and the SMEs' responsiveness to the impacts of the coronavirus pandemic.

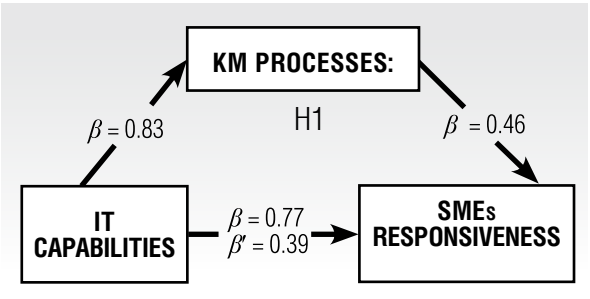

Fig. 2. Path Diagram Model for the relationship among the various variables

Table 11.

Results of regressing SMEs' responsiveness against IT capabilities

Model	R	R Square	d.f	F	Coefficients	Beta	Sig. Value
1	.832	.692	(1,134)	301.158	Constant = 0.931 IT capabilities = 0.772	0.832	0.000

Table 12.

Model summary: IT capabilities and knowledge management

	R	R-sq.	MSE	F	df1	df2	p
	.88	.78	.09	468.26	1.00	134.00	.00
	Coeff	**se**	**t**	**p**	**LLCI**	**ULCI**	
Constant	.71	.16	4.52	.00	.40	1.03	
IT_CAP	.83	.04	21.64	**.00**	.75	.90	

Table 13.

Model summary: IT capabilities, knowledge management, and SMEs' responsiveness

	R	R-sq.	MSE	F	df1	df2	p
	.86	.74	.10	190.05	2.00	133.00	.00
Coeff		**se**	**t**	**p**	**LLCI**	**ULCI**	
Constant	.60	.18	3.31	.00	.24	.96	
IT_CAP	.39	.09	4.48	**.00**	.22	.56	
KNWMGT	.46	.09	5.00	**.00**	.28	.65	

5. Discussion

Improved IT around the globe has contributed to tremendous changes in the way SMEs are operating. The presence of a coronavirus pandemic has come with its share of drawbacks with devastating consequences on the limited resources businesses such as SMEs. They need to be flexible in order to escape the challenges imposed by the ever-changing environment. Rigid businesses, in most cases, fail. One of the most significant factors to enhance organizations' flexibility is through adopting the proper IT capabilities. IT capabilities, through supporting efficient management of internal activities, can lead organizations to quick and accurate decisions. Additionally, with the dynamism brought about by the rise of the coronavirus pandemic, IT capabilities can be used to obtain information and knowledge from external sources, which can be an added value to the organization's operations. It further enhances and facilitates communication regardless of geographic restrictions, and to enable work from a distance in some tasks.

Ajayi and Olayungbo [45] affirm that IT plays a vital role in strengthening the competitive advan-

Table 14.

Andrew F. Hayes analysis results

Model summary: IT capabilities and SMEs' responsiveness

	R	R-sq.	MSE	F	df1	df2	p
	.83	.69	.12	301.16	1.00	134.00	.00
Coeff		**se**	**T**	**p**	**LLCI**	**ULCI**	
Constant	.93	.18	5.07	.00	.57	1.29	
IT_CAP	.77	.04	17.35	**.00**	.68	.86	

The total effect of X on Y

Effect	se	T	p	LLCI	ULCI	c_ps	c_cs
.77	.04	17.35	.00	.68	.86	1.25	.83

The direct effect of X on Y

Effect	se	t	p	LLCI	ULCI	c'_ps	c'_cs
.39	.09	4.48	.00	.22	.56	.63	.42

Indirect effect(s) of X on Y:

	Effect	BootSE	BootLLCI	BootULCI
KNWMGT	.38	.09	**.22**	**.55**

tage of SMEs, and can be used to access the international markets. Telecommuting, for example, can be used as motivational factors for individuals to work for SMEs. The use of information technology is a motivator for young employees whose firms are unable to pay higher salaries due to the impacts of the coronavirus. Using information technology allows employees to operate from home and works to curb the spread of coronavirus. SMEs can consequently minimize the number of workers in the office to allow the majority to work from home. Enterprises can, therefore, work as they follow directives from the Health authorities.

Knowledge can be acquired from clients or other firms. Sharing of knowledge with both the internal and external agencies can contribute much to supporting the SMEs to make better decisions on their various operations. This practice can be a contributing factor in dealing with the impacts of the COVID-19 pandemic.

The study also reports that KM processes act as an essential mediator between IT capabilities and the SMEs' responsiveness. The mediation is effected by three facets of KM processes that include knowledge acquisition, knowledge sharing and knowledge application. Vaidyanathan and Kidambi [31] argue that organizations need the exchange of information among employees to allow the provision of insights, develop and use networks of knowledge, particularly in SMEs. The flow of information in a firm facilitates both innovations as well as general development [29]. The use of social media information, for instance, can help firms to know the reactions of the various firms, present, and potential customers and the kind of services and products highly needed by these customers. Innovative approaches always form the archetypal way to ensure that SMEs thrive in a market characterized by unprecedented changes, challenges and opportunities.

Conclusion

The study proposed a model that linked IT and SMEs' responsiveness, IT and KM, and KM and SMEs' responsiveness to changes brought by the coronavirus pandemic. The study reveals the relationship between IT capabilities and SMEs' responsiveness. A relationship between KM processes and the SMEs' responsiveness in the wake of the coronavirus pandemic has been revealed. IT capabilities were also assessed to relate to knowledge management processes. The Andrew F. Bayes mediation test carried out ascertained that knowledge management partially mediates between IT capabilities and the SMEs' responsiveness. Information technology consequently can be used to support the operations of SMEs during changes brought about by the coronavirus pandemic. Furthermore, knowledge management processes could be used to support this relationship through the flow of pertinent information for developing the business processes. ■

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