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SUSTAINABLE INFORMATION SYSTEM FOR ENHANCING VIRTUAL COMPANY RESILIENCE THROUGH MACHINE LEARNING IN SMART CITY SOCIO-ECONOMIC SCENARIOS

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ABSTRACT

This paper introduces an innovative framework for the management of virtual companies in smart urban environments, with an emphasis on socio-economic resilience facilitated by Sustainable Information Systems. The system aims to equip virtual enterprises in smart cities with tools for robust operations amid socio-economic challenges. Its effectiveness is evidenced by improvements in investment risk assessment, business process simulation, and HR project management, enhancing efficiency and foresight. A key feature is predictive analytics for crisis demand forecasting, enabling swift market adjustments and strategic inventory management. It also helps identify alternative clients and suppliers, ensuring business continuity. Integrating machine learning and augmented reality, the system supports automation and strategic decision-making, significantly benefiting the e-commerce sector by addressing fluctuating demand, supply chain issues, and market adaptations during crises. The Sustainable Information System for Virtual Company Management in Smart Cities offers crucial support for e-businesses facing these socio-economic challenges, facilitating their navigation through turbulent times. Its meticulously designed architecture and functionalities make it a powerful instrument for assisting virtual companies in crisis conditions, fostering their sustainable growth within the socio-economic framework of smart urban settings. Comparative studies with existing models underscore this system's superior efficiency and holistic approach, highlighting its contribution to enhancing the operational efficiency of virtual companies by 95%, reducing the time needed for critical activities like investment risk analysis and business process simulation, and bolstering the socio-economic resilience of smart cities against crises

Keywords: *sustainable information systems, virtual company resilience, smart city management, crisis response, machine learning, augmented reality, e-commerce adaptation*

1. INTRODUCTION

In today's globalized world, where borders are becoming increasingly less noticeable, the socio-economic development of cities is gaining new significance, especially in the context of integrating digital technologies. Virtual companies operating within smart city environments not only serve as drivers of innovation and economic growth but also play a crucial role in shaping a sustainable future. However, these companies face unprecedented challenges related to crisis conditions - from natural disasters to economic downturns, political instability, and pandemics, requiring them to quickly adapt and maintain stability.

In this work, we focus on the socio-economic component of managing virtual companies in smart cities, recognizing that successful business operations in the modern world require not just technological sophistication but also a deep understanding of the socio-economic context. An intelligent management system focused on sustainability and innovation plays a crucial role in ensuring the adaptability and resilience of virtual companies in the face of unpredictable challenges. This system facilitates inventory management optimization, effective customer and supplier search, as well as forecasting and responding to market changes, thereby increasing the resilience of e-commerce and paving the way for its further development and innovation in conditions of instability.

The importance of this article is highlighted by several factors. Firstly, virtual companies are becoming increasingly popular as they allow entrepreneurs to create and grow businesses without the need for physical presence. Secondly, crisis situations, such as the COVID-19 pandemic or the war in Ukraine, can have a significant negative impact on business operations. Thirdly, advancements in artificial intelligence technologies offer new opportunities for creating more efficient and innovative management systems.

This research is pertinent for entrepreneurs considering the establishment or growth of a virtual business, and for cities aiming to foster a conducive business climate for the development of digital economies. This article is structured as follows: the “Related Work” section delves into recent related references; the “Architecture of Proposed Intelligent System” section describes the modular structure of the intelligent system and its components; the “Case Study” section presents an example of the system’s implementation and the results of experimental studies; the “Conclusion” section offers a summary of the research.

2. RELATED WORK

Research on virtual companies in crisis situations is a relatively new field in which researchers examine the specifics of establishing and managing virtual companies in situations such as wars, the COVID-19 pandemic, economic crises, natural disasters, and so on.

Mićić and Mastilo, 2024 examine how COVID-19 accelerated digital transformation in workplaces, leading to a permanent shift towards hybrid work models. Radukic et al., 2024 analyze the efficiency of goods and labor markets in the Western Balkans, revealing competitive pressures and efficiency disparities. Kuzmak and Kuzmak, 2024 discuss social responsibility in Ukrainian businesses, emphasizing transparency and sustainable development, while Shevchenko, 2024 presents a methodology for assessing global digital trade development through country clustering and integral indicators.

Ismagilova et al., 2019 highlight the significance of smart cities in enhancing citizens’ quality of life and sustainable development, especially from the perspective of in-formation systems. Huang et al., 2022 emphasize the role of digital technologies in city management in China, particularly the use of Geographic Information Systems (GIS). Xu and Geng, 2019 focus on people-centric intelligent services and their importance for the evolution of smart cities. A bibliometric analysis by Guo et al., (2019 indicates a growing interest in smart city research. Baldi et al., 2022 explore the adoption of technologies among citizens of smaller cities and their impact on sustainable development. Huang et al., 2021 stress the importance of smart cities in addressing rapid urbanization challenges in China. Ji et al., 2021 illustrate the significance of meeting citizens’ needs in the advancement of smart cities. Radu, 2020 highlights the pivotal role of in-formation technology in smart city evolution. Yigitcanlar et al., 2020 underscore the importance and risks of artificial intelligence in the growth of smart cities. Javed et al., 2023 pinpoint the significance of Explainable Artificial Intelligence for the development of smart cities. These studies provide valuable insights into how intelligent methods and technologies can influence the growth of smart cities. They highlight the role of in-formation systems, digital technologies, intelligent services, and other innovations in enhancing the quality of life for citizens, city management, and addressing sustainable development challenges. Bibliometric analysis also indicates an escalating interest in this topic within the scientific community. Such research is beneficial for devising strategies and solutions for the advancement of smart cities and improving citizens' quality of life (Pavlov, K., Pavlova,O.,Ilyin,L.,Novosad,O. & Bortnik,S., 2023).

The integration of intelligent methods, such as enterprise architecture (EA), in urban environments is crucial for the development of smart cities and enhancing the quality of life for citizens. Research conducted in this context reveals various facets of this im-portance. An analysis by Anthony Jnr, B. et al., 2020 suggests that the digital transformation of virtual enterprises can enhance citizen services in smart cities through alterations in business models and processes. A study by Anthony Jnr, B., Petersen, 2023 discusses the importance of implementing EA to support sustainable city development, identifying new variables such as knowledge transfer and support that facilitate successful EA adoption. In the work of Anthony Jnr, B. et al., 2021, the utility of EA in the context of smart cities is explored, and factors influencing its successful implementation are identified. Radu, Vodă, 2023 suggest that the COVID-19 pandemic has accelerated the digital transformation of smart cities, emphasizing its significance for citizens and public administrations. Guo et al., 2021 investigate how EA contributes to achieving organizations' internal orientation, identifying mechanisms that support this process. An analysis of the work by Petersen et al., 2019 underlines the importance of data-driven information systems for service de-livery in smart cities. Summarizing these studies, it is evident that the adoption of intelligent methods, particularly EA, is paramount for optimizing city management and enhancing the quality of life for citizens. They assist in adapting to modern world changes, such as the COVID-19 pandemic, and contribute to increasing efficiency and resilience of urban infrastructures, which are vital aspects of smart city development (Wołowiec, T., Pavlov, K., Pavlova, O. & Zaichuk, K., 2022).

In the research conducted by Anthony Jnr, B. et al., 2020, the digital transformation of virtual enterprises (VEs) in smart cities is examined, emphasizing the role of information and communication technologies (ICT) in the opportunities of new business models and VE processes to address urban growth challenges and social issues. ArchiMate modeling language was used in this study to illustrate the digitization of VEs for shared services in smart cities, highlighting the necessity of digital changes to improve citizen and stakeholder service.

In a related study, Anthony Jnr, B. et al., 2020 explored the management of digital trans-formation in smart cities through EA, recognizing the potential of digitalization for optimizing services and making significant changes in the ways citizens and stakeholders interact. The study reviewed 70 scientific articles from 1999 to 2020, revealing the development and contemporary possibilities of EA and its role in the digitization of smart cities.

Additionally, Anthony Jnr, B. et al., 2023 presented in their research an Enterprise Architecture Framework (EAF) to support smart cities in aligning information technologies (IT) and business strategies for the digitization of the urban environment. They employed a mixed-method approach, using quantitative data from questionnaires and qualitative data from group discussions to empirically validate the developed EAF. The conclusions highlighted the potential of the developed EAF in assisting enterprises in identifying and evaluating digitization initiatives and their impact on the adoption of EA for the digitization of the urban environment.

Furthermore, a comparative review of studies (Table 1) is provided, which are most similar to our research from the above analyzed ones, examining the current aspects of managing virtual companies in smart cities, indicating their novelty and key focuses.

Table 1. Comparative overview of studies on enterprise management in smart cities

Research	Novelty
Anthony Jnr, B. et al., 2023	Data Research on the impact of digital transformation on the functioning of virtual companies and the provision of collaborative services in smart cities
Anthony Jnr, B. et al., 2020	Analysis of the digitization of virtual enterprises and their collaboration in smart cities using the ArchiMate modeling language
Radu, L.-D., Vodă, A. I., 2023	Analysis of the impact of the COVID-19 pandemic on digital transformations in smart cities and the role of information technologies in crisis management
Guo, H. et al., 2021	Research on the influence of enterprise architecture on achieving organizational coherence and the development of digital ecosystems in smart cities
Anthony Jnr, B., 2020	Analysis of the management of digital transformation in smart cities through enterprise architecture approaches
Wang, K. et al., 2020	Evaluation of financial risks in supply chains for small and medium enterprises in smart cities
Petersen, S.A. et al., 2019	Implementation of innovative management systems, including virtual enterprises and data exchange within smart cities

Source: Development of the authors.

The studies by Anthony Jnr, B. et al., 2023 as well as Anthony Jnr, B. et al., 2020 serve as the nearest analogs to this research. Both delve into the impact of information technology and digital transformation on the functioning of virtual enterprises and service management in smart cities. However, our study introduces a novel contribution by focusing on the specific aspect of an intelligent management system in crisis situations and its impact on the stability and survival of virtual companies in smart cities. Additionally, our research emphasizes the use of artificial intelligence in developing the management system, a current trend in technology and business development.

3. ARCHITECTURE OF THE SUSTAINABLE INTELLIGENT SYSTEM

The management of virtual companies stands at the forefront of the socio-economic transformation, particularly within the evolving landscape of smart cities. As urban environments become increasingly digitalized and interconnected, the concept of virtual companies emerges as a pivotal component of this new reality. These entities, existing primarily in digital form, leverage cutting-edge technologies to operate, innovate, and interact with stakeholders in ways that traditional businesses cannot. This paper delves into the intricacies of managing such companies, recognizing the unique challenges and opportunities they present.

In addressing these challenges, our research draws upon the outcomes of previous studies and current advancements in data processing to propose a comprehensive framework for the lifecycle of a virtual company. This framework encompasses four key stages: the ideation and calculation of the virtual business concept, the creation of the virtual entity, its management, and eventual closure. Each stage is supported by a set of functional blocks within an intelligently designed system architecture, tailored to enhance the resilience and operational efficiency of virtual companies in crisis situations.

Key to this architecture is the application of machine learning for risk assessment and demand forecasting, the development of simulation models for business processes, and the strategic use of augmented reality and Large Language Models for dynamic management and multi-agent coordination. These technological innovations not only facilitate the foundational processes of registering and developing a virtual company but also enable adaptive management strategies and efficient communication channels with city authorities and stakeholders.

As embark on a detailed analysis of each functional block and its contribution to the system's intelligence, it's crucial to appreciate the broader implications of this research. The successful management of virtual companies in smart cities signifies a major step forward in harnessing the power of technology for socio-economic development. By navigating the complexities of the digital age with innovative solutions, we can unlock new potentials for growth, sustainability, and resilience in the urban ecosystems of the future.

To automate the management of virtual companies for smart cities, the authors analyzed the outcomes of their previous studies (Lipyanina, H. et al., 2020; Lipianina-Honcharenko, K. et al., 2022; Lipianina-Honcharenko, K. et al., 2023; Lipyanina, H., Sachenko, O. et al., 2020; Dulishkovych, O. et al., 2021), considering current research in data processing (Anfilets, S., et al., 2020; Lytvyn, V. et al., 2019; Komar, M. et al., 2017), and formulated four key stages of data processing for the intelligent system, subsequently developing its architecture (Figure 1):

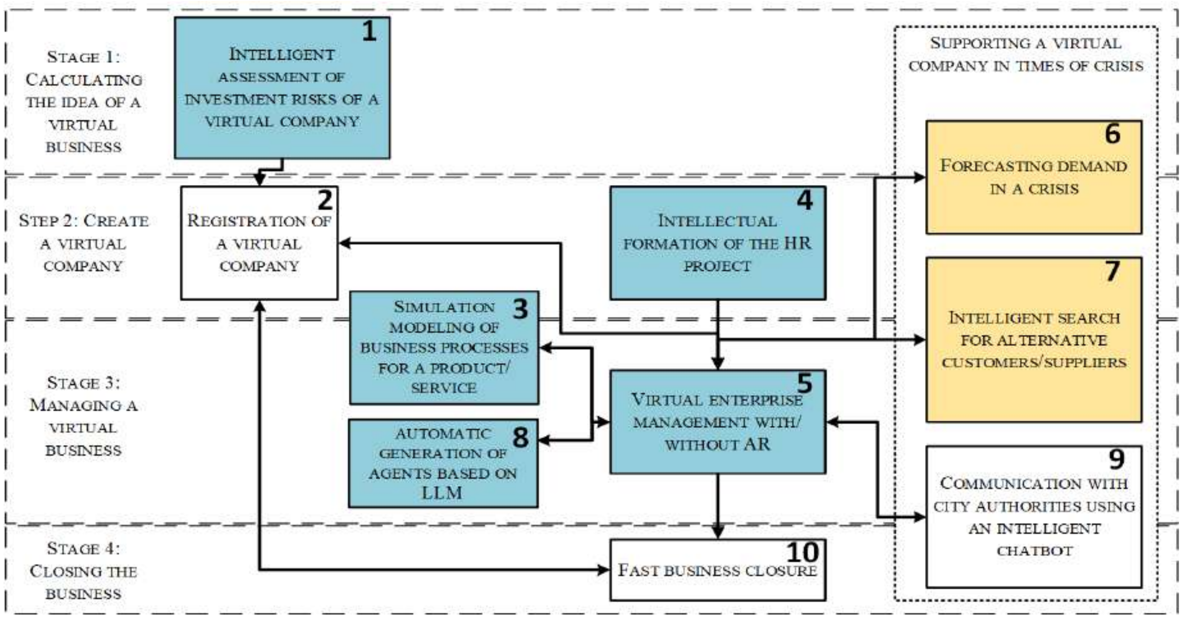
Stage 1: Calculation of the virtual business idea.

Stage 2: Creation of the virtual company.

Stage 3: Management of the virtual business.

Stage 4: Business closure.

Figure 1. Architecture of the Sustainable Intelligent System for Virtual Company Management in Smart Cities.



Source: Development of the authors.

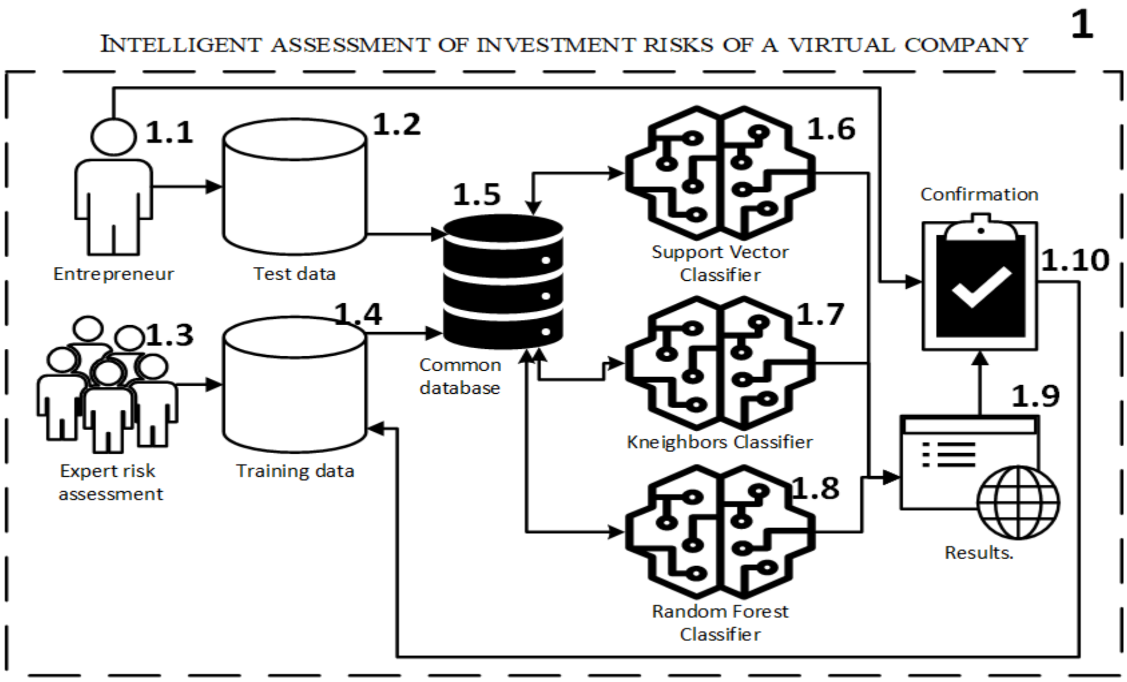
The proposed system (Figure1) for managing virtual companies in smart cities has its functional blocks at each stage to perform specific tasks. The first stage involves the assessment of investment risks for the virtual company using machine learning (Block 1) and forecasting demand in crisis conditions (Block 6). This enables the company to make informed decisions about establishing or developing a business during crisis situations. The second stage pertains to the creation of a virtual company and includes enterprise registration (Block 2), development of simulation models for business processes (Block 3), team formation using machine learning (Block 4), and further demand forecasting in cri-sis conditions (Block 6). This ensures the stability and efficiency of the virtual company in risky environments. The third stage encompasses the management of the virtual business with and without the use of augmented reality (Block 5), intelligent searching for alternative clients and suppliers (Block 7), and communication with city authorities (Block 9) using an intelligent chatbot. There's also the capability to automatically create and coordinate multi-agents based on Large Language Models (LLM) for performing various tasks and achieving different objectives. The final stage involves quick business closure (Block 10) and potential additional communication with city authorities (Block 9). Such a system aims to ensure resilience and successful management of virtual companies under the complex conditions of crisis situations.

Next, we will discuss the functional features of each block responsible for the sys-tem's intelligence and conduct a detailed analysis.

3. 1. INTELLIGENT ASSESSMENT OF VIRTUAL COMPANY INVESTMENT RISKS

The process of intelligently assessing the investment risks of a virtual company (Block 1, see Figure 1) involves a sequential series of steps to help entrepreneurs make in-formed decisions about investing in a virtual business. This process employs machine learning algorithms to analyze and predict risks based on input data. Let's delve into each stage of this process (Figure 2) for a better understanding of its intricacies and significance in decision-making in an unstable market environment and crisis situations.

Figure 2. Block for intelligent assessment of virtual company investment risks.



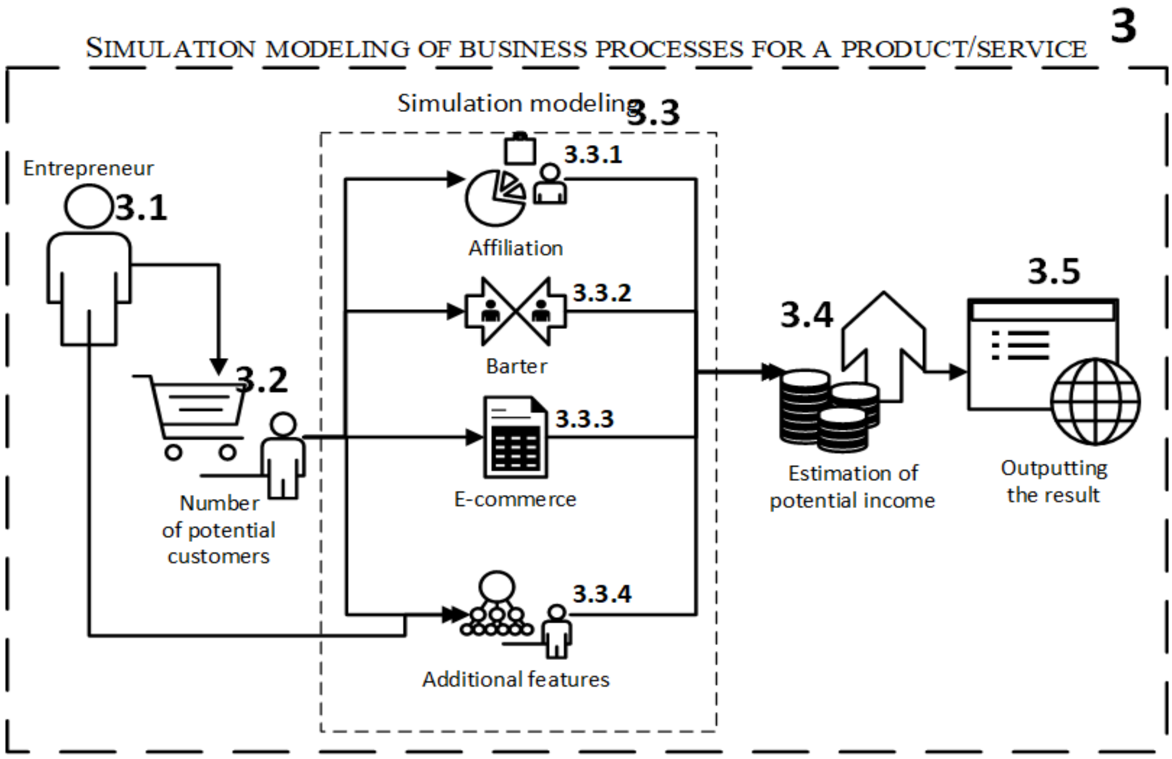
Source: Development of the authors.

In this process, the entrepreneur (Block 1.1) provides test data, which is transmitted to the test data set database (Block 1.2). Data from the test selection then moves to the general database (Block 1.5). Training data (Block 1.4) is formed based on expert assessment (Block 1.3) and added to the general database (Block 1.5). Risk assessment models, such as the Support Vector Classifier (Block 1.6), Random Forest Classifier (Block 1.7), and KNeighborsClassifier (Block 1.8), query the training data and retrieve it from the database (Block 1.5). After obtaining training data (Block 1.4), risk modeling is conducted for each method. The models query the test data (Block 1.2) for risk assessment and also retrieve it from the general database (Block 1.5). The obtained results are presented for further analysis and assessment by the entrepreneur (Block 1.1), who can provide their evaluation and confirm the result (Block 1.10). After confirming the result, data is included in the training data (Block 1.4) for further system use.

3. 2. SIMULATION MODELING OF BUSINESS PROCESSES FOR PRODUCTS/ SERVICES

Within the framework of simulation modeling of business processes for products/services (Block 3, see Figure 1), we will consider the data flow (Figure 3) and the sequence of operations. The initial step involves the entrepreneur (Block 3.1) inputting in-formation regarding the potential client base (Block 3.2) and opportunities (Block 3.4) for the product/service. From Block 2, information is further divided into components of the simulation model (Sousa, P. O., Salgado, A. C., 2019), such as Affiliation (Block 3.3.1), Barter (Block 3.3.2), E-commerce (Block 3.3.3), and Additional Opportunities (Block 3.3.4), which are also part of Block 3.3 - Simulation Modeling. The next step is modeling and estimating potential revenue (Block 3.4), which is then displayed on screen (Block 3.5) for review and decision-making by the entrepreneur. This model allows for analyzing various scenarios and predicting the out-comes of the product/ service activity based on the input data and parameters.

Figure 3. Block of simulation model of business processes for products/services.

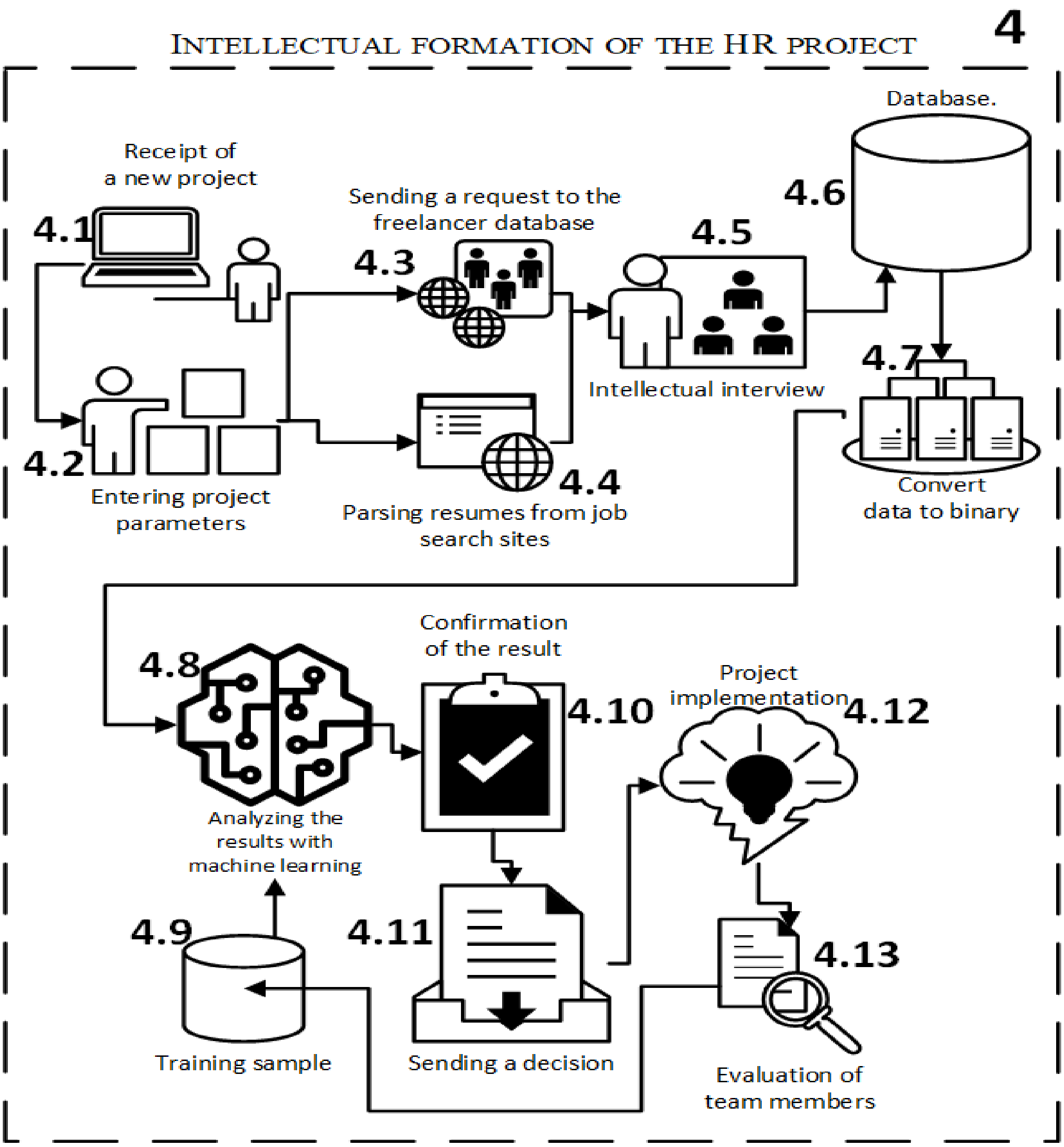


Source: Development of the authors.

3. 3. INTELLIGENT HR PROJECT FORMATION

The intelligent process of forming the HR team (Figure 4 and Block 4, see Figure 1) for a project based on machine learning begins with the introduction of a new project (Block 4.1), where the manager sets the project parameters. Next, the request to form a team and the manager's requirements are sent to the freelancer database (Block 4.3), and resume parsing (Block 4.4) from other resources is also conducted. The chatbot intelligently inter-views candidates (Block 4.5) using scenarios and parameters, and the results are stored in the database (Block 4.6). The obtained data is converted into a binary format (Block 4.7), after which it is used for analysis (Block 4.8) using machine learning methods and the training sample (Block 4.9). The manager can confirm or reject the result (Block 4.10), and in the case of a positive decision, the chatbot sends the decision to the approved candidates (Block 4.11). Once the team is formed, the project execution begins (Block 4.12), the manager evaluates the team members' work (Block 4.13), and this data is used to train the system (Block 4.9).

Figure 4. Block for intelligent HR team formation for a project.



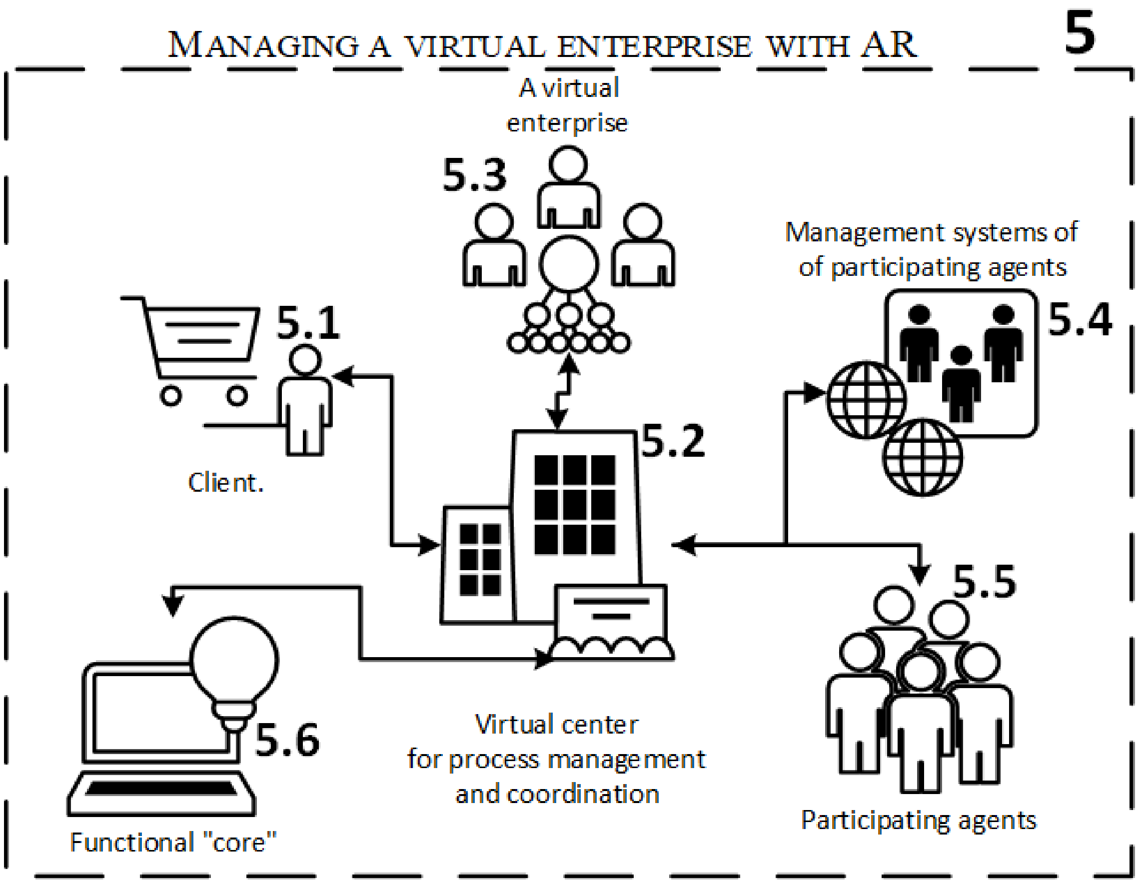
Source: Development of the authors.

3. 4. VIRTUAL ENTERPRISE MANAGEMENT

Virtual enterprise management (Figure 5 and Block 5, see Figure 1) is a complex pro-cess that requires the interaction of various parties and systems to achieve successful out-comes. In this context, clients (Block 5.1) interact with the virtual process management and coordination center (Block 5.2), where planning, management, and process control take place. The functional "core" (Block 5.6) combines various information systems and a database for the effective management of participant agents (Block 5.5) and their management systems (Block 5.4). Together, all these components form the virtual enterprise (Block 5.3), which operates and coordinates with clients and participant agents to provide products and services.

The connections between these blocks demonstrate essential communication chains, ensuring the optimal functioning of the virtual enterprise and meeting client needs.

Figure 5. Block for virtual enterprise management.

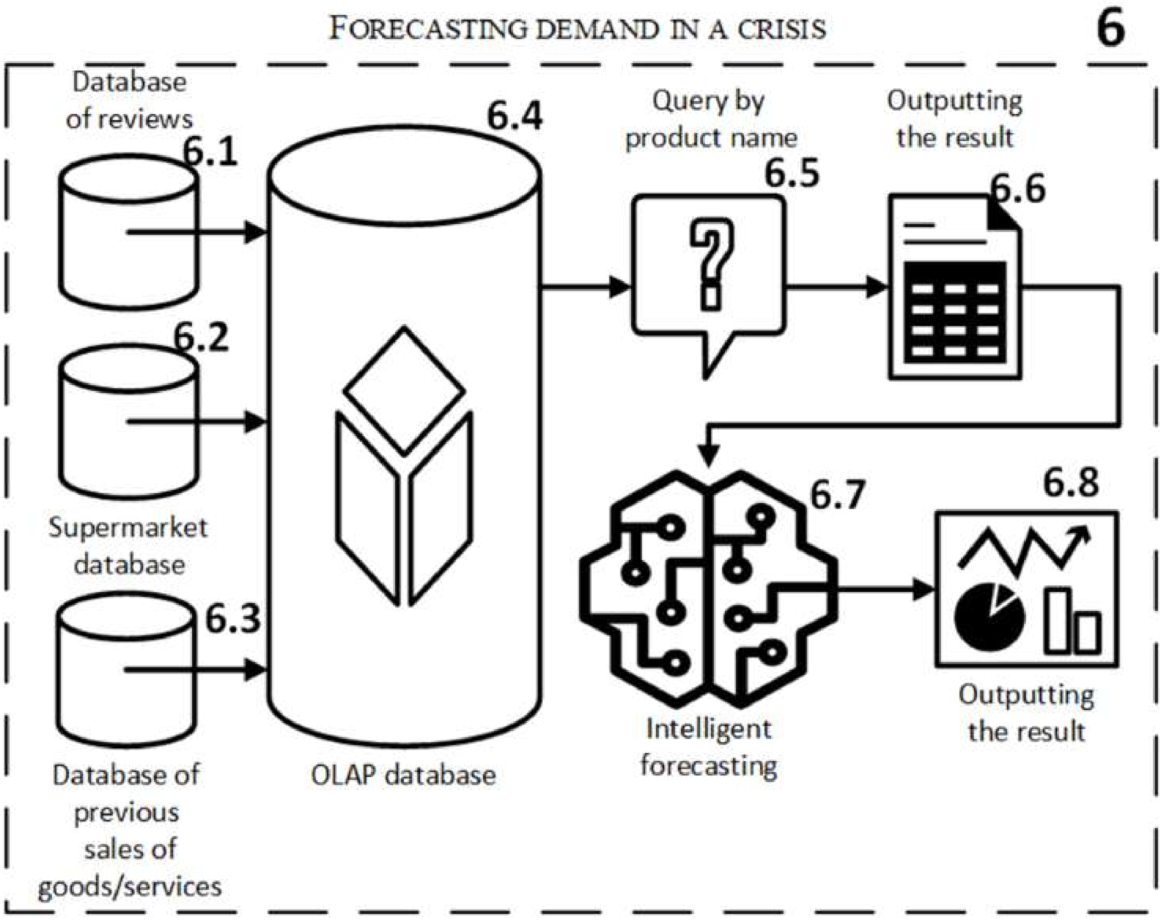


Source: Development of the authors.

3. 5. DEMAND FORECASTING IN CRISIS CONDITIONS

In crisis situations, there can be significant changes in the demand for goods and services (Block 6, see Figure 1), which complicates forecasting tasks for businesses. To respond to such changes and ensure effective inventory and production management, an approach for intelligent demand forecasting has been developed (Figure 6). The forecasting process begins with parsing customer reviews (Block 6.1) or collecting data from supermarkets (Block 6.2). Additionally, data on the sales of goods or services from previous years (Block 6.3) is inputted. This data converges in the OLAP database (Block 6.4) (Queiroz-Sousa, P. O., Salgado, A. C., 2019), where it is prepared for subsequent analysis. The system then queries product names (Block 6.5) and gathers data (Kovalchuk O. et al., 2022) on their demand over time, which is presented in a table (Block 6.6).

Figure 6. Block for demand forecasting in crisis conditions.



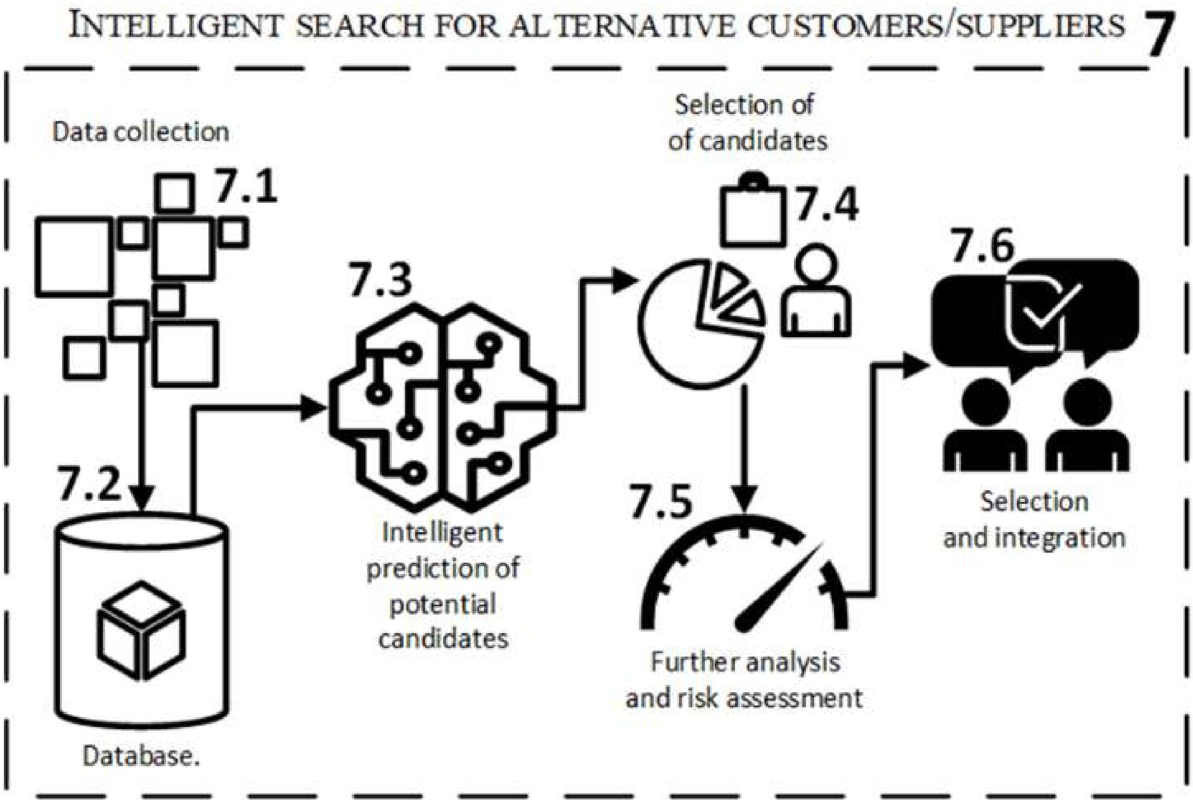
Source: Development of the authors.

Based on this data, the intelligent system (Block 6.7) develops a multi-level forecast, taking into account changes in consumer demand that may arise in crisis conditions. Forecasting results (Block 6.8) provide businesses the opportunity to pre-plan production and manage inventories in a way that meets the changing market needs. This approach helps reduce risks and optimize business processes in times of economic instability.

3. 6. INTELLIGENT SEARCH FOR ALTERNATIVE CLIENTS/SUPPLIERS

The process of intelligent search for alternative clients/suppliers (Figure 7 and Block 7, see Figure 1) starts with data collection (Block 7.1) from various sources, including social media and websites, and further storing them in an OLAP database (Block 7.2). The data then undergoes intelligent analysis (Block 7.3) using analytical methods and ma-chine learning algorithms to identify potential candidates. Selected candidates are assessed (Block 7.4), including risk and opportunity analysis, based on which a selection is made (Block 7.5). The final stage involves choosing and integrating the selected alternatives (Block 7.6), readiness for further collaboration, and using this data for strategic decision-making.

Figure 7. Block for intelligent search of alternative clients/suppliers.

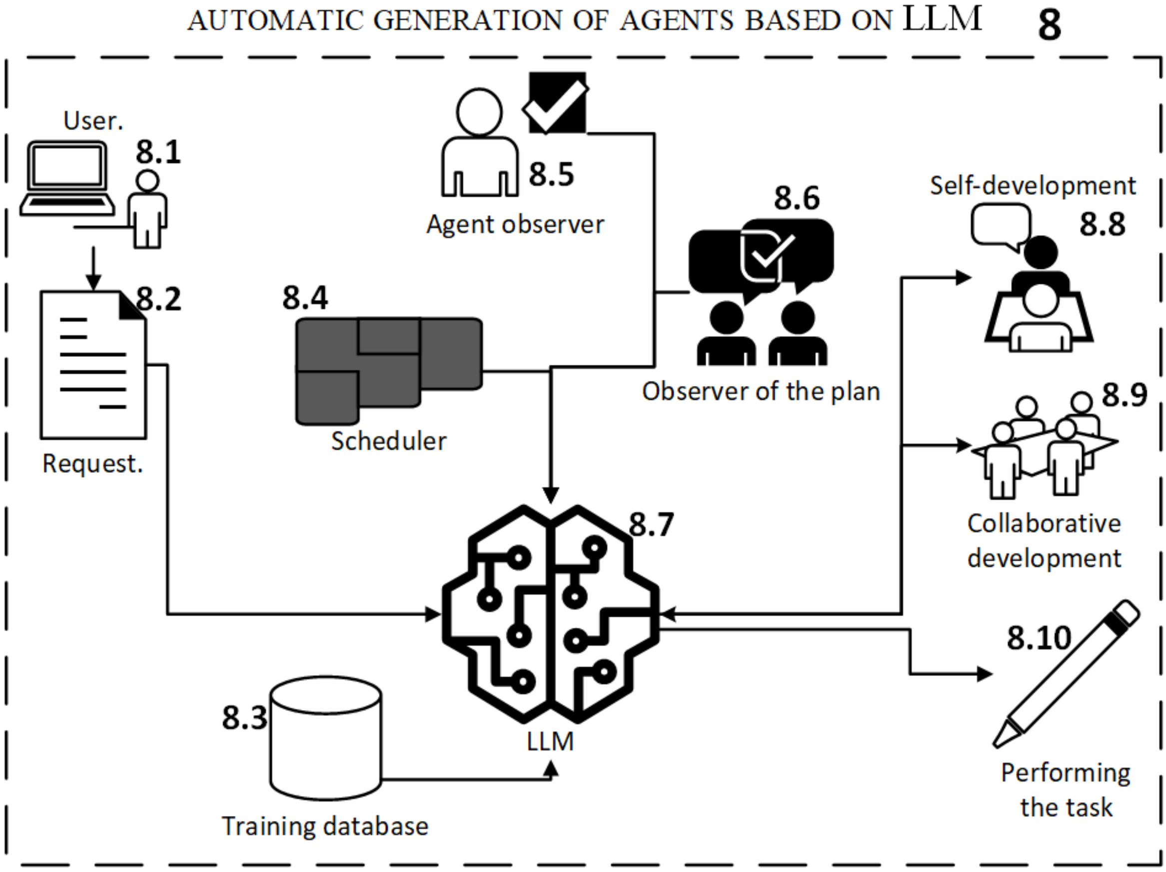


Source: Development of the authors.

3. 7. AUTOMATIC AGENT GENERATION BASED ON LLM

In the description of the automatic agent generation process (Chen, G. et al., 2023) (Figure 8 and Block 8, see Figure 1), the user (Block 8.1) sends a request to solve a task, which is directed for analysis to the LLM model (Block 8.7). Here, the request is processed and analyzed for further planning and task execution. The training database (Block 8.3), scheduler (Block 8.4), agent observer (Block 8.5), and plan observer (Block 8.6) also interact with the LLM model, providing additional information, agent evaluations, and plan analysis. On the other hand, agents can self-develop (Block 8.8) and collaborate (Block 8.9) based on advice and knowledge acquired from the LLM model. Finally, the LLM model creates a task exe-cution plan, which is passed on for implementation (Block 8.10). This interaction enables the system to efficiently create and manage agents for diverse tasks.

Figure 8. Block for automatic agent generation based on LLM.



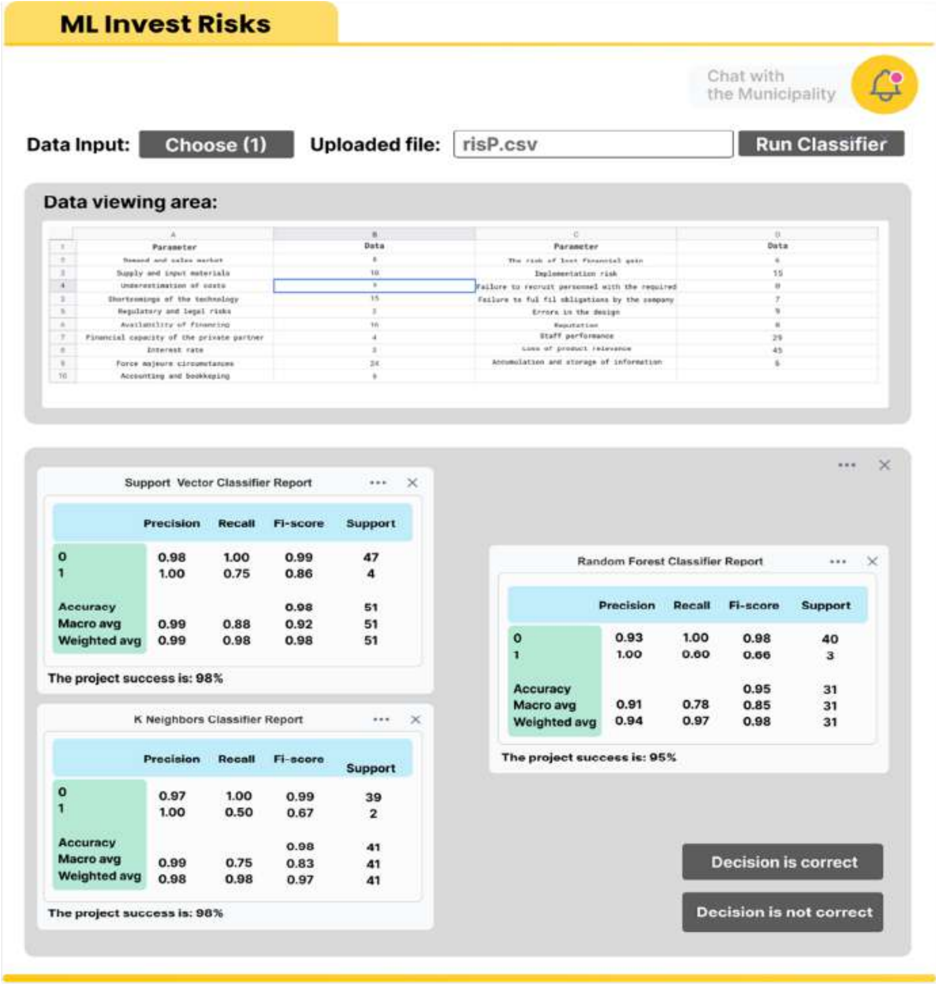
Source: Development of the authors.

4. RESULTS

Let's consider the implementation of the proposed architecture of the Intelligent System for Managing Virtual Companies for the Smart City using a web-oriented system, simplifying user interaction without requiring installation on their computers. For clarity, we'll explore the business project "SmartMed", aimed at developing and implementing an innovative medical system in a smart city. This business project encompasses components like telemedicine, collection and analysis of medical data, as well as providing health and treatment recommendations via artificial intelligence insights. Additionally, the system allows real-time communication with city authorities through a chatbot (see Figure 9-17).

Thus, in the initial phase (see Figure 1. Block.1 and Figure 2), a potential entrepreneur inputs business idea information (see Figure 9). Risk assessment for a potential company in a smart city indicates a multi-level spectrum of factors that can impact business success. Demand and sales market (8 points) and supply of raw materials (10 points) define market conditions and raw material availability. Included in the assessment is the danger of underestimating costs (5 points) and technological flaws (15 points), affecting financial stability. Availability of funding (16 points) and the financial capability of a private partner (4 points) determine resources. Interest rate assessment (3 points) and force majeure circumstances (24 points) indicate financial and economic risk. Accounting (9 points) and reputation management (8 points) help ensure financial control. Staff performance (29 points) and product obsolescence (45 points) define key success factors. Failures in hiring qualified staff (0 points), non-performance of obligations (7 points), design errors (9 points), the risk of missed financial benefits (6 points), and implementation risk (15 points) are taken into account for internal control and efficient management.

Figure 9. Window for the intelligent assessment of investment risks of a virtual company.



Source: Development of the authors.

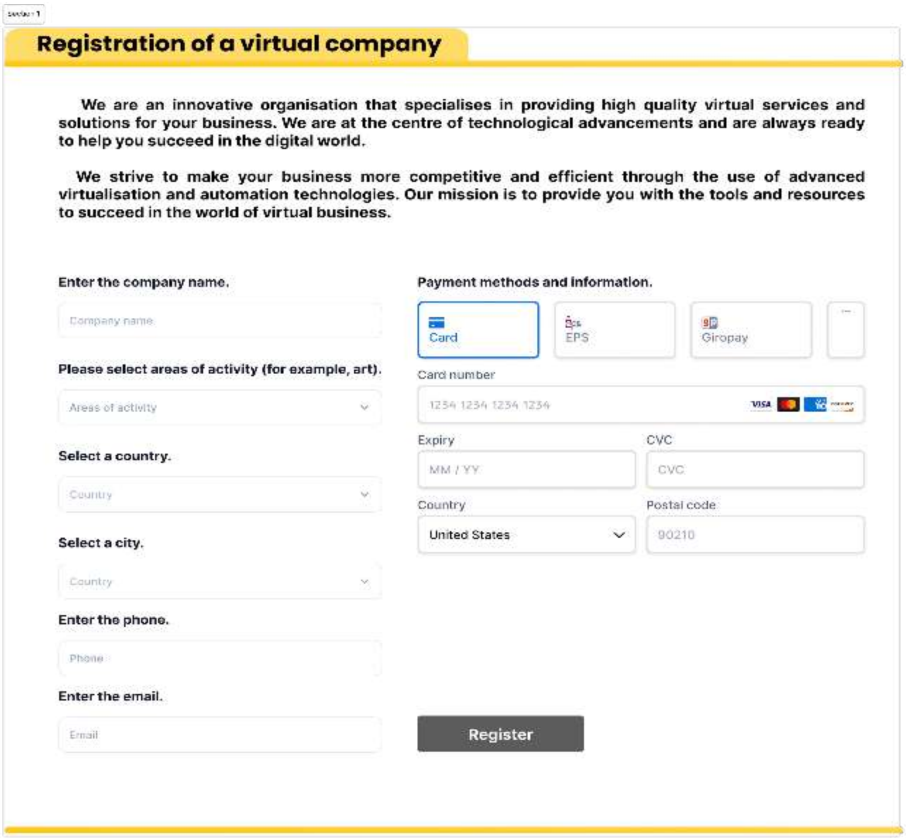
The proposed system uses different risk assessment models, such as Support Vector Classifier, Random Forest Classifier (Kovalchuk, O. et al., 2023) i KNeighborsClassifier for data analysis. These models receive training and test data from the database for risk assessments. Assessment results are presented to the entrepreneur for further analysis (see Figure 9). The project re-sults showed a very high success rate in risk assessment for the virtual company. Risk assessment models such as Support Vector Classifier, Random Forest Classifier, and KNeighborsClassifier showed good performance indi-cators: 98%, 95%, and 98% respectively. This demonstrates their ability to provide reliable and accurate risk forecasts, aid-ing the entrepreneur in making informed investment decisions in a smart city. The overall project success in risk assessment reflects the system's high efficiency and its capability to ensure reliable risk analysis and management for business in an unstable market environment.

Next, the entrepreneur (see Figure 1, Block 2) has the opportunity to input information about their virtual company directly into the system (Figure 10). They can enter the company name, choose the industry, specify the location, provide payment details, indicate the contact phone number, and email address.

The system then allows for simulating a potential customer flow and revenue from them (see Figure 1, Block 3, and Fig 3). In the context of the "SmartMed" company, the entrepreneur can specify the potential number of clients and additional services directly in the system. The presented simulation model structure then forecasts the revenue stream. In this case (Figure 11), each business process is represented as a separate stream, including "Affiliation", "Barter", "E-commerce", "Shared Ownership", and "Money". The "Affiliation" stream depends on the

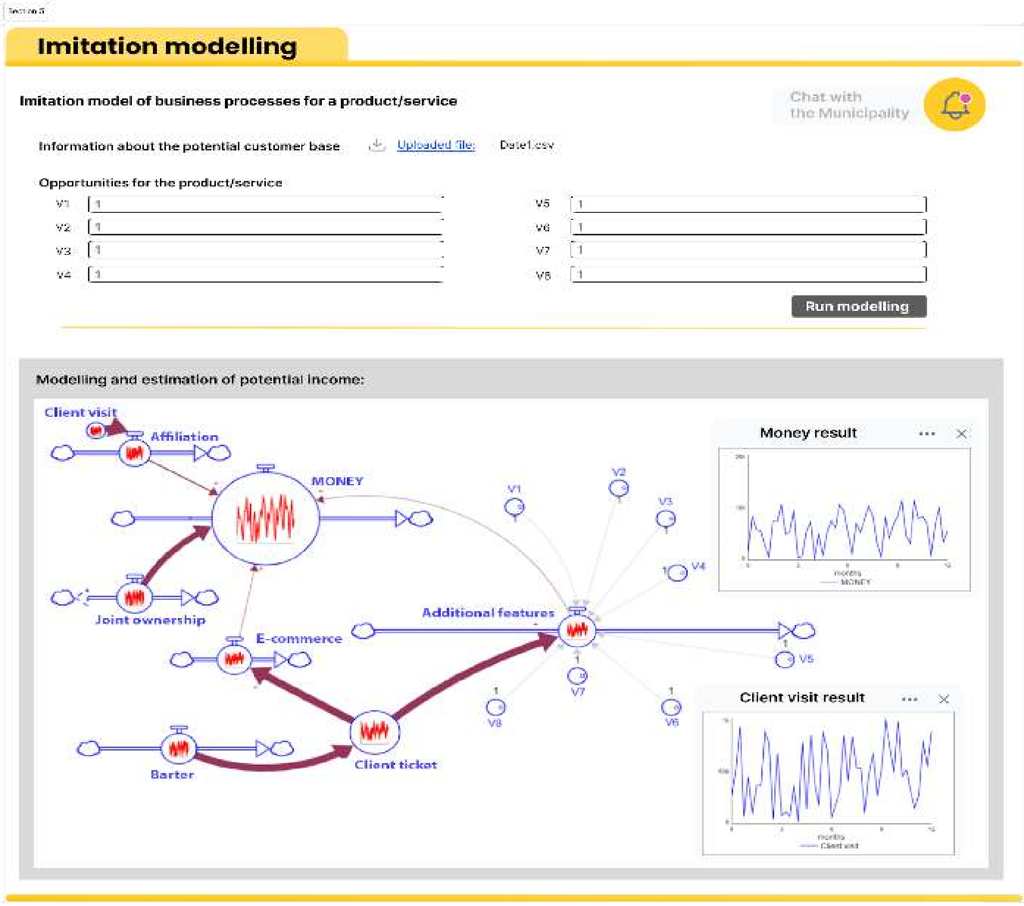
"Client Visits" parameter, the "Barter" stream affects only the number of clients and depends on the "Money" stream, while the "E-commerce" stream only affects clients. However, the "Shared Ownership" stream has the most influencing parameters due to additional opportunities. Additional opportunities V1-V8 for "Smart-Med" might include innovative features such as the ability to remotely consult patients through virtual meetings (V1), personalized health programs and recommendations based on data analysis (V2), interactive training sessions and exercises for rehabilitation (V3), health monitoring via wearable devices (V4), reminder systems and medical event calendars (V5), the introduction of virtual reality for psychotherapy and stress reduction (V6), a platform for exchanging medical information between doctors and patients (V7), and the use of artificial intelligence for disease diagnosis and prediction (V8).

Figure 10. Virtual company registration window.



Source: Development of the authors.

Figure 11. Simulation window for business processes for a product/service.



Source: Development of the authors.

Within the system, entrepreneurs have the opportunity to intelligently select the best employees for their medical business (see Figure 1, Block 4, and Figure 4). This is achieved through an intelligent process of HR team formation using a chatbot, which assists in finding ideal candidates, considering their skills, experience, and personal qualities.

To implement the intelligent chatbot, the development environment chosen was DialogFlow (Dialogflow, 2024). DialogFlow allows for the creation of agents - modules for natural language understanding (NLP - Natural Language Processing). Questions for the chatbot were formulated based on both soft and hard skills (Hendarman, A.F., Cantner, U., 2018; Iorio, S. et al., 2022). All these questions are entered into a database (Table 2) and there's always the possibility of expanding this list and adjusting it according to needs and requirements, which is uploaded in csv format. For effective machine learning application in our study, a test sample is needed, which includes ideal candidates with specified answers (Table 2). Since perfect candidates don't exist in an ab-solute sense, the entrepreneur (Figure 12) enters the ideal candidate (in the csv file) into the training sample, who will best match the job requirements.

Table 2. Sample of typical interview questions for employees

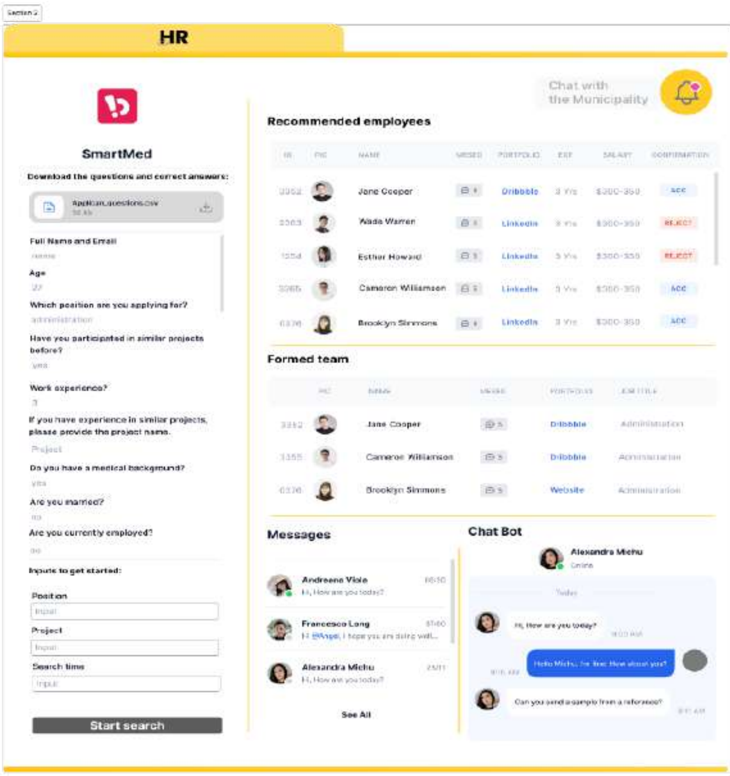
ID of the question	Question	Perfect answers	Data type
1	Last name and first name, email	name	Object
2	Age	27	int64
3	What position are you applying for?	Administration	Object
4	Have you participated in similar projects?	yes	Bool
5	How old are you?	3	int64
6	If you have had experience in similar projects, please write the name of the project?	Project	Object
7	Do you have a medical degree?	yes	Bool
8	Are you married?	no	Bool
9	Are you currently working?	no	Bool
10	Do you have experience with modern medical technologies and equipment?	yes	Bool
11	Are you willing to learn and improve your medical skills?	yes	Bool
12	Do you know how to communicate effectively with patients and their families?	yes	Bool
13	Are you ready to adhere to the standards of medical ethics and confidentiality?	yes	Bool
14	Do you have experience working in emergency situations and are ready to act in critical moments?	yes	Bool
15	Do you have the skills to work in a team and collaborate with other medical professionals?	yes	Bool
16	Are you ready to work with patients of different ages and in a structured work schedule?	yes	Bool
17	Do you intend to work at SmartMed on a long-term basis?	yes	Bool

Source: Development of the authors.

After this, the entrepreneur specifies the time he allocates for candidate search (Figure 12). Our system initiates the candidate search process, which includes parsing resumes and sending requests to freelance sites. Following this, the system starts a dialogue with potential candidates, exploring their skills and experience. Based on the acquired data, the system creates a selection of the best applicants using the RandomForestClassifier method and sends the results to the entrepreneur for review and approval. If the entrepreneur is unsatisfied with the outcome, he has the option to restart the search and selection to find the most suitable candidates.

From the classification results, it's evident that candidates with ID=3352, 2363, 1254, 3365, 0376 (Figure 12) have the best qualifications for the "SmartMed" administrator position. These applicants provided answers closest to the ideal ones. Next, the entrepreneur chooses those who appeal to him the most and forms his team.

Figure 12. Window for intelligent selection of the best employees.

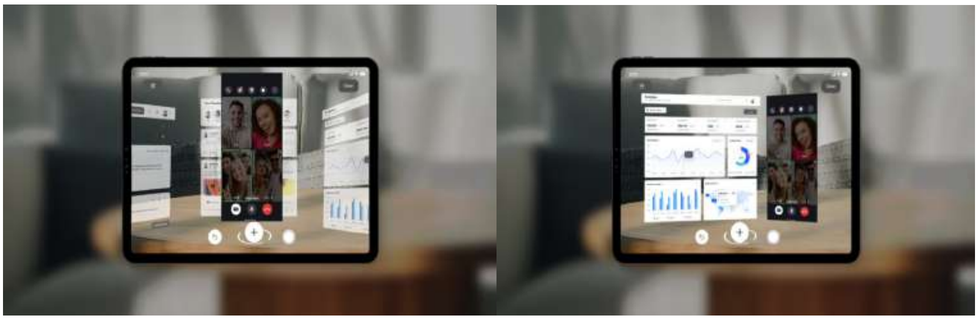


Source: Development of the authors.

Additionally, within the framework of the Intelligent System for Managing Virtual Companies for the Smart City, access to augmented reality mode is available (see Figure 1, Block 5, and Figure 5), which allows integrating various AR-spaces for different needs.

Visualizing this using the administrative management example (Figure 13), the AR space creates a virtual workspace where employees can interactively engage with documents, track work processes, and collaborate effectively with colleagues. This enhances the work process in the administrative areas of "SmartMed," simplifies documentation processing, and provides a more convenient and productive collaboration method for the company staff.

Figure 13. AR-space window for administrative management.



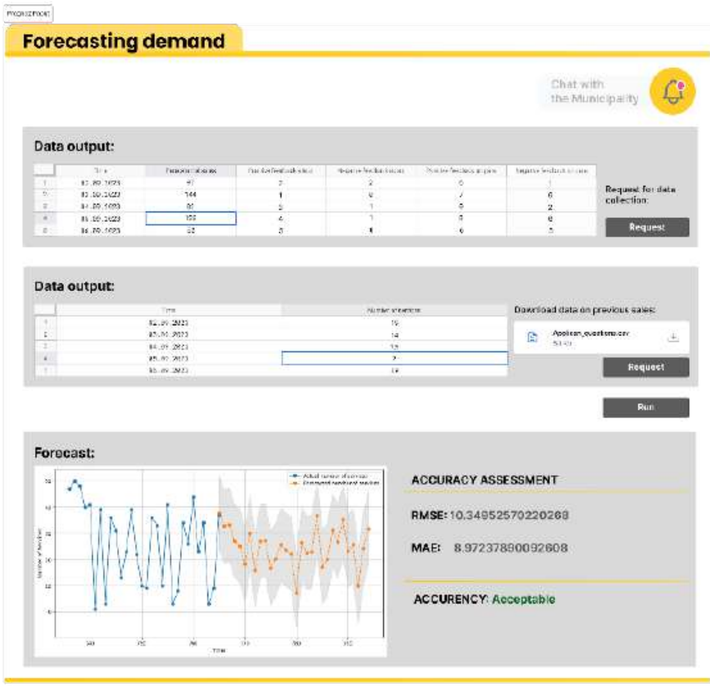
Source: Development of the authors.

Further for "SmartMed", intelligent demand forecasting is presented (see Figure 1, Block 6 and Figure 6), taking into account crisis situations (Figure 14), which allows for effective responses to such changes and optimization of inventory and production management. For the entrepreneur, the forecasting process starts with a data collection request from various sources (Figure 14). The system autonomously parses client reviews from online sources (e.g., websites, social networks) and receives data from supermarkets and pharmacies about medical goods. Also, the system receives data about the sales of goods and services from previous years. Based on forecasting methods, results are derived, providing the business with the opportunity for strategic company management. This task will be further investigated in subsequent scientific papers.

In this example, a forecast for the parameter "number of services" is made based on other parameters, such as "paracetamol sales", "positive feedback about the service", "negative feedback about the service", "positive feedback on paracetamol", and "negative feed-back on paracetamol", using the HistGradientBoostingRegressor model (Sharma, S. et al., 2023). After training this model on the data, a forecast for each of the parameters "paracetamol sales", "positive feedback about the service", "negative feedback about the service", "positive feedback on paracetamol", and "negative feedback on paracetamol" is made using the XGBoost meth-od for 10 days in the future. After receiving these forecasts, a forecast for the "number of services" parameter is constructed for the same period using the previously obtained fore-casts, considering the interrelationships between these parameters.

The obtained (Figure 14) RMSE (Root Mean Square Error) and MAE (Mean Absolute Error) values (Duhan, M., Bhatia, P. K., 2022) indicate the accuracy of the model's forecast. An RMSE of approximately 10.35 measures the root mean square error between the actual and predicted values. A higher RMSE value indicates that the root mean square error is about 10.35 units. An MAE of approximately 8.97 measures the average absolute error between the actual and pre-dicted values. A lower MAE value indicates a smaller average absolute error, reflecting better accuracy of the model's forecast. Therefore, the obtained results indicate that the model demonstrates acceptable accuracy in forecasting the number of services.

Figure 14. Intelligent demand forecasting window.



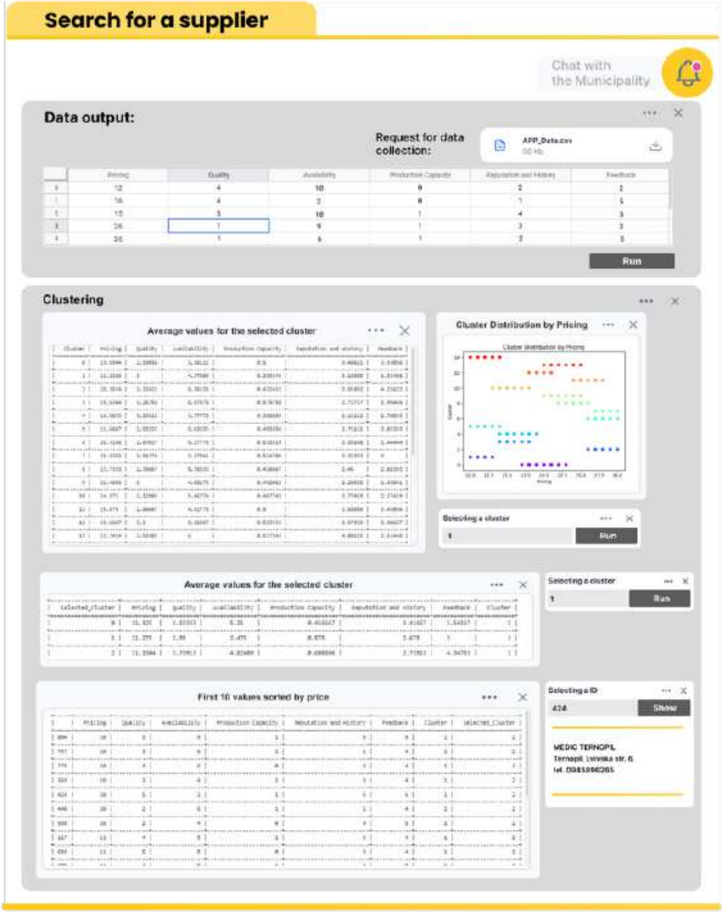
Source: Development of the authors.

Within the framework of the Intelligent System for Managing Virtual Companies for the Smart City, there's a distinctive feature which becomes especially crucial in the context of crisis situations. This is the process of intelligent search for alternative clients and sup-pliers (see Figure 1, Block 7, and Figure 7), which assists businesses, like "SmartMed," in responding to shifts in demand and market conditions during crises, ensuring they find new avenues to sustain and grow their business.

Entrepreneurs initiate a data collection request (Figure 15) from various sources, such as social media, websites, and other online platforms. This process begins with gathering data on potential suppliers, considering parameters like price, quality, product availability, production capacity, reputation, and other vital factors for the business. A clustering method, for instance, K-Means (Sirola, M., Hulsund, J. E., 2021), is then applied to group suppliers into clusters with similar characteristics. A particular cluster is then selected, which matches selection criteria like the lowest price and high quality. The final stage involves analyzing results, including averaging values and selecting the best supplier among shortlisted candidates.

In this case (see Figure 15), crucial criteria might be cost-effectiveness and product quality. Based on these parameters, one of the potential candidates could be supplier 424 with a low price (10 points) and excellent quality (5 points). Additionally, quick delivery (3 days), a good reputation (5 points), and positive reviews (5 points) could also be im-portant. This candidate stands out from others due to its competitive pricing and positive market reputation, making it an attractive choice for businesses.

Figure 15. Window for intelligent search of alternative suppliers

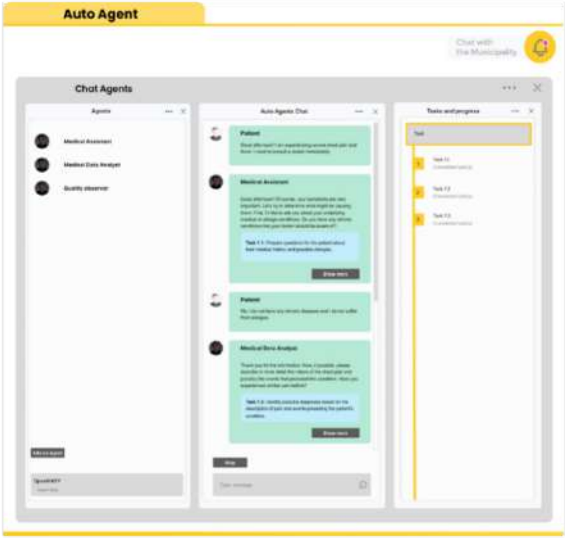


Source: Development of the authors.

In the “SmartMed” process, a patient sends a request for a medical consultation through the virtual system (see Figure 1, Block 8, and Figure 8). This request goes to the LLM model for analysis, where it undergoes processing and examination with the objective of planning and executing the task, namely providing the medical consultation. During the query analysis, the LLM model acquires additional information from the training database, the planner, agent observer, and plan observer for a more detailed examination and consultation plan formulation.

For the “SmartMed” system’s consultation implementation (Figure 16), various agents play a significant role, including a medical assistant, medical data analyst, and quality observer. When the patient communicates their symptoms, the medical assistant responds by asking additional questions to determine the patient’s medical history (Task for the doctor). Concurrently, the medical data analyst conducts an analysis of the entered data and attempts to determine potential diagnoses (Task for the doctor). The quality observer plays a role in ensuring the quality of medical services and procedures. After the patient analyses their symptoms, they confirm the need for immediate medical assistance (Task for the doctor). Finally, after all these interactions and analyses, the LLM model generates a specific action plan for providing the medical consultation and forwards it for execution. This interaction and data processing allow the “SmartMed” system to effective-ly provide medical consultation and respond to situations requiring immediate assistance.

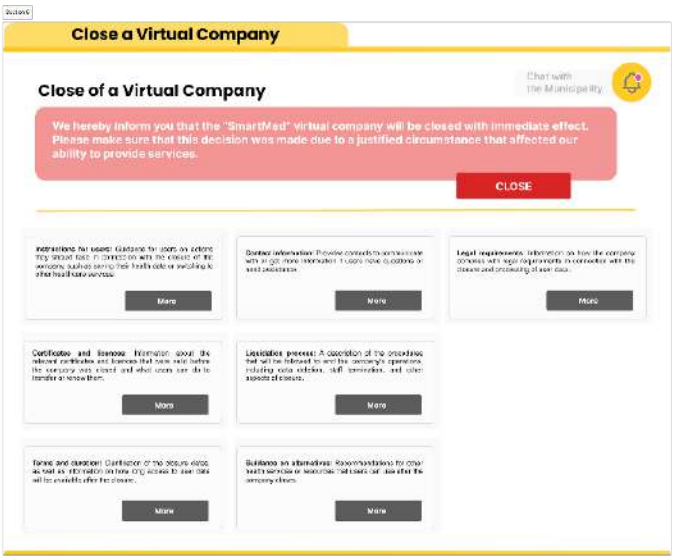
Figure 16. Window for the automatic generation of agents based on LLM



Source: Development of the authors.

The rapid closure (Figure 17) of a virtual company entails ceasing its operations and suspending all services and activities related to the company's functioning and data analysis. This may occur due to financial difficulties, strategy changes, business closure, or other circumstances. Closure includes terminating user access to the system, storing data in compliance with confidentiality requirements and legislation, informing users about the cessation of operations, and the liquidation of the company's resources and infrastructure.

Figure 17. Window for the rapid closure of a virtual company



Source: Development of the authors.

Below is a comparative Table 3 of research analogues and the Intelligent Management System for Virtual Companies for the Smart City. The advantages and disadvantages of the research and system are highlighted.

Table 3. Comparative analysis of research analogues with the proposed system

Parameter	Study 1	Study 2	The proposed system
General content of the study	Smart city development and architectural approaches	Digitalization of virtual enterprises in smart cities	Management of virtual companies in smart cities
Use of management models	Yes	Yes	Yes
The use of information technology	Yes	Yes	Yes
Application of machine learning	No	No	Yes
Use of augmented reality	No	Yes	Yes
Availability of all stages of management in one system	No	No	Yes

Source: Development of the authors.

The proposed system offers a detailed architecture and functionality for managing virtual companies in crisis situations. It employs innovative technologies, such as ma-chine learning, for risk assessment and demand forecasting. Also, the system provides detailed functional blocks at every development stage of virtual companies. Compared to studies by Anthony Jnr, B., Petersen, S.A., 2023; Jnr, B. et al., 2020, the proposed system has a more extensive functionality for managing crisis situations in smart cities.

To evaluate the effectiveness of the proposed system based on expert data, Table 4 was created, indicating the time taken to solve tasks with the system, considering data input, and the time taken to solve tasks without using the system. The system's effective-ness is calculated relative to the average value among benchmark indicators.

Table 4. Evaluation of the effectiveness of the developed system

Action	Hour with system	Time without the system	Efficiency
Investment risk assessment	~1-3 year	~2-60 days	~99,72%
Simulation modeling of business processes	~1-2 year	~14-90 days	~99,84%
Formation of HR	~1-120 year	~5-30 days	~80,00%
Forecasting demand in a crisis	~1-5 year	~1-5 days	~95,83%
Search for alternative customers and suppliers	~1-5 year	~7-60 days	~99,61%
Average indicator	~5-120 year	~14-90 days	~95,00%
Investment risk assessment	~1-3 year	~2-60 days	~99,72%

Source: Development of the authors.

Thus, the Intelligent System for Managing Virtual Companies for the Smart City proved to be highly effective (see Table 3), providing impressive efficiency indicators compared to the situation without its use (task execution time decreased on average by 95%). The efficiency evaluation based on average values shows that implementing the system significantly reduced the time required for a series of critical operations, such as investment risk assessment, simulation modelling of business processes, demand forecasting in crisis conditions, and searching for alternative clients and suppliers. It's especially worth noting the high level of efficiency in tasks related to investment risk assessment and simulation modelling. All of this contributes to enhancing the efficiency of managing virtual companies in smart cities and promotes their resilience even in crisis situations.

5. DISCUSSION

In crafting the Sustainable Intelligent System for Virtual Company Management in Smart Cities, especially designed for crisis scenarios, each task plays a pivotal role in ensuring the system's operational efficiency. These tasks have facilitated the integration of advanced technologies across all aspects of virtual company and smart city management, aligning with the principles of socio-economic sustainability.

The innovative approaches to risk assessment introduced by our system significantly improve the accuracy and reliability of evaluations. This enables companies to manage investments with greater efficacy amidst socio-economic uncertainties. Through simulation-based business process modeling, companies can conduct research and develop new products and services without excessive expenditure of resources, reflecting a commitment to socio-economic efficiency and innovation. The application of intelligent methods for team formation enhances productivity and ensures that personnel qualifications match the necessary tasks, addressing critical socio-economic objectives such as employment quality and workforce optimization.

Our system equips entities with all the essential tools and resources for the effective real-time management of virtual companies, bolstering their stability and growth within the socio-economic fabric of smart cities. Machine learning models incorporated into the system allow enterprises to accurately predict demand in times of crisis, aiding in the optimization of inventory and production management from a socio-economic standpoint. Data clustering and analysis techniques enable the identification of optimal partners, supporting businesses through socio-economic challenges. Additionally, the automated generation of agents based on Large Language Models (LLM) streamlines communication with stakeholders and partners of virtual companies, ensuring swift and high-quality support, which is vital for maintaining socio-economic relations and trust.

This comprehensive incorporation of advanced technologies not only elevates the efficiency of virtual company management in smart cities but also underscores the system's commitment to fostering a resilient and competitive socio-economic environment.

Compared to previous research in the domain of managing virtual companies for smart cities, our work stands out due to its crucial feature - the integration of intelligent technologies, such as machine learning and augmented reality, into a cohesive system. The models and methods introduced in this article, including the simulation modeling of business processes and automatic agent generation based on LLM, unveil new possibilities for virtual company management. These applications aim to enhance the quality and efficiency of managing virtual companies in smart cities, especially during emergencies and crisis situations.

The implemented system showcased high efficiency (task execution time decreased on average by 95%). Average values indicate that employing the proposed system significantly reduces the time required for critical operations, such as investment risk assessment, simulation modeling of business processes, demand forecasting during crises, and searching for alternative clients and suppliers. Particularly worth highlighting is the high efficiency in investment risk assessment and simulation modeling. All these contribute to improving the efficiency of managing virtual companies in smart cities and fortifying their resilience, even in crisis situations.

Among the limitations, it's noteworthy that the system currently relies on existing data and models, and further refinement can be achieved by implementing newer ma-chine learning and data analysis methods. Additionally, the system is limited in terms of data source accessibility and interaction capabilities with third-party applications.

Furthermore, in the context of the Sustainable Intelligent System for Virtual Company Management in Smart Cities, these limitations highlight the need for continuous evolution in sustainability-focused data integration and analysis. Enhancing the system's ability to interact with diverse data sources and third-party applications is crucial for achieving a more holistic and sustainable approach to managing virtual companies in smart cities. This would not only improve the system's adaptability to dynamic urban environments but also bolster its capacity to respond effectively to sustainability challenges and crisis situations in smart cities.

Potential further research opportunities encompass expanding the system's functionality to include new facets of virtual company management, such as the introduction of additional intelligent agents or the development of more detailed forecasting models. Integration with other information systems and broadening the system's application scope beyond virtual company management are also plausible. Such research endeavors can facilitate the further evolution and refinement of intelligent information systems in the context of smart cities and assist enterprises in better adapting to crisis situations and emergencies.

Building on these insights, future research could also explore the integration of sustainability metrics and practices within the Sustainable Intelligent System for Virtual Company Management in Smart Cities. This could involve developing modules that specifically focus on environmental impact assessment, resource optimization, and sustain-able business practices. Additionally, enhancing the system's capability to analyze and respond to urban sustainability challenges, such as energy management and waste re-duction, could significantly contribute to the broader goals of smart cities. By incorporating these elements, the system would not only aid virtual companies in navigating crisis situations but also align their operations with the sustainability objectives of smart cities. This holistic approach would further empower companies to operate efficiently while contributing positively to the urban ecosystem, reinforcing the synergy between business resilience, intelligent management, and sustainable urban development.

In summary, the results from implementing tasks within the Sustainable Intelligent System for Virtual Company Management in Smart Cities strongly highlight its considerable potential, notably in managing crisis scenarios with a socio-economic lens. This system furnishes companies with the necessary tools to uphold resilience and efficiency across diverse socio-economic conditions, facilitating streamlined management and decision-making processes. Importantly, it advocates for a smart, sustainable approach to addressing the socio-economic challenges that might impede success, providing businesses with the agility to quickly adjust to changing socio-economic landscapes and preserve their competitive advantage. This focus ensures that virtual companies can not only navigate the complexities of modern urban economies but also contribute positively to the socio-economic wellbeing of smart cities.

6. CONCLUSION

In the realm of smart cities, where socio-economic dynamics play a crucial role, particularly under crisis conditions, the significance of e-commerce is heightened. The Sustainable Intelligent System for Virtual Company Management in Smart Cities stands out by effectively forecasting demand, optimizing inventory, and identifying alternative supply strategies, enabling e-businesses to adeptly navigate the uncertain socio-economic landscapes. This intelligent system facilitates increased efficiency and resilience, ensuring the success of e-commerce ventures even in the face of challenging crisis scenarios. Our research focuses on the development of this intelligent system to tackle the varied management challenges that virtual companies encounter in smart cities amid socio-economic upheavals.

The findings from our investigation indicate that the developed system has considerable potential in managing a wide array of tasks related to the operation of virtual companies in smart cities. It supports more precise and timely decision-making processes, encompassing intelligent investment risk assessment, business process simulation modeling, resource management, demand forecasting, identification of alternative clients and suppliers, and the automation of agent generation using Large Language Models (LLM). By equipping entrepreneurs and local governments with such tools, the system encourages the cultivation of a more resilient and competitive socio-economic environment within contemporary smart cities.

Compared to analogous systems, our proposed solution stands out for its comprehensive focus on navigating socio-economic challenges in smart cities during crises. Leveraging advanced technologies such as machine learning and augmented reality, it enhances productivity and the precision of decision-making. The integration of an intelligent chatbot and the automation of agent generation based on LLM facilitate efficient user interaction and process automation. This holistic approach unifies all aspects of management into a cohesive system, streamlining the management processes for virtual companies for entrepreneurs.

Proposing this intelligent system signifies a pivotal advancement in the management of virtual companies in smart cities, particularly amidst socio-economic challenges. Future research could delve deeper into assessing the system's practical effectiveness, expanding its functionalities, and exploring additional dimensions of virtual company management in smart cities. This system paves new paths for entrepreneurs and local governments to attain greater efficiency and stability within the urban socio-economic framework. Developing such intelligent systems is vital in progressing towards smart cities that not only improve residents' quality of life but also ensure a stable socio-economic business environment.

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