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Economically Optimal Digital Solutions to Manage Integrated Network Flows

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***Abstract*—The development of the industrial Internet of things, the standardization of data exchange protocols, is one of the drivers that makes the modern world big business follow the main trend of integrating into commercial networks. The concept of digital interaction and the construction of multi-level structures of complex topology have caused the urgent need to develop algorithms to manage integrated flows in such networks. The solutions, which are built on these algorithms, form the basis of software for servers that control all business processes. To develop them, it is necessary to use mathematical modeling and methods of optimization theory, taking into consideration the stochastic nature of working conditions. The enterprise economic efficiency is one of the main criteria. A special feature of this task is the implementation and information anisotropy of commercial networks, as well as the heterogeneity of distribution and autonomization of resources. Today, most of the networks are among the transnational corporations. Although the exchange of business data takes place in real time, the material flows of goods or raw materials are regullated by various national laws. This leads to customs procedures, a number of restrictions in moving across borders, and it requires taking into account the distribution of processes in space and time. The paper considers the conditions for forming optimal algorithms of digital interaction in the nodes of a commercial network. The authors proposed the methods to solve this problem with the help of the complicated bulk-service algorithm multiserver system QS. They showed the practical application in the conditions of the industrial Internet of things, and mathematically calculated algorithms as a basis of the software to manage the operating distribution centers. They gave an example of practical application in the conditions of the industrial Internet of things and the mathematical algorithms that underlie the software to manage existing distribution centers.**

***Keywords*—algorithm; control; multimodal; digital; inter-machine interaction; math model**

I. INTRODUCTION

Development of IIoT (Industrial Internet of Things) applications and their integration with ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) systems brings to a higher level the interaction of enterprises with each other and with consumers. These processes appear most vividly in network commercial structures [1]. Another trend is the penetration of SIM solutions, extended digital omnichannel interaction with the identified consumer, which is possible due to real-time information about customer preferences, the history of relationships and the current location.

Unlike other economy branches, the entire population is included in the retail client pool; every person is a consumer of FMCG (Fast Moving Consumer Goods), Food Retail [2], while the number of suppliers is measured in thousands. In addition, it is necessary to emphasize the growing share of Private Label, as this trend has covered all major retail companies, and it generates internal structural flows.

The prerequisite for implementing IIoT was the need to determine not only the destination, but also the storage conditions and the realization period of a product using its code. An important feature of the FMCG food segment is a very short time between the production date and the Expiry Date, during which SCM (Supply Chain Management) is performed and generates storage, distribution, logistics and marketing problems. Taking into account the anisotropy of the socio-demographic landscape and seasonality of demand, it is impossible to manage these processes effectively in conditions of complex network topology without M2M (Machine-to-Machine) digital algorithms [3]. Effective management of commercial network business structures has become possible with the development of Web 3.0 networks, application of 4G wireless networks, VPN solutions, and, first of all, cloud services XaaS. This includes not only the widespread business-oriented SaaS (Software as a service) products, such as Microsoft Dynamics NAV from the software family MBS. Particularly the network commercial structures, which were scattered geographically, needed the information technologies IaaS, PaaS and cloud computing models to give numerous company divisions access to a unified information and technological platform. The integration of the operating system, DBMS (Database Management System), connecting sotware, development and testing tools in the cloud server, was a driver for the development of the largest network companies.

One of the major problems in the process of transition to digital inter-machine interaction in the scale of a commercial network was the optimization of all business components in a cross-functional mode. The intense competition in this segment of entrepreneurship causes the need for the complex interaction of all top-level departments: procurement, production, marketing, transport, and logistics. Attempts to solve the optimization problem separately, for each of them, break the total balance and reduce the general efficiency of business.

Currently, the range of activities of network commercial structures covers not only trade, but also the service provision, mail, tourism, providing, digital service products. Their directions of business, such as retailing, manufacturing, services, reflect the widespread demand of the mass sector.

Due to the availability of affordable digital solutions, the commercial network activities achieve a qualitatively different level. According to Infoline, large retailers have approached the indicators, when the main players control up to 80% of the market [4]. FMCG segment companies occupy the top lines in the rating. The driver of development here is the penetration of digital technologies, the provision of artificial intelligence systems with sensory systems, the development of alternative wired and wireless channels, high-speed access to the global network, and the development of multiplatform business solutions available for replication.

In this regard, it is necessary to solve the problems, which are associated with the expansion of business into the transnational field of activity, and to ensure the development of computer digital infrastructure and high levels of third-party logistics. At the same time, the core of server management systems is scientifically cogent algorithms, which are based on mathematical models and modern calculation methods.

When modeling the flow of goods and loads, it is necessary to take into account the uncertainty that both market movements and consumer preferences, as well as the changing legal framework and the G2B structure make.

II. SETTING THE TASK OF MANAGING INTEGRATED FLOWS

To model the processes that occur in a commercial network, let us single out the concept of a physical network. It includes the nodes (for example, trade enterprises, united by a single brand, management, general economic structure, distribution and market policies), consolidated transport pool, production units, terminals, warehouses, distribution centers, logistics services. We introduce the concept of an interface, which is a contact surface in mutual commercial activities. For example, to provide more than 12,000 of its own outlets, the largest multi-format network company X5 Retail Group (X5) built about forty distribution centers. All operations are automated using digital standardized solutions. Each SKU (stock keeping unit) is provided with machine-readable barcode, QR (Quick Response Code) or RFID (Radio Frequency Identification) recognition markers. The use of EAN/UCC and ITF standards makes it possible to carry out the whole complex of operations on the physical interaction of network nodes regardless of their location. The company's hybrid cloud servers are loaded with scalable, multiplatform software, designed for real-time operation, with IDaaS (Identity-as-Service) technology, which performs the functions of authentication, authorization and identification data management.

The formation of optimal algorithms for the commercial network [5] is possible only if an adequate mathematical model is constructed. This allows solving a number of problems:

- End-to-end support of object activities.
- Formation of development strategy based on advance indicators.
- Work in conditions of market uncertainty by using the mathematical theory of stochastic processes.
- Dynamic interaction with consumer demand
- Carrying out stress tests.

In this case, the main priority is to formulate clearly the input and output characteristics when servicing integrated network flows. Such a set of data should be formalized by a vector of arguments, which are used in the mathematical modeling of each physical object to describe the inter-machine interaction. It is also necessary to determine a package of digital data for information exchange, and kinds of sensors that are involved in forming computer interconnection algorithms. In addition, the software needs to take into account the length of time in all processes in a commercial network.

The methods presented in the literature [6] are based on the application of queuing theory and rather simple models. Cross-system [7] interaction implies the coordination of the top-level units activities. To solve this problem, it is proposed to combine the use of economic regulation, mathematical models [8] and scientifically based methods.

III. FORMALIZATION OF THE TASK BY USING DIGITAL TECHNOLOGIES

Let us consider an example of interaction of contact surfaces of commercial services. When forming a model, the business sector is irrelevant, since it is obvious that the interpretation can be the broadest. These are tourist, security, medical and various areas of service. Today, the introduction of M2M interaction and the exchange of machine-readable information are permissible almost everywhere. Mail is the most significant segment of the network retail trade, and it uses effectively not only modern digital encodings, but also algorithms of the external side of logistics 3PL (Third Party Logistics) [9]. This allowed the postal service to become a leading player in the online trade market, and today it serves the expanding online retail market.

First of all, let us introduce the concept of a physical serving unit. It can be a robotic stacker of an automatic warehouse, a sorting machine for mail, or a person – a shop loader, a G4S service employee, a waiter or a guide. For abstracting from specific content, let us call it the interface element. For each element, we introduce a characteristic μ – rate of service. Respectively, each business option has its own kind of service demands. Let us introduce λ which indicates the demand rate. Since in a competitive environment the business tries to work with the maximum load, it is necessary to make a model [10] that takes into account the possibility of using all available resources for work. This corresponds to the most rational rate of the company's capacity utilization.

IV. MATHEMATICAL SUBSTANTIATION OF THE SOLUTION METHOD

To solve this problem, we apply a complicated algorithm of multiserver systems of QS-queueing system. If there are several free interface elements, they all start working when a demand is received. At the same time, the rate of service increases in s times: $\mu^* = s\mu$, where s is the number of element. After the work is done, all elements are released. If a demand is received, provided that the system demands a service, then the load is distributed.

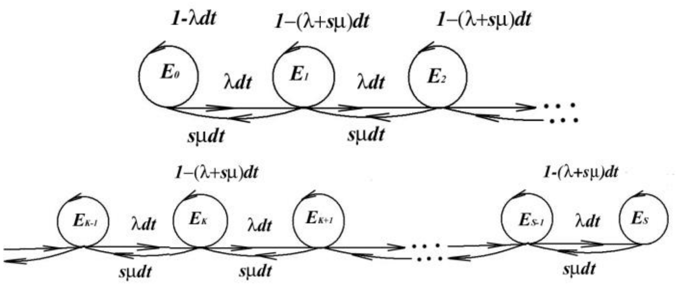

Fig. 1. Transition graph

When modeling, we use the Markov process [11], and if all the interface elements are involved in the work, it does not matter how the elements are distributed between the demands. Fig. 1 shows the graph of system transitions. We can write the equations of the system state:

$$\left.\begin{aligned} &P_0 = -\lambda P_0 + s\mu P \\ &0 = -(\lambda + s\mu)P_k + \lambda P_{k-1} + s\mu P_{k+1} \quad k = 1,2,\dots,s-1 \\ &0 = -s\mu P_s + \lambda P_{s-1} \end{aligned}\right\}$$

From these equations we get:

$P_k = \left(\frac{\lambda}{s\mu}\right)^k P_0$ for $k = 0,1,\dots,s$, and since $\sum_{k=0}^{s} P_k = P_0 \frac{1-\psi^{s+1}}{1-\psi} = 1$, then we get the probability of servicing $P_{service}$ and the average number of demands s in the system: $P_{service} = 1 - P_s = \frac{1-\psi^s}{1-\psi^{s+1}}$,

$$\tilde{s} = \sum_{k=0}^{s} kP_k = \frac{1-\psi}{1-\psi^{s+1}} \sum_{k=0}^{s} k\psi^k = \psi \frac{1-\psi^s\left[s(1-\psi)+1\right]}{(1-\psi^{s+1})(1-\psi)}.$$

These formulae allow determining the parameters of the system.

V. A PRACTICAL APPLICATION FOR THE DIGITAL INTERACTION OF A DC NODE

For practical purposes, it was necessary to describe the interaction process of several systems [12]. This is relevant in reality not only for commercial activity, but also for any activity, which is related to the sequence of operations or services.

In commercial tasks, this is primarily associated with the development of the concept of distribution centers (DCs). At the same time, the benefits are obvious for both suppliers and consumers.

These are:

– a significant reduction in transportation costs.

– Expanding the opportunities for maximum availability of the agreed range of goods in the network

– Possibility to reduce the flow of documents

– Reduction of labour costs

– Growth in goods sales due to modern CRM solutions, Internet-portals web 3.0.

Mono-format DCs provide the centralization of goods flows from the producer to the network nodes (including wholesale consumers), deliver goods and form an assortment efficiently. Today, the largest players have already completed the logistics division.

The activity of the powerful structure "The Post of Russia" is an illustrative example of network commerce, generated by the departure of retail in the online space. Post office activities provide most of the physical flows of suppliers from more than 20 countries, which are affiliated in online store systems. The rate of increase in freight traffic has lead to the situation when their work is in the mode of jetlag, and the congestion that periodically arise in the postal terminals indicate the need for a more serious approach to the algorithms of their activities. Significant funds are now invested in modern equipment to receive, process and sort mail items, optimize logistics processes, and develop hybrid mail, which is intended for state and commercial organizations that carry out mass targeted mailings. This will not only improve the quality of service and speed delivery, but also relieve the post offices, reduce queues and strengthen control over incoming goods. The analogue of the distribution center here are automated sorting centers, which also require the optimization of logistics and business processes. We can also see the similarity in launching the "first mile" mail service for terminal flows to the client.

Today, a powerful segment of C2C (Consumer-to-consumer) serves to designate an electronic trading scheme. However, the difference from other schemes is that both the buyer and the seller are not entrepreneurs in the legal sense. In most schemes, such a relationship is organized by a third party, the organizer of the trading platform. Most often these are ad-aggregator sites, online Internet-auctions. Advantages of the C2C scheme are, first of all, low transaction costs and, respectively, a competitive price for the goods.

VI. INTELLIGENT PROGRAM OF THE INTER-MACHINE INTERACTION SERVER

The most difficult problem was to develop a mathematical model and form algorithms as the basis of software.

Here we need a methodology to form standards of interaction in the structural divisions of the commercial network, and it should be not only in the form of basic algorithms, but also the system scientific approach, which was developed by the practicing specialists and is based on the application of the mathematical apparatus. These kinds of control objects include demands passing sequentially through several interface elements. The activity of the described above distribution center (DC) as a node of a commercial FMCG network is an example shown in Fig. 2.

In this case, we single out two stages. In the first stage, the goods are received from the input distribution. This reflects the contact surface with the external environment and physically represents a set of elements for loading or unloading transport, and storing digital data in the computer's memory from a computer-readable SKU encoding. In the second stage, after analyzing this information, sorting and distribution of goods is carried out according to zones and subdivisions of the distribution center. In this case, the decoded digital marks are processed by using algorithms to determine the storage regimes (temperature, humidity), the maximum duration, safety and the selection of the corresponding DC zone. If the distribution track cannot be determined, the load undergoes the departure process. The probability of such an event is $(1-\theta)$.

In this case, Queueing Systems form a network which is characterized by the links between the individual systems and the properties of the systems themselves (Fig. 2).

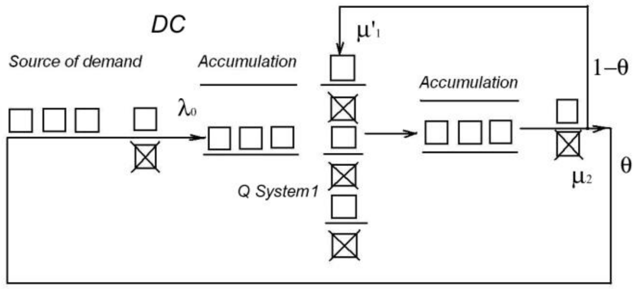

Fig. 2. Network QS structure

For algorithmization, let us first consider the problem in general. There is a network that includes the number of interface elements M and one source of demand. In this case, demands coming out of the i-th system ($i=1,2,....,M$) with probability θ_{ij} enter the system, or leave the network ($j=0$). Demands come directly from the source to the j-th system with probability θ_{0j}. The matrix of transmissions, that is probabilities of receiving demands from one system to another, has the form: $T=\left\|\theta_{ij}\right\|$.

This matrix is stochastic on the right and, respectively:

$$\theta_{00}=0,\ 0\le\theta_{ij}\le 1 \text{ for } i,j=1,2,....,M,\ \sum_{j=0}^{M}\theta_{ij}=1$$

A transmission graph is also formulated. The vertices of this graph correspond to the elements of the interface; the arcs indicate the possibility of a demand transition from one Queueing System to another, and the numbers on the arcs indicate the probability of this transition. Figure 2 shows the transmission graph of a widespread QS structure.

To determine the characteristics of the network, first of all, it is necessary to determine the demand rate in each system, which is in the steady state. Then it is true:

$$\lambda_j=\sum_{i=0}^{M}\lambda_i\theta_{ij} \quad j=1,2,\dots,M$$

λ_0 is the demand source rate. In the matrix form (1) has the form: $\overline{\Lambda}=\{\lambda_1,\lambda_2,...,\lambda_M\}$, then $\overline{\Lambda}=\overline{\Lambda}T$. The demand rate depends on source λ_0. The rank of the equation system is equal to M and we may determine from it:

$$\lambda_i=\alpha_i\lambda_0 \quad i=1,2,....,M$$

There is a finite number of demands in a closed network, and a transmission matrix $T_1=\left\|\overline{\theta}_{ij}\right\|$ will satisfy $\lambda_j=\sum_{i=1}^{M}\lambda_i\overline{\theta}_{ij}$.

The flow rate in a closed network is determined by the total number of requirements. For example, if we choose i_0 as a basic one, then we can determine:

$$\lambda_i=\alpha_i^{(i_0)}\lambda_0 \quad i=1,2,....,M$$

Thus, we achieve the algorithm invariance.

In the steady state of an open network, the probability of finding a demand is determined as $P=PT$. Hence we get: $p_j/p_0=\lambda_j/\lambda_0=\alpha_j$. The relative frequency of passing through the interface element j for T is equal to $\hat{p}_j=n_j/N$, where n_j is the number of demands in system j, N is the total number of demands in the network.

For a sufficiently large time interval $n_j/n_0\to\alpha_j$. Thus, requirements α_i once pass through the system j before returning to the source. Therefore, $\overline{u}=\sum_{j=1}^{M}\alpha_j\overline{u}_j$, where $\overline{u}_j$ is the average time spent in the system with the Number j.

The complexity of calculating networks is that the simplest demand flow, which enters the system, will generally have an aftereffect at its output. However, it should be considered that the flow summation takes place in multiserver systems, and according to CLT (Central Limit Theorem), the total flow loses aftereffect when 4... 5 flows are summed. For such representative networks, there is a steady-state regime, and if for each system $\psi_i=\dfrac{\lambda_i}{\mu_i}<1$, then it is a superposition of steady-state regimes of systems, which are loaded with sources whose rates λ_i are determined by relations (2).

The network state $E_{n_1,n_2,...,n_M}$ can be specified by a vector, each component of which is the number of demands in the corresponding system:

$\bar{n}_{(i)} = \{n_1^{(i)}, n_2^{(i)}, ..., n_M^{(i)}\}$. Let us express the probability of these network states in a steady state as $P_{n_1,n_2,...,n_M}$. It is possible to transform this expression as: $P_{n_1,n_2,...,n_M} = P_{n_1}^{(1)} P_{n_2}^{(2)} ... P_{n_M}^{(M)} = \prod_{i=1}^{M} P_{n_i}^{(i)}$, where $P_{n_i}^{(i)}$ is the probability of the n_i-th state, which is calculated provided that this system is loaded with a Poisson source with rate λ_i.

These results can be generalized in case of a closed network, when a finite number of demands m circulate in the network. In this case, only those components $n(t) = \{n_1(t), n_2(t), ..., n_M(t)\}$ are necessary, for which $n_1(t) + n_2(t) + ... + n_M(t) = m$ and $P_{n_1,n_2,...,n_M} = 0$ at $n_1 + n_2 + ... + n_M \neq m$.

The flow rates can be determined from equations (3) by using the transmission matrix $\lambda_j = \alpha_j^{(i_0)} \lambda_{i_0}$, where λ_{i_0} is the flow rate in an arbitrarily chosen system i_0, which in turn is determined by the number of requirements in the network. If $P_{n_1}^{(1)}, P_{n_2}^{(2)}, ..., P_{n_M}^{(M)}$ are probabilities, then $P_{n_1,n_2,...,n_M} = \frac{P_{n_1}^{(1)} P_{n_2}^{(2)} ... P_{n_M}^{(M)}}{\sum P_{n_1}^{(1)} P_{n_2}^{(2)} ... P_{n_M}^{(M)}}$ at $n_1 + n_2 + ... + n_M = m$ and $P_{n_1,n_2,...,n_M} = 0$ at $n_1 + n_2 + ... + n_M \neq m$.

Now we can calculate the distribution center activities. The nature and the specific form or mode of implementing, both flows and services, are of no fundamental importance.

VII. PRACTICAL CALCULATION FOR THE PRESENTED MODEL

To demonstrate the application of this technique, we use the data from SOK. This business structure is widely represented not only in servicing the retail segment (chain store), but also in the networks of service stations, agricultural trade, in the direction of HORECA, etc. When choosing this company as an example, we took for account that the reporting information was transparent and based on company's banking. In addition, the corporation activities cover online trading completely, and this allows tracing the entire flow of goods and services.

The initial data for the system Fig. 2 will be: accumulator volume, rate of service, number of posts, and rate of input flow.

Applying formulae, it becomes necessary to achieve inequalities for a steady-state regime in a node: $\frac{\lambda_1}{3\mu_1'} = \frac{\lambda_0}{\theta 3\mu_1'} < 1$ and $\frac{\lambda_2}{\mu_2} = \frac{\lambda_0}{\theta \mu_2} < 1$.

Table I shows the numerical data of calculating time spent in the service queue; Table II shows the recalculation for the changed data.

TABLE I. CALCULATION RESULTS FOR SELECTED SOURCE DATA

Average waiting time in the service queue						
	Intermediate accumulator for 15 positions					
	rate of service = 0,15			***rate of service = 0,08***		
	Number of posts			***Number of posts***		
Rate of input flow	5	8	14	5	8	14
30	5.8	3.2	1.1	9.3	5.4	2.3
70	28	7.9	2.7	64	22	7.4
120	-	21	8,4	-	81	16
220	-	78	19	-	-	34

TABLE II. CALCULATION RESULTS FOR CHANGED SOURCE DATA

Average waiting time in the service queue						
	Intermediate accumulator for 25 positions					
Rate of input flow	*rate of service = 0,15*			*rate of service = 0,08*		
	Number of posts			***Number of posts***		
	5	8	14	5	8	14
30	4.9	2.8	0.8	8.1	4.2	1.6
70	21	6.4	2.0	47	14	5.7
120	51	17	6.2	94	47	12
220	-	55	14	-	88	22

Hence, we see clearly the non-linear dependence, for example, when the flow is increased by less than 2 times with a small number of sharing posts, the service queue increases indefinitely. This example shows the potential for selecting parameters of commercial network nodes, and it should be used in the economic calculation at the stage of business design.

VIII. CONCLUSION

Expansion of commercial networks has been planned for many years to come. The parameters of this process can be predetermined. Thus, the widespread digital technology development for the purposes of system management, forecasting, and the transition to advanced economic indicators is the main direction to increase business efficiency. There is a developed technical base to solve such a large-scale task. It is based on digital technologies to identify any goods, loads, auxiliary activities. Equipping computers with numerous sensory devices allows receiving complete information not only about objects, their dimensions, weight, but also about storage conditions, travel routes, expiry date. Also computer programs support the level of emergent stocks and predict purchases without human participation. Today inter-machine synchronization of network nodes fully provides the level of third-party logistics 3PL. The organizational and technical platform allows integrating the information and physical space of the network business. Such systems have already become widespread in the online sales segment; they used digital technologies to integrate SCP (supply chain planning) and SCE (supply chain execution) into SCM. In this business, the concept of outsourcer 5PL provider has been formed.

Software products continue to be improved. The capabilities of hybrid cloud services, IDaaS, UCaaS (Unified communications as a service) systems, and cloud bursting technologies that take into account seasonal load variables are being used more extensively. This approach allows using multiplatform applications on mobile devices of both automatic systems and enterprise managers.

The mathematical model presented in this paper and analytical expressions allow transmitting the work of a commercial network node to the level of inter-machine interaction with the use of computer coding of the entire assortment. It becomes possible to consider changes in the rate of integrated network flows and program the management server. At the same time, it is possible to use the developments which offer an algorithm for representing the seasonal rate of loading of commercial structures. Based on the cutoff of economic data, it allows getting the mathematical expectation rate. In addition, the results obtained are well applied to the modeling of the sales funnel.

The relevance of research in this direction is determined by the fact that even without the organizations of counterparties, the cumulative staff of the leading commercial networks is tens of millions of people. Therefore, the issues of the qualitative and effective organization of their work are not only economic in nature, but also of social importance.

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