Mapping a Set of Tools to Ensure Cloud and Distributed Computing, Virtualization Tools and Data Storage Systems in the Work of the Transport and Logistics Center

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Abstract: - The existing "gaps" in approaches to the deployment of transport and logistics centers (TLC) within the edges of the backbone network lead to errors in the implementation of the spatial development strategy. Information support solutions for the implementation of terminal, transportation, and warehousing technologies are the least elaborated. As a result, errors have to be corrected in the process of operating the information architecture. There is a need to complement the existing TLC deployment management system with new tools that enhance the validity of TLC location assessment and eliminate the randomness factor in the choice of information architecture for TLC backbone network objects. This research aims to develop a flexible solution for network architecture design using cloud, fog, and edge layers. The main requirement for a flexible solution is that it can be rapidly deployed when the technology architecture changes. The proposed tool visualizes the structure of the network architecture and allows the analysis of information flows by capturing data on the movement of material cargo within the center and between TLC network facilities. The mapping tool considers the network computational load evaluation factor for the cloud, fog, and edge layers. The scientific novelty of the research results is achieved by the principle of system management of the components of complex systems. The practical significance of the results of the study lies in the possibility of using the mapping tool in the process of information architecture design at the stage of making decisions about the deployment of TLC network objects.

Key-Words: - transport and logistics center, backbone network, information architecture, cloud and distributed computing, visualization tools, storage system, cloud, fog, and edge layers.

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1 Introduction

The issue of construction and effective functioning of transport and logistics centers (TLC) is a priority of strategic development on a national scale. The difficulties of solving this issue are not only related to the size of the state territory and the level of transport infrastructure development, although these factors also largely determine the choice of tools for the deployment of TLC in the backbone network. The variability in the decisions made is also due to the level of integration of the off-the-shelf distributed infrastructure into the TLC information support system.

At the same time, even the process of deploying a single TLC based on a distributed algorithm to build an information architecture is complex. After all, it must take into account the allowable limits of TLC parameters, such as computing power of nodes, peak power consumption and workload of CPUs (processors) and storage (memory) during operations, information network bandwidth, etc, [1]. The deployment process, which must consider the parameters of TLC in the backbone network, becomes a task that requires a unique solution for each project. There are, however, general approaches to this, which aim to reduce and distribute the computational load on the network. Thus, there is a need to take into account the parameters of TLC location in the backbone network – TLC equipment, TLC cargo handling capacity, etc, [2].

A factor that increases entropy in the decision-making process for information architecture TLC is that within the backbone network, individual TLCs are scalable, and the structure of the network architecture differs. A set of cloud and distributed computing provisioning is also not a standard solution. Scaling limits are determined by modeling (mapping) the structure of network components and analyzing their behavior to select the best solution, [3].

The hypothesis of this study was to test the thesis that the characteristics of the information architecture of TLC within the backbone network create risks of achieving deployment performance criteria.

This study seeks to improve the validity of the decision to deploy TLC within a backbone network by visualizing the set of enablers of cloud and distributed computing. The mapping of the set of facilities will be in demand for network architecture simulation design and for subsequent calculation of the cost of the TLC deployment project. The proposed method of visualizing a set of network architecture facilities by mapping eliminates the entropy factor when selecting TLC deployment parameters within a backbone network.

2 Problem Formulation

The growing need to use network resources and servers that process and store information at the edge of the network has shown the limits of the cloud computing paradigm and provoked the active development of the fog and edge computing paradigm, [4]. As a result, we can operate intelligent devices whose parameters in terms of storage capacity, computing power, and query processing time allow us to significantly reduce the response time of the generated processes, [5]. This is a major advantage of distributed computing paradigms in storing and processing end-user information in distributed nodes.

The design of the distributed infrastructure for TLC within a backbone network can be performed according to different scenarios, the variability of which is determined by the multiplicity of devices and connections involved. In addition, the nodes of the TLC backbone network differ from each other – they have different logistical constraints, different freight flow, and multimodal transport characteristics. At the same time, they are synchronized into one backbone network.

When deploying TLC, the development of its information architecture is based on a project-based approach, [6]. The functional requirements side of the project includes such factors as multi-platform interfaces, as well as the ability to flexibly configure business intelligence, scenario modeling, and planning of transport and logistics processes. The implementation of the project involves taking into account the interests of the owners of business processes, which constitutes the subjective side of the project implementation, [7]. The distributed infrastructure must take into account the human factor and offers settings for the work of a wide range of users TLC, [8] which include cargo owners, freight customers and their representatives, logistics companies, freight forwarders, first- and last-mile carriers, owners of containers, railcars, and vehicles, as well as logistics infrastructure, controlling organizations, TLC operators, and system integrators. This approach is aimed at spreading the practice of considering human factors in the design of production and logistics systems, which is opposed to the current approaches to engineering design. In general, researchers point out that today's transportation logistics problems require solutions based on intelligent transportation systems that take advantage of artificial intelligence, [9], [10].

Mapping of a set of cloud and distributed computing facilities, virtualization facilities, and storage systems is performed to visualize the designed distributed infrastructure. The infrastructure at the stage of operation should provide the implementation of a set of services that form the main volume of operations that load the distributed infrastructure, which includes transportation and logistics services proper and related information and technological services for TLC users.

Variability in the design of TLC deployment scenarios involves the use of simulators to conduct preliminary studies and build fundamentally feasible scenarios for the implementation of distributed infrastructure. Simulators allow for diagnosing the deployment environment, building device and application integration scenarios based on input parameters for CPU and storage (memory) usage, communication channels, and bandwidth.

Separate studies focus on demonstrating the capabilities or comparing simulators for configuring components and configuring cloud, fog, or edge environments, [11], [12]. Given the diversity of distributed infrastructure topology, it is believed that there is no simulator capable of covering all aspects of each experiment, [1].

It has been observed that design teams experience the greatest difficulty in developing simulation scenarios for mobile sensors or mobile devices. While for TLC deployments, as the node element of a backbone network, scenarios with integration of mobile devices are of particular interest. TLCs of different capacities form the backbone network, which is made up of the necessary and sufficient number of synchronized TLCs to be commissioned. Accordingly, the integration of mobile sensors and mobile devices into the distributed infrastructure will ensure the efficient organization of freight intermodal routes and scheduled freight speeds.

Another challenge, in addition to building TLC deployment scenarios based on the advantages of mobile devices and sensors, is determining the scalability boundaries of the distributed architecture. Designing TLC within the edges of a backbone network assumes a simulator capable of handling scenarios with hundreds or thousands of components without sacrificing computational resources. Regardless of the functional characteristics of the various simulators, their use involves parameter loading. And it is logical to assume that simply enumerating their combinations is not the best option. The optimal solution is to load a mapped network architecture configuration in emulation mode. This practice is widely used to evaluate critical components of the software and application architecture, [13].

Application of the simulator, however, does not solve the separate problem – to take into account the factor of assessing the location of logistics infrastructure, [14], because we are talking about a chain of TLC nodes within the backbone network. The complexity of the task lies in the uneven density of nodes and varying lengths of backbone networks. Therefore, the deployment of a new TLC node includes such a parameter as the demand for processing freight flow data not provided by the existing nodes or resulting from errors in the design and operation of the information architecture. Calculation of the demand should be based on the volume of operations that load the distributed TLC infrastructure of each node and section of the backbone network.

Another factor to be considered in the design of the distributed infrastructure for TLC within the backbone network is the rational use of the potential of the cloud, fog, and edge layers. The potential of the layers is a topic of discussion at the intersection of the three concepts of edge technologies: edge devices, edge computing, and edge analytics, [15]. The range of possible solutions is correspondingly narrowed when the TLC design involves all three or at least two frontier technologies, [16]. For example, peripheral devices cannot execute advanced analytical algorithms due to various constraints such as limited power supply, small memory capacity, limited resources, etc. And yet, using the potential of the cloud, fog, and edge layers to design a TLC information architecture within the backbone network is the most promising solution, [17].

Based on the fact that the project of building an information architecture involves the implementation of an information support system for each of the nodes within the backbone network, it should be said that the volume of processed information is so large that the project involves data processing centers with specifications close to cloud nodes. However, if we talk about deploying TLC, which is a group of specialized terminals for the implementation of intermodal transportation, such distributed infrastructure does not require large computing power. A rational solution, then, is to use fog and edge layer nodes to assemble a configuration of devices located at the edge of the network with wireless connectivity capabilities and allow the use of mobile applications.

It is possible to reconcile such diverse distributed infrastructure requirements by applying a universal approach to mapping deployable TLC based on a model that combines all three layers in the architecture, [18].

A generalization of the results on the research topic, [3], [12], [14], [17], showed the insufficiency of empirical (applied) solutions for modeling the structure of network components. We faced the task of effectively utilizing the hardware and software of the fog and edge layers of the architecture. With all the variety of hardware choices for distributed infrastructure design in the given studies, [6], [7], [9], [16], no solution adequate to the task was found that could be deployed within the framework of TLC architecture development.

3 Problem Solution

To begin with, let’s highlight the main structural blocks – the departments that make up the pilot transportation and logistics center. These are the TLC security service, input and output cargo terminals for rail and automotive transport, transport fleet, cargo distribution center, warehouse complex, customer service department, economic department, and customs and logistics department, as well as technical and IT departments as auxiliary services. The structure and the order of interaction between the elements of the structure are shown in Figure 1 (Appendix).

The following is a description of the entities shown in Figure 1 (Appendix) and the links between them. In the diagram, solid lines show the routes of incoming and outgoing traffic and cargo, and dashed lines show the information communication within the complex. The flows of arriving traffic equipped with passes arrive through the entry checkpoint. The specific checkpoint is determined depending on the type of cargo traffic (automotive or rail) to the appropriate type of terminal. Next, unloading, handling, labeling, and registration of incoming cargo takes place on the territory of the terminal. Data on the incoming cargo enters the terminal database, as well as the economic and customs-logistics department databases. Then the transport is sent and placed in the parking lot or in the depot of the transport fleet, where, if necessary, it is additionally repaired and serviced. After being in the transport park, the vehicle can be loaded with new cargo as part of the outbound freight process through an outbound terminal of the appropriate type. Information about this is also recorded in the databases of terminals, economic and customs, and logistics departments. The end of the logistics process within the TLC is the departure of the cargo after verification of the compliance of the exported cargo with the travel documents at the exit checkpoint.

The logistics process in terms of a business process can be considered more broadly, but in conjunction with the hardware and architecture of the TLC network, the event “the departure of the cargo” is considered the final event. The processes represented on the map are terminated by the event, as the current study considers the logistics processes of the internal telematics contour. The outer telematics contour might also be an object for mapping, however, this is beyond the scope of this study.

As for the cargo, once it has been registered, it goes through the cargo distribution center to the exit terminal or, depending on the type and dimensions, to the appropriate sector of the warehouse complex. Information about this is recorded in the database of the cargo distribution center. After arrival, verification of marking, and placement of cargo in the appropriate sector of the warehouse complex, the information is also recorded in the database of the complex.

Interaction with customers is carried out through the customer service department, and records are made and added to the department’s database at each stage of the logistics process. The entire document flow for the transport of goods and additional services provided by the TLC, the customer data is supplemented by the corresponding entries in the databases of the economic and customs and logistics departments and is associated with the cargo stored and already available in the database of the TLC warehouse complex.

The presented TLC transport and information flow diagram (Figure 1, Appendix) shows the links of information and transport flows of the enterprise and is the departure point for the subsequent mapping.

Mapping of a set of facilities of the distributed architecture of the TLC is carried out in the system in terms of the cloud-fog-edge-user model of the device, [19], [20]. The following presents the proposed mapping of computing and networking devices that are part of the warehouse complex architecture. As an example, the working diagram of mapping for the warehouse complex is shown, since it is for this building block of the TLC architecture that most of the distributed infrastructure devices are required.

According to the CFEU model, [18], for each of the computational vertices it is necessary to specify a set of parameters of the form:

$$V_{e41_1}^{E}\left(c_{e41_1}^{E}, w_{e41_1}^{E}, tc_{in\,e41_1}^{E}, tc_{out\,e41_1}^{E}\right) \quad (1)$$

where for the vertice V with the number n on the level L:

c_n^L – vertice internal storage volume V,

w_n^L – computing power of the vertice V,

$tc_{in\,n}^L$ – vertice input capacity V,

$tc_{out\,n}^L$ – vertice output capacity V, and for each of the edges – by parameters of the form:

$$E_{mn}^{KL}\left(tc_{mn}^{KL}\right) \quad (2)$$

where its weight tc_{mn}^{KL} – between these vertices. To mark the vertices on the map we introduce indices of the form

$$V_{wXY_Z}^{W} \quad (3)$$

where w, W is the first letter of the name of the TLC architecture layer to which the specified vertice belongs, X is the vertice hierarchy level in the layer, Y is the ordinal number of the vertice, Z is the number of the vertice group to which the vertice belongs at the current hierarchy level.

Thus, an entry of the form

$$V_{e31_1}^{E}\left(c_{e31_1}^{E}, w_{e31_1}^{E}, tc_{in\,e31_1}^{E}, tc_{out\,e31_1}^{E}\right) \quad (4)$$

will mean "computational vertice, level 3, at layer E (edge) with computational power c, storage capacity w, input throughput capacity tc_{in}, and output throughput capacity tc_{out}», and a notation of the form

$$E_{e31_1,u11_1}^{EU}\left(tc_{e31_1,u11_1}^{EU}\right) \quad (5)$$

will mean "a channel between vertices at layer E (edge) level 3 and layer U (user) level 1 with throughput capacity tc ».

For the user layer vertices (sensors, command interpreters, and users), since they are the source of computational tasks and data, having only the output bandwidth, the set of parameters is valid:

$$V_{un}^{U}\left(0,0,0,tc_{out\,un}^{U}\right) \qquad (6)$$

For command interpreters in the same layer, converting verbal and physical units of employee interaction into commands for computers and mobile devices of the edge layer, it is true

$$V_{un}^{U}\left(0,0,tc_{in\,un}^{U},tc_{out\,un}^{U}\right) \qquad (6)$$

The basic part of the devices that relate directly to the edge and user layer of the warehouse complex is shown in Figure 2 (Appendix).

The edge layer contains the main processing units of automatic forklifts and AGV carts (ALD), warehouse drones (Dr), zonal RFID scanners (ZRF), employee personal computers (PC), etc. The compute units are connected via zonal routers (Rout) and hubs (Hubs) into a single network and transmit data via a local multiport switch (Sw. L) to the local warehouse server (Srv. L) as well as higher in the hierarchy. The local warehouse server stores and processes the main databases about the contents of the warehouse sectors. The lower, user layer contains the sets of sensors (S) associated with the warehouse machinery, the employee-users of the PC (U) as sources of tasks, and the interpreters (Intp) of the commands they enter into the PC. In addition, since there are RFID-tagged cargoes within the warehouse complex, the layer contains the tags of this cargo (RFt). Note also that the position of the cargo tag is periodically fixed by remote RF communication with the scanner, in the range of which such a tag.

So, having presented the hierarchy of the main means of the distributed infrastructure of the warehouse complex, it makes sense to complement the level of data representation. Next, let us describe the infrastructure elements that are located within the warehouse complex, but are not directly related to this structural unit, but are part of another structural unit - the TLC security service (Figure 3, Appendix).

Figure 3 (Appendix) shows that the edge layer of the architecture contains the RFID scanners of the pass system (PRF), the camera electronics (VSC), and the firefighting and alarm system (FEW), physically connected to the security servers via the network via hubs or routers. The user layer contains the camera sensors and the public address and fire suppression systems, as well as the radio frequency zone passes (RFp) carried by employees and visitors.

The order of interaction between the cloud, fog, and upper part of the edge layer of the TLC warehouse complex architecture is shown in Figure 4 (Appendix).

As shown in Figure 4 (Appendix), the local switch of the warehouse complex (Sw. L) is the link to the main warehouse server (Srv. WH) for the above-described automated and electronic warehouse equipment. The main warehouse server is located in the fog layer of the architecture. It stores data on the contents of the warehouse, past movements, and the location of the cargo in the warehouse and distributes them to the warehouse sectors. In addition, preliminary calculations of routes for automated warehouse equipment are performed on the warehouse server. At the same time, this switch makes it possible to establish a connection with the servers of other TLC departments to transfer some of the warehouse data corresponding to their content. For example, the server of the customs and logistics department (Srv. CLD) receives data on customs documents issued for the cargo, and the server of the economic department (Srv. ED) receives data on financial operations related to the cargo in the warehouse.

Servers in this layer have sufficient performance to cope with the tasks of cargo information storage and routing. In addition, communication with a large cloud server (Srv. Cloud) TLC is provided through the backbone network equipment (Sw.D) to perform more complex calculation operations and backup data storage. Backing up local data with its duplication in several storages is necessary in case of failure of server equipment or network equipment along the data route. Data storages are the most unstable components of computer and server systems because they are subjected to constant high load and work in servers continuously for long periods, [21]. The same reasoning holds for server hardware along the data path.

As the main solution for the implementation of storage, processing, and routing of data streams it is proposed to use servers, storage, and network equipment of the Open Compute Project standard, [22]. We believe that the use of this standard will allow us to avoid the risks associated with changes in corporate policy regarding the distribution of licensed products. In particular, the manifestation of this risk is the inaccessibility of direct delivery of hardware from European and American vendors to the Russian Federation due to the complicated geopolitical situation.

As a basic solution for implementing the storage, processing, and routing of data streams, it is proposed to use servers, storage, and networking equipment of the Open Compute Project standard due to the unavailability of direct shipping to the Russian Federation products of European and American vendors due to the difficult geopolitical situation, [23].

Thanks to the openness of the specifications and the availability of full technical documentation for the devices, such equipment is already being produced domestically from local and Asian electronic components available in Russia to meet the growing demand for them from companies and organizations, [24].

In this way, the proposed variant of mapping provides an opportunity to construct the configuration of devices at all levels of the four-layer structure of the network architecture based on the results of the operation with the map. The mapping tool allows decomposing a set of devices of different functional purposes, located on the territory of one structural unit.

The study provides an example of the decomposition of security and warehouse task devices functioning together on a common territory of the warehouse department. The used mapping approach demonstrates the flexibility property stated as the main requirement for the developed solution. This property can be useful in terms of unplanned changes in the technology stack and allows for enhanced technological autonomy.

The proposed mapping option increases the validity of network architecture design decisions and accelerates and simplifies the process of visualizing device configuration changes across network architecture layers. And these very benefits set the proposed results apart from other solutions that do not have such a deep level of detail, and therefore are quite complex in practical application.

4 Conclusion

The following results have been obtained as part of this study. The task of visualizing the structure of a transport and logistics center by mapping the infrastructure elements and the connections between them was set and justified at the beginning of the study. As part of this justification, the aim was to reduce entropy in decision-making processes in the construction of the architecture of the TLC, taking the design approach as a basis. The objectives were the need to ensure the implementation of a set of transport and logistics services and the need to define scalability limits for such an architecture within the departments and the complex as a whole, with physical parameter limits and the specific purpose of the devices in the different layers of the infrastructure of the center as constraints.

In the course of the mapping, the main structural units of the system and the relationships between them were first identified and then, based on one of these structural units, a system of notations was described within a cloud-fog-edge-user model and a map of interaction between technical devices and automated solutions in their communication with each other through network and switching devices, and the information processes occurring in the system were described.

Mapping a set of network architecture tools can be applied in emulation mode on various device-and-network cloud, fog, and edge infrastructure simulators such as Simgrid, Yet Another Fog Simulator (YAFS), iFogSim 2, etc., [12]. This will reduce the number of approaches to the simulator to diagnose the deployment environment and build scenarios for device and application integration.

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Appendix

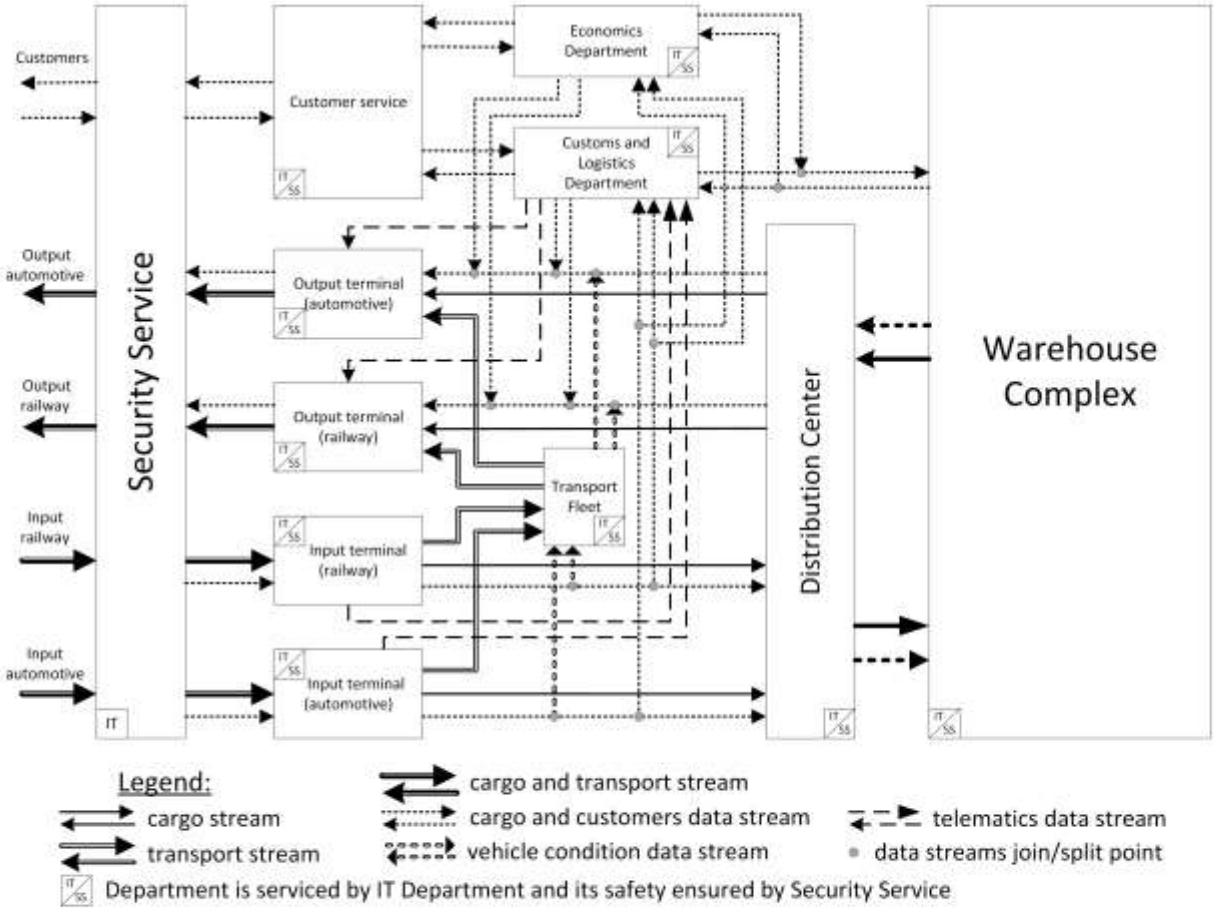

Fig. 1: Scheme of transport and information flows of the transport and logistics complex.

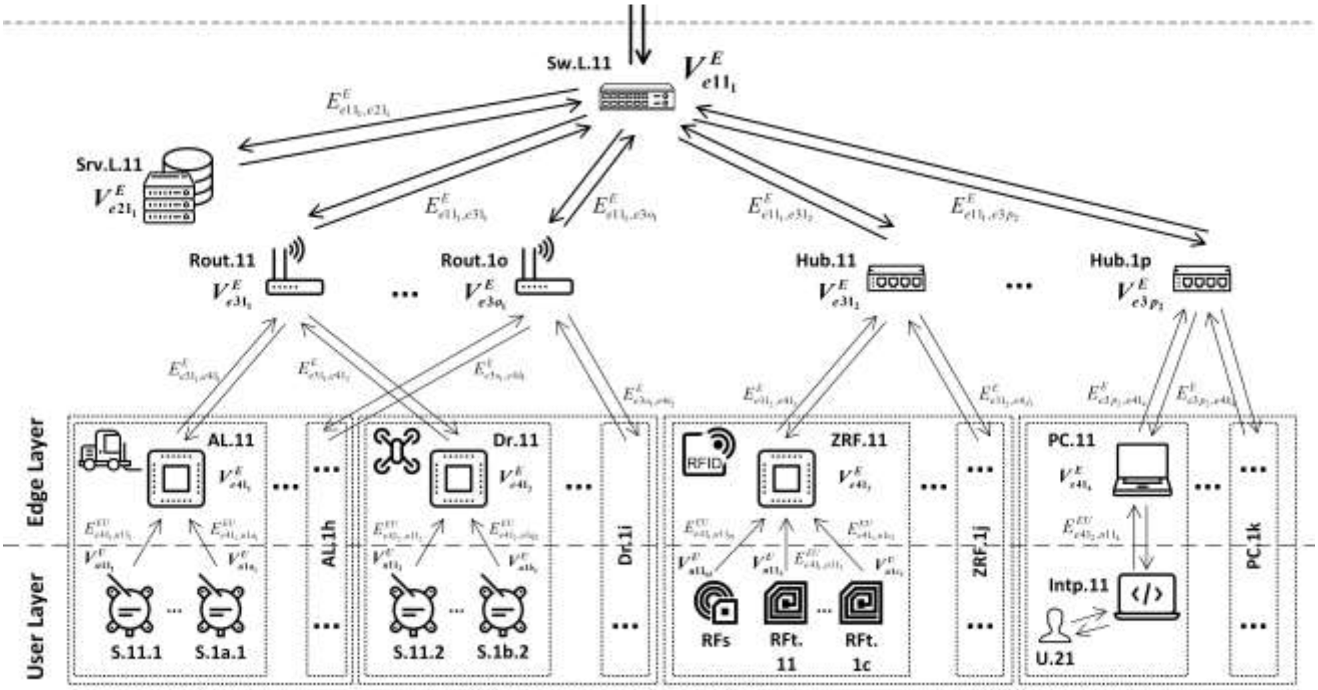

Fig. 2: Map of the information infrastructure of the lower levels of the warehouse complex on the CFEU model.

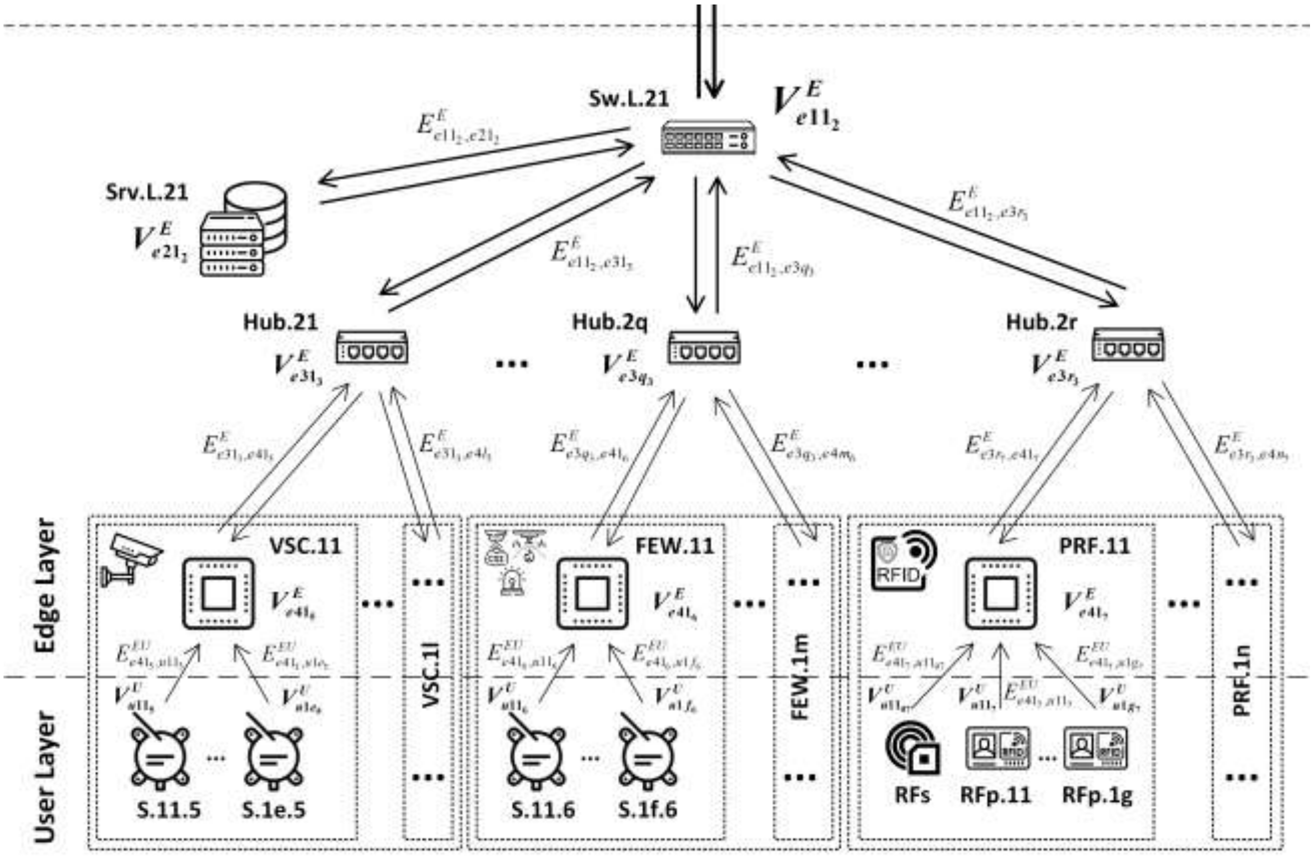

Fig. 3: Map of the added information infrastructure of the security service at the lower levels of the warehouse complex on the CFEU model.

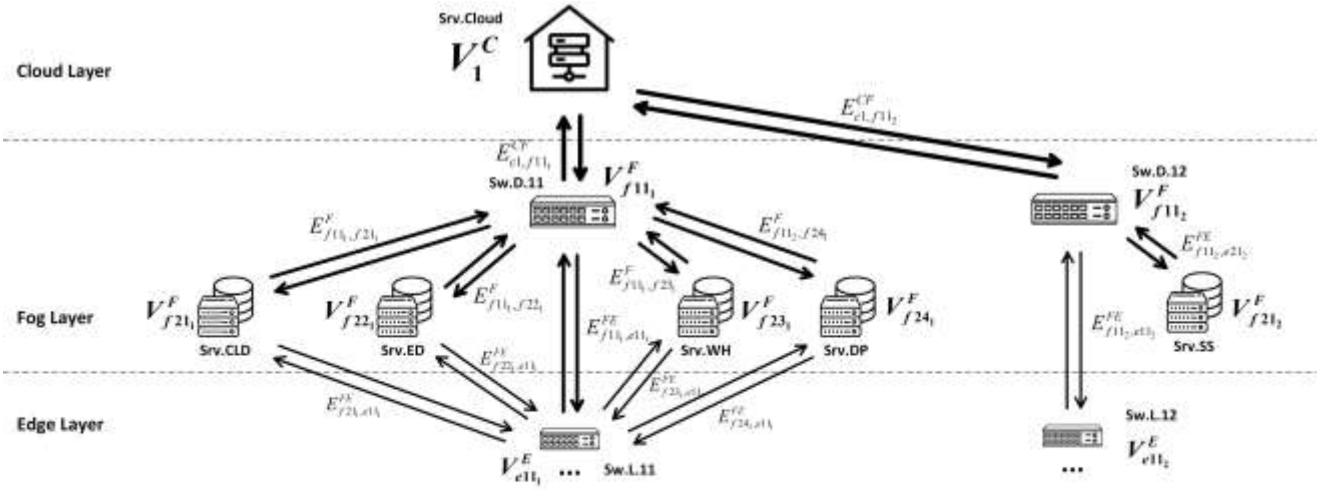

Fig. 4: Map of the information infrastructure of the upper levels of the warehouse complex on the CFEU model.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Nikita Shagov performed formal analysis and investigation.

Natalia Mamedova conducted data curation and formed a methodology.

Arkadiy Urintsov was responsible for acquiring funding, administering the project.

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Conflict of Interest

The authors have no conflict of interest to declare.

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