Management Projects for Digital Ecosystems of Automotive Enterprises: Truck Sharing

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Abstract. The paper offers an approach to the development of a truck sharing management system for a digital ecosystem, which comprises an automobile plant, auto parts suppliers, customers and service centers. The management is based on predictive associative search models. To improve the efficiency of the situational management based on situational awareness, quantum clustering algorithms are used.

Keywords: Nonlinear Process; Knowledgebase; Associative Search Models; Quantum Clustering.

1 Introduction

The most promising consequence of the digital transformation of enterprises and companies and the creation of their digital platforms has been the creation of digital ecosystems (DES). The digital ecosystem is a socio-technical complex, which mainly includes independent players [1]. They combine to create an offer of greater value than a product or service that any of the participants can offer on their own (the Win-Win principle). Some digital ecosystems are developing complex solutions, implementing mutually beneficial algorithmic interactions in a single information environment, lending their resources, information and analytical systems and services to partners for temporary use.

At the same time, DES bring clarity, relevance to the relationship between automated systems and economic agents. Other important attributes of digital ecosystems are their sustainability and sustainable development, which should be taken into account when developing algorithms for functioning and control systems for digital ecosystems. In this case, DES can be interpreted as complex dynamic systems. In particular, these can be multi-agent systems.

An example of a successful project that can be implemented on the basis of a digital ecosystem is a Truck Sharing project. Thus, in Shanghai, a pilot project of DES was launched on the basis of the INGKA holding (owns the IKEA brand), which implements the concept of using a common truck fleet by several companies, which allows optimizing operating costs. INGKA's partners in DES are: warehouse operator Beiye New Brother Logistics and leasing company DST from Shenzhen, which provided access to its own network of charging stations. It is planned to replicate the project in Amsterdam, Paris, New York and Los Angeles. It is noteworthy that the project plans to use electric vehicles.

PJSC KAMAZ in Russia has launched an online service for truck sharing, “SPECSHARING”, which replaces the purchase of special vehicles (dump trucks, bulldozers, cranes, etc.) with a rental service. Truck sharing service has the same scheme as passenger car sharing. It provides for the rental of KAMAZ dump trucks for a period from one day to a year. At the same time, the cars are insured and have undergone scheduled maintenance. Also, in the " SPECSHARING " service from "KAMAZ" there is an opportunity to get a rental truck with a driver. The rental service for KAMAZ dump trucks has already begun to operate in a number of cities in Tatarstan, Bashkortostan, the Samara region and Nizhny Novgorod (Russia), and soon it will be available in the Moscow region with a subsequent launch in St. Petersburg and Krasnodar.

Truck sharing is an alternative to leasing or classic rental format. The client rents a truck to meet short-term business objectives and must not pass a complicated procedure of purchase of the car and then be concerned about its content. Clients do not need to interact with many owners of special equipment, synchronize them with each other, conduct calculations and document flow with each - all this is performed by "SPECSHARING " while all participants are provided with convenience and safety. At the same time, the main participant - the manufacturer of trucks of various types and modifications - also receives certain advantages. Besides the fact that the company, in addition to the sales of its products, it is also the seller of services (which, as experience shows, brings a considerable profit in itself), it also provides additional stabilization of the production rate.

The dynamics of the model range is characterized by nonstationarity: some models are removed from production, new ones appear instead. After the completion of the certain model production, spare parts for it continue to be produced for at least 10 years. In such conditions, truck sharing helps to equalize the satisfaction of demand and stabilizes the production process, including the warehouse logistics option (taking into account the supply of components not only to the assembly line, but also to the truck sharing services). Discount sales bring additional flexibility in production planning.

This paper presents an approach to organizing management in a digital ecosystem that implements projects of this type. The conditions for the stable functioning of the DES are described. The tasks are formulated and solved, the solution of which enhances the coordination of actions of the direct participants in the transport process.

The forecast (plan) for the production of trucks is created taking into account the distributed forecast of the economic activity of enterprises and companies in the territory considered in the project. If the cars available in a particular service center become insufficient, then it is possible to use the free resources of other service centers or (if this situation arises systematically) to organize an additional supply of new trucks from the factory. During the implementation of the project, it may be necessary to divide the service centers into the categories of available equipment and the number of available trucks, which can improve the financial performance of the project.

2 Business Problem Description

The management of the described DES should ensure the technical and technological consistency of the participants in the transport process, as well as the observance of their economic interests, when operating within the framework of a unified planning system. The trucks participating in the project undergo standard scheduled service at specialized service centers.

For each service center, its service capacity is known, as well as the number of parking spaces with security. The average travel time between all service centers is also known. We also know the approximate number of trucks of various brands and types that are in demand at the production facilities closest to each service center - territorial clusters.

In this problem, the number of service centers is assumed to be 250, the distance between them is from 25 to 1,000 km. Taking into account the forecast of the needs of each territorial cluster in various types of trucks, the task is to "balanced" supply of the necessary trucks of various models - to each service center either for subsequent sale to customers, or for use in a truck sharing service with the possibility of further sale of used equipment at a discount.

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The model should provide for the possibility of restructuring the network and changing the capacity of service centers in the event of the emergence of new economic objects where trucks will be in demand, or there will be changes in the demand for trucks at already operating facilities. Also, the current capabilities of suppliers of components and the forecast of the need for components and spare parts should be known, which will eliminate situations with their shortage or late delivery - both to the plant itself and to service centers.

A necessary condition for the implementation of such a project is a clearly defined relationship between the plant and the network of service centers. The interaction of service centers between themselves and the parent enterprise should also include the solution of the problem (if necessary) of the dynamic redistribution of spare parts and labor. Such a network structure can ensure the sustainable development of the digital manufacturing ecosystem under consideration.

Obviously, to manage all the services discussed above, an intelligent add-on is required - a control support system, which, based on predictive real-time models, will form and simulate various scenarios for given values of the main parameters of the digital production ecosystem. For the development and commissioning of the project in question, it is necessary to have an operating digital platform of the plant, which will provide information and algorithmic support for solving problems arising in the ecosystem.

3 Managing the KAMAZ PJSC Digital Ecosystem for the Stable Functioning of Truck Sharing

The formed management system should ensure uninterrupted and effective implementation of the business plan for shared transportation for all participants. In fact, we are talking about solving a complex logistic problem of creating transport systems, possibly containing transport corridors and transport chains. Such systems should ensure technological unity and joint planning of the transport process (optimal routing) with warehouse and production processes.

In order to be able to quickly correct the transportation plan required in case of unforeseen changes in the technological situation, it is advisable to use multi-agent technologies [2].

The system approach to the investigation of multiagent systems is effectively exemplified in representation of such objects as *multimodal* ones [3]. Their multimodality appears both in the decomposition of the production process into independent stages (phases) and in the study of various operation modes as control objects.

In both cases, the extended state vector $x_{k1}^{1} \dots x_{km}^{1} \dots x_{kM \dots}^{1} x_{k1}^{s} \dots x_{km}^{s} \dots x_{kM}^{s}$ is used to describe the object where the index $k,\ k = 1, \dots, K$ denotes a time point of discrete system operation, $s, s = 1, \dots, S$ is the number of mode (step, phase), m is the number of the input vector's component. Values of some components of the state vector for various modes may be constant, in particular, zero.

In the work [4], an approach was presented to solving the problem of optimal traffic routing management for a territorial cluster based on associative predictive models of multi-agent systems in which agents perform a common task: to deliver goods in accordance with the drawn up plan. The performance of multi-agent systems has been interpreted as their robustness as complex dynamic systems [5].

The multi-agent control systems themselves were interpreted as systems with a block state vector. Each block M corresponded to a description of the functioning of a certain carrier company as an agent. The criterion for the feasibility of a task common for agents is the fulfillment of the conditions so that the system does not lose stability as a result of the agents' actions. To predict the possible loss of stability, associative search algorithms were used, in particular, their version for identifying non-stationary systems [3].

The stability conditions of the model can be determined, for example, by wavelet analysis methods [3]. Wavelet analysis uses a special linear transformation of processes to analyze data characterizing the properties of the object dynamics under study. Such a linear transformation is carried out on the basis of special soliton-like functions (wavelets) that form an orthonormal basis in.

Wavelet analysis allows you to examine signals in the frequency domain that changes over time. For a system with one output and several inputs, we have

$$x(t) = \sum_{k=1}^{N/2^L} c_t^x \varphi_{L,k}(t) + \sum_{j=1}^{L} \sum_{k=1}^{N/2^j} d_{j,k}^x \psi_{j,k}(t),\ \ N \geq 2^L \qquad (1)$$

$$y(t) = \sum_{k=1}^{N/2^L} c_t^y \varphi_{L,k}(t) + \sum_{j=1}^{L} \sum_{k=1}^{N/2^j} d_{j,k}^y \psi_{j,k}(t), \quad N \geq 2^L \tag{2}$$

where: L is the depth of the multiresolution decomposition $k < t$; (k<t); $\varphi_{L,k}(t)$ are scaling functions; $\psi_{j,k}(t)$are wavelet functions obtained from mother wavelets by means of extension, compression and shifting (in this article, Haar wavelets are considered as the mother ones); j is the analysis detailing level; c_t and $d_{j,k}$ are the scaling and detailing coefficients respectively. The coefficients are calculated using Mallat algorithm [3].

Sufficient system stability conditions can be expressed through the coefficients of multiresolution wavelet decomposition.

The possibility of loss of stability by individual agents (and, consequently, by the entire system) was determined using the digital twin of the transport system, built on the basis of simulation models. If stability could be violated, then separate areas of instability were identified and the transportation plan was subjected to local adjustments. A high-precision information retrieval ("virtual") linear model was built:

$$\hat{y}_m(t) = \sum_{i=1}^{L} a_i \, \hat{y}_m(t-i) + \sum_{j=1}^{n} \sum_{r=1}^{R} b_{jr} x_{rm}(t-j),, \tag{3}$$

where for a sharing system: $\hat{y}_m(t)$ is the actual time remaining by the moment t for the timely delivery of the m-th order; $x_{rm}(t), r = 1, \dots, R$ are the factors of possible deviation of the delivery time from the contract schedule. L and R are a constant. The coefficient values are determined when you set up the predictive associative model.

Further, to solve the problem of optimal routing, it was proposed to use the iterative deepening A * (IDA *) algorithm - the application of the idea of iterative deepening in the context of heuristic search [4]. The coefficient values are determined when you set up the predictive associative model.

To speed up the operation of the algorithm in real time, it seems appropriate to use the methods of parallelization of IDA * algorithms. Within the framework of the optimizing problem the functioning of a truck sharing scheme as agents, we will consider individual service centers that act as elements of a sharing scheme.

If it was assumed in the optimization problem of the relay transportation scheme that the number of trucks is sufficient to solve it, in the present problem this condition becomes decisive and is formulated as a key constraint. Also, an important condition for uninterrupted operation is a sufficient number of spare parts and components that allow car repairs to be carried out within an acceptable time frame. The last condition applies to both planned and emergency repairs.

4 Forecasting the Dynamics of Demand and Possible Bottlenecks

When forming the optimal (under existing constraints) plan, in particular, a certain level of requirements for the availability of various spare parts is laid down. The model for forecasting the requirements for the m-th nomenclature unit has the structure:

$$z_m(t) = \sum_{i=1}^{l} a_i z_m(t-i) + \sum_{l=1}^{L}\sum_{i=1}^{I} b_{il} x_i(t-l), \tag{4}$$

where: $z_m(t-i)$ is the actual need for the m-th inventory at the time $(t-i)$; $x_l(t-j)$ - random factors of the need for the m-th spare part at the moment $(t-j)$, which can lead to an adjustment (sometimes very significant) of the generated plan. These can be abnormal and emergency situations, as well as other factors due to the peculiarities of a specific production situation. So, the associative identification algorithm can be used.

Delivery forecast. The forecast of deliveries, generally speaking, should take into account random factors, which can also lead to the adjustment of the formed plan. Random delivery models can be useful in changing market conditions arising from changes in external market factors.

The optimal supply planning process can be described in terms of a multidimensional Markov process. In this case, the state of the system at each step is characterized by a random vector

$$\alpha(t) = \{\alpha_1(t), \alpha_2(t), \alpha_3(t)\}, \tag{6}$$

where: $\alpha_1(t)$ is the total demand for components at time t, , $\alpha_2(t)$ is the total delivery from the warehouse, $\alpha_3(t)$, is the current volume of traffic.

5 Situational Awareness

The above-described scheme for supporting the management of the transport system is based on predictive models of real time, which are able to warn about the possibility of exiting the normal mode of operation (which is interpreted as the possibility of loss of stability by the multi-agent system).

The patterns $x_{1m}, \ldots x_{Rm}, y_m$ characterize the production situation. We use associative search algorithms to predict the situation. These algorithms are smart least squares. Indeed, at the training stage, the set of patterns is subdivided into clusters, which are further corrected as information accumulates. For the forecasting algorithm to work at time *t* in the cluster containing the current pattern, several patterns are selected that are close to the current one in the sense of the selected criterion (association). Next, a system of linear equations is solved using the least squares method [3].

Thus, we have a point (unique for the moment t) linear model of a nonlinear process, the best in the sense of the root-mean-square criterion. In the non-stationary case, the solution is sought in the space of wavelet transformations. It should be noted that in order to analyze and predict production situations, it is necessary to take into account various factors $x_{pm}, p = 1, \ldots, P,$ characterizing certain features p of the current production situation, determined by the external environment.

In a particular case, this can be interpreted as the likelihood of an event occurring that can affect the dynamics of the production situation. In the model, its value can be determined in an expert way, or through production and fuzzy models. The results of analyzing and predicting situations taking into account these (often difficult to formalize) factors are called *Situational Awareness* (*SA*).

The digital industrial ecosystem of truck sharing should in particular, ensure the sustainability of work in the event of unforeseen situations associated, for example, with natural disasters or natural anomalies, or - with the influence of the "human factor". To solve such problems, a certain "dynamic reserve" is needed, capable of providing a quick redistribution of transport units to solve certain sudden problems.

Certain regularities (for example, limiting the movement of heavy vehicles in the spring, or a possible sharp decrease in the average speed of movement during weather anomalies) must be taken into account in the model in advance.

Based on the proposed predictive models, the management scheme of this DES will ensure a balance between demand forecasts and real production capabilities, taking into account seasonal and other factors. Situational driving awareness will increase the intensity of the truck while reducing the overall life of the truck.

The scheme ensures the economic efficiency of the activities of all participants in the process and is preferable in the environmental aspect. Many SA publications suggest using a specific classification of situations to analyze and support management.

In particular, a variety of cognitive methods based on semantic metrics are proposed for determining the proximity of situations, allowing expert assessments to be taken into account. It should be noted the importance of taking into account the rate of change of external factors, which must correspond to the rate of decision-making in the control system, as well as the rate of classifying the current situation to a certain class.

6 Case Studies

Q-means clustering. At the stage of training the associative search algorithm that predicts the production situation with Situational Awareness, data is clustered. Further, in real time, the identification problem is solved for the current time instant. At the same time, digital portraits of “similar situations” are selected from the data archive for the algorithm to work.

The selection is carried out from the cluster into which the current vector of inputs falls. The *k*-means algorithm can be used to cluster the sets of indicators characterizing the production situation. In conditions of Big Data, when, in addition to the need to process large amounts of data, high speed of algorithms is also required, it seems appropriate to use quantum computing.

Today we only carry out simulations, however, in anticipation of the real implementation of quantum computers in production control, this is quite timely. The IBM Quantum Experience cloud quantum computing platform was used for modeling.

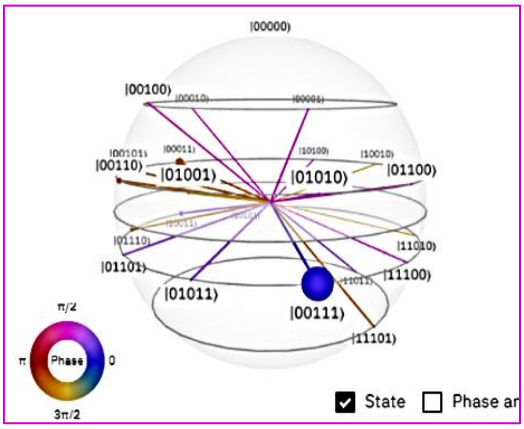

Fig.1. Multiagent system state

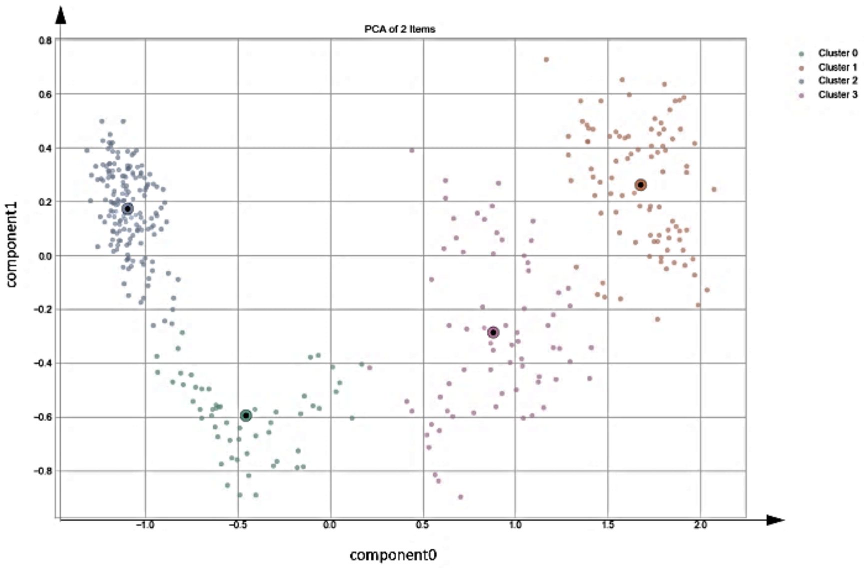

Fig.2. Production situations *q*-clustering

7 Conclusion

Within the framework of the concept of trucking, the following advantages can be distinguished for the producer and consumers - DES participants: convenience for a wide range of clients; reduction in the cost of transport services; improvement of the ecological situation; ensuring the rhythm of car production; facilitating the launch of new models on the market; decrease in the average age of trucks; improvement of the road safety situation; simple solutions for the seasonality of the use of equipment, etc.

Real-time predictive identification models proposed in the paper to optimize the tracking scheme provide an opportunity to prevent disturbances in the stability of the DES functioning and ensure their sustainable development, since they take into account the nonstationarity of the processes under study and the impact of poorly formalized factors characterizing the production situation.

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