Proceedings of the 8th International
Scientific and Practical Conference
«Progressive Science and Achievements»

(September 6-8, 2026).
Dallas, USA

No
308

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Application and Adaptation of Data Mining for Innovative Crisis Management of Transport and Logistics Enterprises Under Environmental Turbulence and Systemic Risk (within the WARMI Paradigm)

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Abstract. The article explores the features and specifics of the application of Data Mining technologies in innovative anti-crisis management by transport and logistics companies in the service sector under the WARMI paradigm. The key areas of use of intelligent data analysis are identified: forecasting, anomaly detection, classification, clustering and early detection of crisis signals. The need for integrating Data Mining with Big Data, machine learning and mathematical optimization for the formation of a proactive and adaptive anti-crisis management system is substantiated.

Keywords: *Data Mining, crisis management, transport and logistics companies, service industry, WARMI paradigm, uncertainty, turbulence, systemic risks, data mining, machine learning, Big Data, forecasting, risk management, adaptive management.*

INTRODUCTION.

The modern service sector operates in conditions of qualitatively complicated external environment [1], characterized by high dynamics of uncertainty [2], turbulence, instability and systemic risks. For transport and logistics companies, this situation is particularly acute [3], since their activities directly depend on the state of infrastructure, transport flows, supply chains, energy and information systems, international trade, geopolitical factors, regulatory changes and consumer behavior [4]. In such conditions, traditional management methods, based mainly on retrospective analysis and expert assessments, are

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insufficiently operational and adaptive [5]. There is a need to transition to intellectualized management technologies [6], capable of detecting hidden patterns, predicting the development of crisis situations and supporting decision-making in a regime of dynamic changes.

One of the most promising tools for such intellectualization is Data Mining - a set of methods for intelligent data analysis, focused on identifying hidden patterns, dependencies, anomalies, clusters and predictive trends in large and diverse data sets. In the transport and logistics sector, the potential of Data Mining is associated not only with increasing the efficiency of current operations, but also with the formation of a fundamentally new mechanism for innovative anti-crisis management [7], which is based on early detection of threats, scenario forecasting and adaptive optimization of management decisions [8]. The relevance of Data Mining adaptation is further enhanced within the framework of the WARMI paradigm, which is considered as a modern conceptual characteristic of the environment in which risks acquire a systemic, interconnected and dynamic nature. In such an environment, the crisis ceases to be an exclusively episodic event and turns into a constantly present factor in the functioning of the enterprise [9]. Therefore, anti-crisis management must transform from a predominantly reactive model to a proactive, intelligent and adaptive management system [10].

The purpose of the article is to systematize the features and specifics of the application of Data Mining and to substantiate the directions of its adaptation for innovative anti-crisis management of transport and logistics companies in the service sector in the conditions of the dynamics of uncertainty, turbulence and systemic risks of the external environment within the framework of the WARMI paradigm.

MAIN PART.

1. Transformation of anti-crisis management by transport and logistics companies. Transport and logistics enterprises are among the most sensitive to external influences of service entities. Their stability is determined not only by internal resources and quality of management, but also by the state of transport infrastructure, availability of routes, changes in demand, cost of fuel and resources, reliability of suppliers, throughput capacity of logistics nodes, regulatory restrictions and stability of information systems. In the conditions, the traditional logic of "crisis - reaction -

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recovery" becomes insufficient. Innovative anti-crisis management should provide continuous monitoring of the environment, early detection of potential threats, assessment of the probability of their implementation, modeling of possible consequences and operational formation of alternative management solutions. Thus, anti-crisis management is transformed into an intelligent adaptive system in which data becomes a strategic resource, and Data Mining is one of the tools for transforming data arrays into management knowledge.

2. Specificity of the WARMI environment as an object of intellectual analysis for transport and logistics companies. Under the WARMI paradigm, the external environment is characterized not only by the presence of risks, but by their high variability, interdependence, and ability to quickly transform from local problems into systemic crises. The non-linearity of processes, the high speed of spreading negative impacts and the presence of numerous interrelated factors are particularly characteristic of the transport and logistics business. Therefore, the object of Data Mining should be not only indicators of the company's activity, but also complex information flows: data on transport operations, routes and delivery times, capacity loading, customer orders, prices, costs, infrastructure condition, weather conditions, market conditions, changes in demand and the behavior of counterparties. The dynamic nature of the data is of fundamental importance. In a stable environment, a model built on historical patterns can maintain acceptable predictive power over long periods of time. In the WARMI environment, the structural parameters of processes can change quickly, so Data Mining models must regularly relearn, adapt to new data, and take into account the possibility of situations that have not been observed before.

3. The main areas of application of Data Mining in transport logistics. In innovative anti-crisis management, it is advisable to highlight several key areas of application of Data Mining. First, forecasting. The methods of intellectual analysis make it possible to forecast demand, volumes of transportation, loading of transport capacities, delivery times, probability of delays, changes in operational costs and other indicators. Secondly, detection of anomalies. Analysis of abnormal values can be used for early detection of disruptions in transport operations, sudden changes in demand, atypical behavior of counterparties, route violations

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or deviations in financial and operational indicators. Thirdly, clustering. Cluster analysis allows you to group customers, routes, transport operations, suppliers and other objects according to similar characteristics, which creates a basis for differentiated risk and resource management. Fourth, identifying associative dependencies. Analysis of relationships between events allows establishing combinations of factors that systematically accompany delays, increased costs, reduced service quality, or the emergence of other problems. Fifth, classification. Based on the accumulated data, transport operations, customers, routes or events can be assigned to different risk classes, for example, low, medium or high. Therefore, Data Mining is able to perform the function of a kind of "intelligent sensor" of the enterprise, which transforms scattered information signals into structured information about current and potential threats.

4. Adaptation of Data Mining methods to anti-crisis management of transport and logistics companies. The peculiarity of anti-crisis adaptation of Data Mining is to change the objective function of the analysis. If under normal conditions, intelligent data analysis is mainly focused on increasing efficiency, then in crisis conditions the priorities become stability, speed of reaction, early warning and minimization of potential losses. Therefore, it is advisable to build the application of Data Mining on the principle: data → cleaning and integration → detection of patterns → risk detection → forecasting → scenario formation → management decision → feedback → model adaptation. This approach assumes a constant cycle of intelligent anti-crisis management. The resulting management decisions generate new data that are used to further improve the models. As a result, a mechanism for organizational and algorithmic learning of the enterprise is formed. The integration of Data Mining with machine learning technologies, Big Data, artificial intelligence, digital twins, intelligent forecasting and mathematical optimization is of particular importance. Such integration allows you to move from simple pattern detection to the formation of analytics, when the system not only shows what is happening, but also helps to determine which management action is most appropriate.

5. Data Mining as an early warning tool for crisis management for transport and logistics companies. One of the most important functions of Data Mining in anti-crisis management is the formation of an early warning system. Its

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task is to detect weak signals of a crisis before they transform into significant operational or financial losses. For a transport and logistics company, such signals can be a gradual increase in delivery time, an increase in the number of refusals, a decrease in vehicle loading, a change in the structure of orders, a deterioration in customer payment discipline, an increase in the cost of individual routes, an increase in the number of claims or a change in the nature of interaction with suppliers. At the same time, a separate indicator does not always indicate the formation of a crisis. It is Data Mining that allows you to detect combinations of signs that, in aggregate, have increased diagnostic value. This is especially important for the WARMI environment, where crisis processes are multifactorial and nonlinear in nature. As a result, an integrated digital risk profile of an enterprise, a separate business process, a route, a client or a logistics project can be formed.

6. Innovative Data Mining model of management decision support for transport and logistics companies in WARMI conditions. Conceptually, an innovative Data Mining system in a transport and logistics company can be considered as a multi-level architecture. At the first level, data is collected from internal and external sources. At the second level, data integration, cleaning, structuring and preparation are carried out. At the third level, Data Mining procedures are implemented: classification, clustering, forecasting, association search and anomaly detection. At the fourth level, intelligent risk diagnostics and forecast scenario formation are carried out. At the fifth level, the analysis results are integrated with mathematical optimization mechanisms and a management decision support system. At the sixth level, management influence is formed: changing routes, redistributing resources, adjusting inventories, changing the structure of transportation, choosing alternative suppliers or changing customer service parameters. At the seventh level, the results are controlled and data is returned to the analytical system. Thus, Data Mining should be considered not as an isolated analytical tool, but as the intellectual core of an adaptive anti-crisis management system.

7. Limitations, problems and prospects for the development of Data Mining for transport and logistics companies. Despite its significant potential, the application of Data Mining faces a number of limitations. These include

insufficient quality of source data, the presence of gaps and contradictions, fragmentation of information systems, the lack of unified data standards, information security problems, the need for qualified specialists and the risk of obtaining unstable forecasts in the event of a sharp change in the structure of the external environment. A special problem is the conceptual shift of data: patterns formed in a relatively stable period may lose their relevance in the event of a new crisis regime. Therefore, the development of adaptive and hybrid models that can combine machine learning, statistical analysis, expert knowledge, scenario modeling and mathematical optimization methods is becoming a promising direction. For transport and logistics companies, the formation of a hybrid intelligent platform that combines Data Mining, Big Data, machine learning, predictive and analytics, digital twins and evolutionary/metaheuristic optimization methods is promising. Such a platform can ensure the transition from crisis monitoring to their intelligent prevention and managed adaptation of the enterprise.

CONCLUSIONS.

The conducted research allows us to conclude that in the conditions of the WARMI paradigm, Data Mining acquires a new meaning as a tool not only for analytical support, but also for innovative anti-crisis management of transport and logistics companies in the service sector.

The specificity of the application of Data Mining is determined by the high dynamism, multifactoriality and nonlinearity of transport and logistics processes. In such conditions, the most significant areas are forecasting, risk classification, clustering, anomaly detection and identification of hidden relationships between factors that affect the stability of the enterprise [11].

The main feature of the adaptation of Data Mining to the WARMI environment is the transition from retrospective analysis to proactive intelligent management, focused on detecting weak signals of the crisis, predicting possible scenarios and timely formation of adaptive solutions.

It is substantiated that the maximum effect of Data Mining is achieved by its integration with Big Data, machine learning, artificial intelligence, digital twins, predictive analytics and mathematical optimization. In this case, a closed loop is formed: data collection - intelligent analysis - risk diagnostics - forecasting - optimization - managerial influence - feedback - adaptation.

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A promising direction for further research is the development of hybrid intelligent models of anti-crisis management of transport and logistics enterprises, in which Data Mining will be combined with machine learning, evolutionary and metaheuristic optimization methods. This will increase the stability, adaptability and speed of response of service enterprises to systemic environmental changes and form the basis for the transition from reactive to intelligent, proactive and continuously adapted anti-crisis management.

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