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INTELLIGENT TRANSPORTATION SYSTEMS AS CYBERPHYSICAL SYSTEMS IN TRANSPORT

Annotation. In paper we offer a report on the results of the comparative analysis of existing concepts of the functioning and development of Smart Logistic. In paper shown that at present ITS is the most developed concept for the implementation of Smart Logistic and, in its essence, approaches the essence of the CPS concept as intelligent automatic (or close to automatic) control systems for physical objects and processes of various nature. Within the framework of the CPS concept, through test studies using various AI methods (GA, ESA, AA and ACAmod), it was determined that the most effective method for optimizing the route of freight traffic is ACAmod, which allows dynamic routing of logistics flows in real time, taking into account the non-stationary dynamics of TF. One of the promising areas for further research, the authors consider the creation of an intelligent system for supporting decisions on transport and logistics management of freight traffic in real time taking into account the influence of external factors of various nature on the transportation processes. The creation of such a system should be based on a modern interpretation of the concept of ITS as a CPS for Smart Logistics. In addition, in this report within the concept of the Cyber-Physical Systems are show the results of determining of the most effective method for optimizing of logistics flows in real time, taking into account the non-stationary dynamics of traffic flows.

Keywords: Cyber-Physical System, Smart Logistics, Intelligence Transportation System.

Introduction

The most effective solution to the problems associated with accelerated motorization under modern conditions is the implementation of the concept of Smart Logistics, namely the development, implementation and application of Intelligent Transportation Systems (ITS), where the effective use of modern intelligent technologies of the Internet of Things (IoT), blockchain (BC), Big Data (BD) and Artificial Intelligence (AI).

However, fundamental and applied theoretical research on Smart Logistics today is largely fragmented, since it is carried out by scientists in different subject areas. These research activities are aimed at solving problems of practical application in various, at best related, sectors of the innovative development of society. Therefore, these scientists have a different vision of ways to improve the efficiency of functioning and development of Smart Logistic, which leads to the formation of different approaches.

In addition, the use of intelligent information technologies for the effective organization, optimization and management of logistics processes for the implementation of freight and passenger transportation in real time with a large and variable workload of the automotive urban road network (URN) is episodic and imperfect. One of the important reasons for this is the lack of adequate methods for discrete optimization of routes with dynamic updates that take into account the real dynamics of traffic flows (TF) on sections of URN.

Purpose of the study

The purpose of the study is to carry out a comparative analysis of existing concepts of the functioning and development of Smart Logistic. In addition, within the concept of the Cyber-Physical Systems (CPS) test studies carry out to determine the most effective methods for optimizing of logistics flows in real time, taking into account the non-stationary dynamics of TF.

Presentation of the main material of the study

Fundamental and applied theoretical studies of the functioning and development of Smart Logistics within the framework of the currently existing concepts of ITS, IoT, PI (Physical Internet), CPS technologies are largely disparate, which often leads to different interpretations of the entity for processes in Smart Logistics and, accordingly, to different visions of ways to improve its efficiency (see, for example, [1 – 4]). In addition, it should be noted that with the development of relevant innovative technologies, in particular, IoT, AI, BD, BC, the essence of a particular Smart Logistic development concept is evolving, bringing their closer to each other [1 – 4].

CPS is a new intelligent complex system that integrates physical and cybernetic components at a deep level. Here, continuous real-time monitoring, modeling (including simulation) and forecasting, analysis and control of physical objects and processes are implemented through a combination of telecommunication and information management technologies, as well as deep (intelligent) computing, storage, processing, exchange and protection of data. The CPS concept was proposed in 2006 [2], and currently its implementation covers various areas of human activity: manufacturing, construction, energy, medicine, etc., where new functionalities are provided to improve the quality of life, achieve technical progress, and therefore they are essential affect the world economy. One of the main areas of its application is the transport industry and logistics.

Historically, the first concept for the effective implementation of Smart Logistic is the concept associated with ITS. The same concept remains the main one at the present time. At the stage of its formation, starting from 1986, ITS was considered by the Mobility 2000 group of scientists headed by Joseph M. Sussman [5] as a decision support system (DSS), which combines information and telecommunication technologies (ICT), to organize the movement of TF, increase the throughput of transport infrastructure, traffic safety, psychological comfort of passengers, environmental sustainability. In this case, as a rule, a person acts as an intelligent agent.

With the development of innovative technologies IoT, BD, BC, AI, PI, the essence of the interpretation and purpose of ITS is evolving, which currently brings ITS closer to the essence of the CPS concept as intelligent automatic (without human intervention) control systems for physical objects and processes of various nature.

Indeed, ITS in modern conditions, in our opinion, should be considered as an implementation of the CPS concept in the field of transport systems, including Smart Logistics. At the same time, ITS represents an extremely complex CPS in the context of DSS information support in the management, which is due to the need to collect, process, transfer large arrays of heterogeneous data in spatially distributed heterogeneous systems, use spatial and temporal information in a multi-scaled information space. Accordingly, resent ITS technologies, as CPS, combine such interconnected and interpenetrating technologies as computer systems, embedded systems (smart sensors, PI infrastructure objects (π-containers, π-movers, π-nodes) etc.), wireless sensor networks, network management systems, IoT, AI, BD, BC, intelligent control systems for transport objects and processes.

The ITS architecture within the framework of the CPS concept generally includes a physical layer, a network layer (cloud network) and an application layer. The physical layer refers to sensory devices, actuating devices (both including smart versions) and a wireless or wired ITS network unit that are closely related to the physical environment (vehicles, participants in transport processes, cargo (including those organized as objects of PI infrastructure), infrastructure elements of transport systems, etc.)). The network layer implements the interconnection and interoperability of devices to ensure data transfer and resource utilization in the ITS. The characteristics of the cloud platform allow to effectively integrate data into the data transfer process.

Accordingly, the intelligent DSS in the context of Smart Logistic in the case of ITS as a CPS mainly consists of a hardware layer, a cloud platform and an application layer for carrying out intelligent deep computing, and is designed to determine the optimal logistics path in the process for transportation of cargo or passengers in real time, taking into account the impact of the physical environment (changing dynamics of TF, controlling the provision of conditions for the transportation of goods, meteorological and environmental conditions, etc.).

As noted above, in the process of evolution, the development of technologies that currently ensure the functioning of the CPS leads to their interpenetration and integration, bringing the concepts of their creation essentially closer to the CPS concept. For example, information networks based on information and communication technologies and IoT provide extensive data on urban freight transport systems that require the use of BD technologies for their collection, processing and transmission [3]. Accordingly, the protection of the received information additionally requires the use of BC technologies. PI combined with AI, both integrated based on embedded systems enables real-time decision making for adapting to urban environments with online communication and connected PI system elements such as π-containers (parcels, pallets), π-movers (vehicles, CAVs, UAVs) and π-hubs (shops, warehouses) [3].

Particular attention is drawn to the problem of gnosiological connections and differences in understanding the essence of CPS and IoT technologies. The IoT concept was formed in the 90s of the last century and at the initial stage was considered as a telecommunications paradigm of the global Internet network, consisting of interconnected physical devices with radio frequency identification (RFID tags) with built-in sensors, and software, which allow identification and monitoring functioning of objects, to transfer and exchange data between the physical world and computer systems using standard communication protocols [2]. As IoT has developed and PIs have emerged and developed, in particular, the emergence of smart sensors and actuators, smart PI-cargoes, etc., IoT technologies have improved, providing strong technical support for CPS research [2]. In recent years, thanks to deep research and understanding of IoT and CPS processes, their development shows a trend towards mutual integration [2].

Therefore, it can be noted that at an early stage in the development of IoT and CPS, there are two different parallel development paths. As the analysis shows [2], at present, CPS can be considered as an evolution of IoT, IoT as the initial stage of CPS application. At the same time, at the present stage of development, in case of IoT pays special attention to network connectivity and obtaining information about physical objects during intelligent identification, positioning, tracking and control. While in CPS, the emphasis is on real-time feedback control of transport processes and objects [2]. In IoT, the information of the main physical objects still requires human intervention, and the requirements for autonomous interaction are low. At that time, in CPS with feedback control, human participation is significantly reduced, which requires that there is strong autonomous interaction in CPS [2].

Such a state of modern development of the concepts of IoT and CPS often leads to ambiguity in the interpretation of the chosen approach to conducting research, in particular, the problems of Smart Logistics and to interpreting the results of these studies. So, for example, in [2], on the basis of the decision-making model on the logistic path declared by the author of CPS, a study was made of choosing the most effective method for optimizing the path of cargo delivery within the framework of the traveling salesman problem (TSP). Here the author compared the results of discrete optimization of the logistics route, which were obtained using such intelligent methods as the method of simulated annealing (SA), genetic algorithm (GA) and the classical ant colony algorithm (ACA) for an array of 31 points according. In this case, the optimization was carried out according to two criteria: the shortest transportation distance and convergence rate solutions. Based on the obtained results, the author proposes an intelligent system for making decisions about logistics routes for CPS, which uses the ant colony algorithm to calculate the shortest path for the logistics of transporting goods according to the distance criterion. During transportation, the Control Center determines the location of the truck using GPS and sends the order to the destination [2]. Within the framework of such interpretation here, in our opinion, mainly the IoT model of intelligent decision-making about the logistics path is implemented, since there is no possibility of managing the logistics by online mode influenced by changes in the external environment during cargo transportation: for example, when changing the characteristics of the dynamics of the TF, namely increased load on the URN sections, traffic jams, traffic incidents, etc., although this should be a necessary attribute for the management process within the framework of the CPS concept.

As the analysis shows, the AI algorithms presented in [2] cannot solve the problems of modeling the optimal route with dynamic updating under the influence of changing environmental characteristics. In [6], a modified ACA (ACAmod) was proposed, in which, unlike the classical ACA [7], ant agents in the graph can move asynchronously with certain (even different) speeds, and it is also possible to fix the results of optimization of a partially traveled path for the possibility optimization of the further route when the length of the graph edges changes during the movement. This makes it possible to carry out simulation modeling of route optimization in real time, taking into account the real dynamics of the TP in sections of the transport network, where ant agents, like cars, move at certain speeds that correspond to the average speeds of the TP in these sections. Thus, this approach makes it possible to implement in Smart Logistics the CPS concept to a greater extent in order to form a decision-making model on the optimal logistics path according to the route travel time criterion.

To determine the most effective method for optimizing the logistics path in real time for the implementation of freight traffic in the conditions of non-stationary dynamics of the TF, in the paper test studies of discrete optimization route in the framework of the TSP problem were carried out using some AI methods (GA, evolutionary SA (ESA), ACA and ACAmod). These optimization algorithms were applied to a set of well-known test problems for TSP: Oliver30, Eilon50, Eil51, Berlin52, St70, Eilon75, Eil76, KroA100, Eil101, Pr107, Pr124, Pr136, Pr144 and Pr152 [8]. The numbers in the title of each of these problems indicate the number of points for which it is necessary to build the optimal bypass route. Consequently, during testing, the smallest number of points was 30, the largest was 152. The criteria for choosing the most effective optimization method when conducting a comparative analysis of the research results were the deviations of the optimal distance obtained using the corresponding method, from the best known result for each of the test problems, as well as the time convergence of the solution.

Data on the results of the work of GA and ESA are taken from open sources [8]. In the paper, test TSPs were calculated using the classical ACA [7], as well as the modified ACAmod [6] developed by the authors with specially selected most optimal values of the parameters of these algorithms, which took the same values.

The results of test studies of discrete route optimization in the framework of the TSP problem using the indicated AI methods by the criterion of the solution convergence time and deviation from the best known distance value are shown in Fig. 1 and Table 1, respectively.

As can be seen from Fig. 1 and Table 1, the most effective method for optimizing logistics flows in Smart Logistics among the AI methods presented in this paper is ACAmod. Its use allows to reduce the search time for the optimal solution by an average of 15% and in most cases to obtain better path optimization results.

Thus, the results of test studies have shown that, within the framework of the CPS concept, the most appropriate method for optimizing logistics flows in the implementation of freight traffic, taking into account the non-stationary dynamics of the TF, is the modified ant colony algorithm

ACAmod.

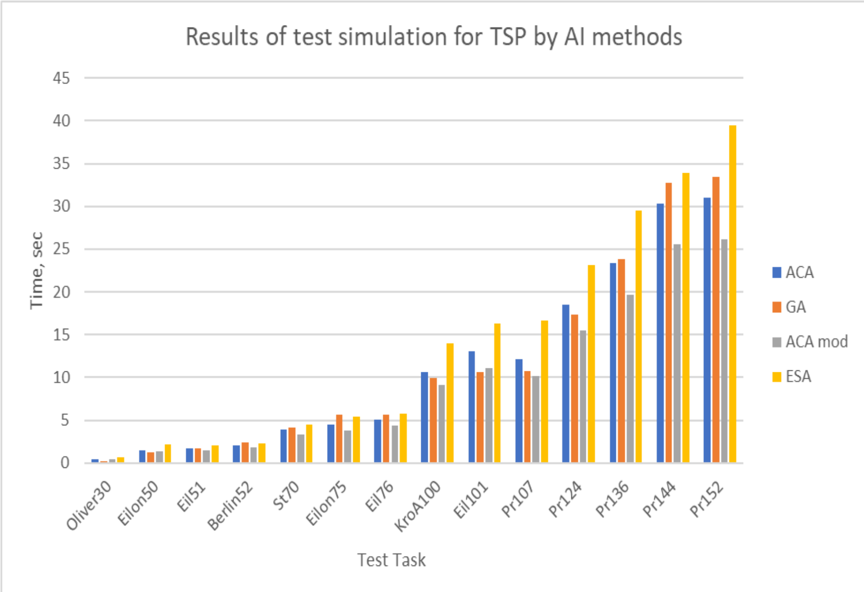

Fig.1. Results of test simulation for TSP by AI methods

Table 1. Results of test simulation for TSP by AI methods

Name of the test task	Number of nodes	Best known value (m)	Classic ant colony algorithm (ACA)		Genetic algorithm (GA)		Evolutionary annealing algorithm (ESA)		Modified ant colony algorithm (ACA mod)	
			Result, m (deviation)	Time (s)	Result, m (deviation)	Time (s)	Result, m (deviatio)	Time (s)	Result, m (deviation)	Time (s)
Oliver30	30	420	420 (0.0%)	0,4	420 (0.0%)	0,2	420 (0.0%)	0,7	420 (0.0%)	0,4
Eilon50	50	425	427.4 (0.6%)	1,5	426 (0.2%)	1,2	427 (0.5%)	2,2	427.4 (0.6%)	1,4
Eil51	51	426	428.1 (0.5%)	1,7	427 (0.2%)	1,7	426 (0.0%)	2,1	426 (0.0%)	1,5
Berlin52	52	7542	7542 (0.0%)	2,1	7542 (0.0%)	2,4	7542 (0.0%)	2,3	7542 (0.0%)	1,8
St70	70	675	679.1 (0.6%)	3,9	675 (0.0%)	4,2	675 (0.0%)	4,5	679.1 (0.6%)	3,3
Eilon75	75	535	547.4 (2.3%)	4,5	550 (2.8%)	5,6	545 (1.9%)	5,4	541.2 (1.2%)	3,8
Eil76	76	538	548.1 (1.9%)	5,1	545 (1.3%)	5,6	546 (1.5%)	5,8	545.8 (1.4%)	4,4
KroA 100	100	21282	21445.3 (0.8%)	10,6	21350 (0.3%)	9,9	21282 (0.0%)	14,0	21388.6 (0.5%)	9,1
Eil101	101	629	646.4 (2.8%)	13,1	655 (4.1%)	10,6	650 (3.3%)	16,3	633.2 (0.7%)	11,1
Pr107	107	44303	44793.8 (1.1%)	12,1	44392 (0.2%)	10,8	44413 (0.2%)	16,7	44428 (0.3%)	10,2
Pr124	124	59030	59412.1 (0.6%)	18,5	59030 (0.0%)	17,3	59030 (0.0%)	23,1	59122.5 (0.2%)	15,5
Pr136	136	96772	99351.2 (2.7%)	23,4	98432 (1.7%)	23,8	98499 (1.8%)	29,5	97541.3 (0.8%)	19,7
Pr144	144	58537	58876.2 (0.6%)	30,3	58599 (0.1%)	32,8	58574 (0.1%)	33,9	58712 (0.3%)	25,6
Pr152	152	73682	74676.9 (1.4%)	31,0	74520 (1.1%)	33,4	74172 (0.7%)	39,5	74231.5 (0.7%)	26,1

Conclusions

Based on the results of a comparative analysis of the concepts of operation and development of Smart Logistic, it was described that the corresponding fundamental and applied theoretical research within the framework of the currently existing concepts of ITS, IoT, PI, CPS technologies are largely disparate. This often leads to a different interpretation of the essence of processes in Smart Logistics and, accordingly, to a different vision of ways to improve its efficiency.

It is shown that at present ITS is the most developed concept for the implementation of Smart Logistic and, in its essence, approaches the essence of the CPS concept as intelligent automatic (without human participation) control systems for physical objects and processes of various nature.

Within the framework of the CPS concept, through test studies using various AI methods (GA, ESA, ACA and ACAmod), it was determined that the most effective method for optimizing the route of freight traffic is ACAmod, which allows dynamic routing of logistics flows in real time, taking into account the non-stationary dynamics of TF.

One of the promising areas for further research, the authors consider the creation of an intelligent system for supporting decisions on transport and logistics management of freight traffic in real time taking into account the influence of external factors of various nature on the transportation processes. The creation of such a system should be based on a modern interpretation of the concept of ITS as a CPS for Smart Logistics.

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