Features of the Information and Technological Architecture of a Typical Transport and Logistics Centre

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Abstract: The article is devoted to solving the problem of optimizing the interaction between the physical infrastructure and information and technological architecture of the transport and logistics center (TLC) as a basic condition for the effective implementation of logistics operations in terms of geographically distributed operations. It has been proposed to optimize interaction by increasing operational efficiency in two areas - ensuring freight accounting in warehouse logistics and information and technology security of TLC facilities, as a network technological complex. The study summarizes the standard solutions used to automate warehouse and transportation logistics activities. It presents a set of technologies and software solutions in the hierarchy of layers of the information and technological architecture of the TLC on the basis of the cloud-fog boundary-user model of the information system (CFEU-model). It is proposed to complement the complex standard solutions for the application of monitoring systems through the technology of radio-frequency identification of objects to track and record the movement of goods, personnel, external visitors and vehicles using modern IoT solutions based on sets of sensors.

1 INTRODUCTION

According to the National Programme "Digital Economy of the Russian Federation", the development of cloud technologies for the real economy is one of the priority areas of its implementation [1]. This is consistent with the demand of organisations from various branches of the economy to develop and implement cloud solutions. They are most relevant under the conditions of geographically distributed operations. And considering the significantly increased level of digital infrastructure development already achieved in IoT and its development trends in Russia [2], solutions based on cloud, fog and edge technologies will be in demand in the medium term. This study focuses on the task of developing the digital infrastructure of the logistics complex and focuses on the optimization possibilities of the information-technology architecture for a typical transport and logistics centre.

A transport and logistics centre (TLC), as defined by the Federal Programme of the Russian Federation "Transport and Logistics Centres" [3], is a network technological complex as a basic element of transport and technological systems of transport freight, comprising a group of terminals, objects of engineering, transport and administrative infrastructure necessary for the complex to function fully. The information and technology architecture of such centres makes it possible to supply the needs of regional, export-import and transit freight traffic and to implement industry-leading logistics solutions for the participants of the transportation process both in the basic version and as a set of additional services.

The elaboration of an information-technology architecture for a TLC is determined by many factors – its purpose and lines of action, its location and geographical features of this area, and by the level of development and accessibility of the transport infrastructure. The natural constraint for elaboration is the choice of a priority type of carriage, harmonized

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infrastructurally in terms of transportation with the receiving TLC [4]. Thus, the structure of a logistics centre offering solutions for road, rail, sea and air transport includes [5]:

1. Terminals used for shipment (sending) and unloading (receiving) cargo moving from and to a place by various modes of transport – road, sea, rail or air.
2. Inner warehouses for cargo and containers of various types, sizes and purposes.
3. A distribution centre that manages incoming (from terminals to warehouses) and outgoing (from warehouses to terminals) cargo flows.
4. A transport fleet that includes, depending on the location and the destination of the centre, one or more transport components:
   - parking area for long-haul and small trucks;
   - a railway depot with transport links-trails;
   - a jetty and docks for cargo and small maritime vessels;
   - an airstrip for small aircraft, helicopter landing pads;
   - departments for the maintenance and repair of road, rail, maritime and/or aviation equipment.
5. Auxiliary structures dealing with tasks related to financial, customs and other reporting, customer relations, maintenance of a TLC information system, equipment and transport, as well as physical and information security of facilities:
   - Economic department;
   - Customs and logistics department;
   - Information technology department;
   - Customer service department;
   - Facility security service, which includes Information security department and Rapid Response Service.

2 RESEARCH METHODOLOGY

This study is based on the example of a typical TLC designed for civilian overland transport by rail and road, whose customers are to legal persons. Therefore, its structure includes all elements except for the components dedicated to logistics operations using small aircraft and maritime transport.

The optimal solution which will provide the possibility of scaling TLC activities in accordance with the above physical infrastructure is the construction of the TLC information technology architecture based on the cloud-fog-edge-user (CFEU) model developed by the team of authors [6]. According to this model, the possible technological and software solutions applied within the structural units of the TLC are arranged according to the CFEU-model layer hierarchy.

The upper, cloud layer of the TLC's information-technology architecture houses one or more large servers as well as the data storage needed to process and store data for complex logistics management tasks: transport routing, placement and movement of cargo flows within the TLC.

The middle, fog layer of the information-technology architecture of the TLC accommodates the large network backbone equipment for transferring processed data streams to the cloud, as well as the servers and storage of the main business units that host the data presented in Table 1.

Table 1: Contents of the servers and stores of the fog layer's organisational units.

Structural unit	Data processed by servers, storage contents
Warehouse departments, Terminals, Distribution points	Data on the quantity, characteristics and location of cargo received, stored and moved
Transport fleet	Data on the location and movement of traffic in the TLC area, Data on the technical condition and status of the vehicle
Security service	Data from CCTV logs and recordings, A database of badges and information on employees and visitors, Movement marking data through checkpoints and zones, Tracks of routes and traffic movements, Fire extinguishing system data
Economics department	Data on economic transactions and settlement relationships with employees and customers
Customs and logistics department	Data on customs and logistics operations and routes undertaken
Technical department, IT department	Data on the status and configuration of the TLC equipment and computer network
Customer service department	Data on customers, active and completed orders

The edge layer of the information-technology architecture of the TLC is formed by the wired and wireless network equipment of the sectors, PCs and mobile devices of the staff, as well as the unique equipment of the departments presented in Table 2.

Table 2: Unique equipment of the structural units in the edge layer.

Structural unit	Equipment assigned to units
Warehouse departments, Terminals, Distribution points	RFID tag scanners on cargo, Electronics for unmanned and guided forklifts, The electronics of warehouse UAVs, RFID equipment
Transport fleet, Technical department, IT department	Microprocessor and microcontroller-based debugging, repair and diagnostic equipment electronics
Security service	CCTV camera and security frame electronics, RFID and contact scanner badge systems, Alarm and public address devices
Economics department, Customs and logistics department, Customer service department	Office equipment

The lowest, user layer of the information-technology architecture of the TLC, in addition to personnel as the source of workflows and RFID employee passes, contains the sensor sets and workflow sources shown in Table 3.

Table 3: Device sensors and data sources in the user layer.

Structural unit	Data processed by servers, storage contents
Warehouse departments, Terminals, Distribution points	Loading and unloading equipment sensors, RFID tags on cargo
Transport fleet	Status and location sensors on vehicles
Security service	Sensors on CCTV cameras, security frameworks and access systems, Sensors on alarm and warning devices, Temporary RFID passes for external visitors
Technical department, IT department	Sensors of debugging, repair and diagnostic equipment
Customer service department	Customers as the source of work tasks

3 RESULTS AND DISCUSSION

3.1 Standard Solutions

The CFEU model discussed above, applied to analyse the architecture of the TLC, allows to focus on its lower layers, e.g. to map information flows and, based on the mapping results, to define an effective logic and strategy for the interaction of the different units. But for its construction at the present stage of development it is not enough to make administrative decisions based solely on optimising the existing facilities of the complex - new ones must also be commissioned and up-to-date technological solutions must be used.

For the automation of warehouse and transport logistics activities, a set of standard solutions is used in the current phase of operation as part of measures to create and support the development of a digital economy, including [7]:

- WMS (warehouse management system) operating in a semi-automated mode and reflecting the events taking place in the TLC. This approach is now being integrated with high-tech equipment such as robotic loaders and trolleys, industrial UAVs, pallet optimisation and sorting systems based on the mass-size characteristics of the cargo;
- mathematical methods for topology digitization, spatial and process modelling of centre processes, allowing the estimation of cargo allocation across storage areas, cargo flows between warehouses to the distribution centre. These methods are not so common and are used by about 15-20% of companies, but are becoming more widespread every year.
- monitoring and tracking systems that track the movement of material objects, vehicles and personnel within the warehouse in real time, comparing real processes with the optimal model to assess the effectiveness of its implementation. These systems are being deployed by companies that feel they have exhausted the resources of manual process optimisation in terms of development.

3.1 RFID in Cargo Logistics

RFID technology has recently become widespread for counting and locating goods stored in warehouses and moving through the distribution centre to and from terminals. The working principle of the technology is to activate passive (for SHF - passive and active) antenna tags on the cargo, on which, during the creation process, information about the object is recorded, and by subsequent identification can be read by the magnetic field of a special near- or far-field scanner [8].

The cost of such a solution including [9] equipment maintenance $\boldsymbol{C}_{\mathbf{mnt}}$, costs include the cost of handheld and zonal scanners $\boldsymbol{C}_{\mathbf{sc}}$, tag printing and recording equipment $\boldsymbol{C}_{\mathbf{pr}}$, and the RFID tags $\boldsymbol{C}_{\mathbf{tags}}$ used , i.e.

$$\boldsymbol{C}_{RFID} = \sum_{i=1}^{M} \boldsymbol{C}_{\mathbf{sc}\,i} + \sum_{j=1}^{N} \boldsymbol{C}_{\mathbf{pr}\,j} + \sum_{k=1}^{M+N} \boldsymbol{C}_{\mathbf{mnt}\,k} + \sum_{l=1}^{P} \boldsymbol{C}_{\mathbf{tags}\,l} \quad (1)$$

The frequently used and most common types of RFID tags [10] are

- upper kilohertz (LF) and lower megahertz (HF) range RFID - short range (10cm - 3m),
- upper megahertz (UHF) band RFID - medium range (3-10 m)
- lower gigahertz (SHF) band RFID - longest range (over 10 m)

All of the above options are in different price ranges [11], with LF and HF RFID being the most affordable. This affordability is driven by the comparative ease of manufacturing low frequency passive antennas as well as short-range scanners, because there is no need to create a large electromagnetic field. The most expensive solutions are based on SHF RFID and their cost is determined by the need to equip RFID scanners and RFID printers with additional microwave modules to operate in the gigahertz range, and active RFID tags intended for the same purpose - with additional power supplies, without which the tag remains passive and its reading is possible in a much shorter range.

In order to optimize costs when solving the problem of cargo accounting in warehouse logistics, the use of passive upper megahertz range (UHF) RFID tags in combination with zone-based RFID scanners with a coverage area of 5-15 metres [9] is proposed. The medium-range tags allow checking and monitoring the current location of the cargo in the warehouse remotely, within a designated area of the room covered by the scanner, and not only by direct physical contact. This is done on the basis of preliminary data about the location and characteristics of the consignment available in the database of the warehouse, distribution centre or terminal area. Another advantage of the solution is that the range of the tag is sufficient for automatic scanning of cargo and objects over short distances. The solution will save both on the cost of RFID tags and the cost of equipment to generate and read them, and, consequently, on its maintenance, due to the absence of expensive gigahertz UHF modules in electronic equipment of this class.

3.2 Security Issues Solving

When developing the information technology architecture of the TLC, the issue to be addressed is the information and technological security of the facility, for which a so-called "external security perimeter" is created [12]. It includes a physical external perimeter - physical and technological restriction to unauthorized persons from reaching internal areas of the facility - and an information external perimeter - restriction of customer access to all internal TLC data, separation of the rights of different categories and groups of employees with access to certain data categories, strictly limited by the framework of official duties, and protection against network attacks on the TLC IT infrastructure.

3.2.1 Employees And Visitors Movement Control

To effectively solve the problem of controlling the movement of employees and unauthorized persons and separating access to areas of responsibility, the widespread means of controlling the physical outer perimeter - CCTV cameras, security personnel and access control areas with badges - are no longer sufficient. The challenge is that typical TLCs consist of many heterogeneous zones that contain thousands of objects of control, and in the case of warehouse structures, hundreds of thousands or millions, each of which can be disabled or illegally removed from the TLC area.

As a practical solution, it is proposed to introduce tracking the location signals of mobile devices of employees and visitors entering the mobile and navigation network coverage area [13] within the TLC in combination with the use of wearable RFID zone passes activated at transitions between TLC zones and at intermediate points [14]. The use of such passes, together with the use of standard physical perimeter controls to monitor the facility's zones, will allow timely detection of unauthorized access attempts by unauthorized persons and employees in areas outside their areas of responsibility, as well as prevent the illegal removal and removal of cargo from the TLC's territory.

3.2.2 Cargo Movement Control

In order to ensure compliance with the transport schedule and cargo integrity, it is proposed to equip vehicles with a set of sensors to monitor the status and location of vehicles (in particular, using the national ERA-GLONASS system [15]). The solution includes fuel level control sensors, as well as cargo presence control based on position sensors and RFID tag scanner. All along the way, data will be transmitted via mobile or satellite network to automated monitoring systems in the fog layer of the information technology architecture of the origin and destination TLCs. In case of a contingency (loss of cargo or connection with transport, emergency situations), this will make it possible to take prompt measures to communicate with the driver or train driver - to clarify the situation, to call an emergency service if necessary, to receive input data for the organisation of cargo search. Such measures would also allow timely detection and action to stop the dumping and sale of vehicle fuel, which is a frequent problem for many logistics and transport companies in Russia [16].

4 CONCLUSIONS

The final set of solutions proposed for the development of the information technology architecture of a typical TLC includes the following components: using the CFEU model to analyse the processes occurring in the enterprise and using it to build a highly efficient TLC architecture, combining it in with common business solutions - warehouse management accounting systems, mathematical methods of space and process optimisation of warehouse processes, monitoring systems, - additionally radio-frequency technology and to track and record the movements of goods, personnel, external visitors and vehicles using state-of-the-art IoT solutions based on sensor suites.

Such a set of solutions will improve the efficiency of the TLC and can be recommended for use and scalability in an overland logistics TLC, provided the location is economically well chosen to provide sufficient land area for the deployment of the centre's infrastructure, combined with maximum transport accessibility [17]. Accessibility factors include, for example, the location of the TLC in a narrow radius from a major railway junction or station and the presence of a multi-lane highway and interchanges in the vicinity of the facility to ensure accessibility for vehicles to and from the facility, provided they successfully pass the procedures at the entry and exit checkpoints.

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