Digital solution to the problem of flow control in mechanical engineering production

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Abstract. Industrial Internet of Things is widely used to solve the industrial automation problem. This concept is aimed at the interaction of controlling computers and industrial equipment. The main problem is considered the development of algorithms for this interaction. Host computers have programs, based on these algorithms. M2M sensors are used as a feedback system to make management decisions during the operation. A condition for the successful implementation of IIoT is the standardization of machine-readable codes and unified data exchange protocols. The criteria for the development of algorithms is the economic efficiency. Optimal algorithms of the digital interaction in subdivision of mechanical engineering production are proposed in this article.

1. Introduction

Development of IIoT (Industrial Internet of Things) applications and their integration with ERP systems, as well as widespread CRM software solutions, brings to a higher level interaction of both enterprises with each other and with consumers. These processes are most clearly emerged in network commercial structures [1]. The prerequisite for implementing IIoT was the need to determine by the code of the goods not only the destination, but also the storage conditions, the period of realization, during which SCM (Supply Chain Management) [2] is performed, generating storage, distribution, logistics and marketing problems. Without M2M (Machine-to-Machine) digital algorithms, these processes cannot be effectively managed in conditions of complex network topology [3]. Effective management of commercial network business structures became possible with the development of Web 3.0 networks, development of 4G wireless networks, VPN solutions (Virtual Private Network), and, first of all, cloud services XaaS. This includes not only the widespread business-oriented SaaS (Software as a service) products, for example Microsoft Dynamics NAV from the MBS software family. We need technologies like IaaS. Their development is due to modern PaaS systems [4,5]. It is necessary to use the control integrated systems of the Total Integrated Automation Portal level at machine-building enterprises and cloud computing models, for access of numerous divisions of companies to a single information and technological platform. The combination in the cloud operating
system server, DBMS (Database Management System), connecting software [6], development and testing tools, served as the 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 [7,8]. The sharp competition in this segment calls for the complex interaction of all top-level departments: procurement, production, marketing, transport, and logistics. Attempts to solve the optimization problem separately for each violate the overall balance and reduce the overall efficiency. The top lines in the rating are occupied by the digital economy segment companies. The driver of development here is the penetration of digital technologies, high-speed access to the global network. Also needed the development of multiplatform business solutions, creation of scalable systems which are available for use, as well as invariant to the operating environment. In this regard, it is necessary to solve the problems of creating inter-machine interaction algorithms [9], to ensure the development of computer digital infrastructure, high levels of third-party logistics. At the same time, the core of server management systems is scientifically argued algorithms based on mathematical models and modern calculation methods. The world’s largest networks are now transnational corporations. A feature of this interaction is that the exchange of business data occurs in real time. At the same time while material ones, are forced to face a number of restrictions when moving across state borders.

2. Statement of the task
For the purposes of modeling, let us single out the concept of a physical network. It includes the nodes, consolidated transport pool, terminals, 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 [10, 11] 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 authentication, authorization and identity management functions. We introduce the necessary formalisms and develop a mathematical model that takes into account work in conditions of market uncertainty.

Dynamic interaction with market is taken into account in the context of continuously changing generations of innovative products. It needs to articulating 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 what kinds of sensors are involved in forming computer interconnection algorithms. In addition, the software needs to take into account the length of time in all processes. Cross-system [12] interaction implies the coordination of the activities of top-level units. To solve this problem, it is proposed to combine the computer and mathematical modeling.

3. Formalization
For the model, the business sector does not matter. These are tourist, security, medical and various areas of service. Today, almost everywhere, the introduction of M2M interoperability [13,14], the exchange of machine-readable information is allowed. First of all, we introduce the concept of a physical serving unit. It can be a robotic stacker of an automatic warehouse. For abstracting from specific content, let’s call it the interface item. For each item, we introduce a characteristic – the rate of service. It is necessary to take into account the possibility of using all available resources for the work. This corresponds to the most rational rate of the company’s capacity utilization.

4. Mathematical substantiation of the solution method
To solve this problem, we apply a complicated algorithm of multiserver systems of QS-queueing system [15]. In practice it is used as a bulk-service system, sharing. We introduce $s$ is the total number
of service points, \( \mu^* = s \mu \) the rate of service [16]. The structure of the dynamics of the transitions of the system [17] can be seen in figure 1.

![Figure 1. State transition structure](image)

We also combine the equations of state of the system:

\[
\begin{align*}
P_0 &= -\lambda P_0 + s \mu P \\
0 &= -(\lambda + s \mu) P_2 + \lambda P_{k-1} + s \mu P_{k+1} \quad k = 1, 2, \ldots, s-1 \\
0 &= -s \mu P_s + \lambda P_{s+1}
\end{align*}
\]

From here we get: \( P_k = \left( \frac{\lambda}{s \mu} \right)^k P_0 \), where \( k = 0, 1, \ldots, s \), and \( \sum_{k=0}^{s} P_k = P_0 \frac{1-\psi^{s+1}}{1-\psi} = 1 \). We can calculate the probability \( \bar{P}_{\text{service}} \) and the average number \( s : \bar{s} = \sum_{k=0}^{s} k P_k = \frac{1-\psi}{1-\psi^{s+1}} \sum_{k=0}^{s} k \psi^k = \psi - \psi^s \left[ (1-\psi) + 1 \right] \frac{1}{(1-\psi^{s+1})(1-\psi)} \),

\[
\bar{P}_{\text{service}} = 1 - P_s = \frac{1-\psi^{s+1}}{1-\psi^{s+1}}. \]

As a result, a model for calculating the system is formed.

5. A Practical application for the digital interaction of a DC Node

For practical purposes, it was required to develop a description of the interaction process of several systems [18, 19]. This is relevant not only for mechanical engineering production, but also for any related to the sequence of operations or services. This is primarily due to the development of the concept of distribution centers [20].

6. Intelligent program of the server of inter-machine interaction

Automatic The most difficult problem was to develop a mathematical model and form algorithms [21] as the basis of software. These kinds of control objects include passing demands sequentially through several interface items as it is shown on network in Fig. 2. In this case, we single out two stages. In the first stage, the goods are received from the external flow (input distribution). This corresponds the contact surface. In the second stage, sorting and distribution of goods is carried out. If the distribution track cannot be determined, the load is returned to the re-performance of the stages. The probability of such an event is \( (1-\theta) \). It reflects Queueing Systems as a network [22].

Let's make a mathematical model. There is a system that includes the number of interface items \( M \) and one source. Demands coming out of the \( i-th \) system, where \( i = 1, 2, \ldots, M \) with probability \( \theta_i \). From the source directly to the \( j-th \) system, demands are received with probability \( \theta_{ij} \). The matrix of transmissions, that is probabilities of receipt of demands from one system to another has the form: \( T = \| \theta_{ij} \| \). This matrix is stochastic [23] on the right and, respectively, is performed: \( \theta_{0i} = 0 \); \( 0 \leq \theta_{ij} \leq 1 \) for \( i, j = 1, 2, \ldots, M \), and also \( \sum_{j=0}^{M} \theta_{ij} = 1 \), at \( i = 1, 2, \ldots, M \).

Also, a graph of transmissions is formulated [24]. The vertices of this graph correspond to the points 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. The demand rate \[ \lambda_i \] of flows in each system in the steady state:

\[
\lambda_j = \sum_{i=0}^{\infty} \lambda_i \theta_j \quad j = 1,2,\ldots,M
\]  

(1)

where \( \lambda_i \) is rate of source of demands. In the matrix form (1) has the form:

\[
\mathbf{p} = \mathbf{A} \mathbf{p}
\]

where \( \mathbf{p} \) is vector of flows and \( \mathbf{A} \) is matrix of transitions. The rank of the system of equations (1) is equal to \( M \) and from it one can determine:

\[
\lambda_i = \alpha_i \lambda_n, \quad i = 1,2,\ldots,M
\]  

(2)

In a closed network, a finite number of demands \( n \) and a transmission matrix \( T = \{ \theta_{ij} \} \) will satisfy

\[
\lambda_j = \sum_{i=1}^{M} \lambda_i \theta_{ij} \quad j = 1,2,\ldots,M
\]

(3)

Thus, the invariance of the algorithm is achieved \( \lambda_i = \alpha_i \lambda_n, \quad i = 1,2,\ldots,M \) in the steady state of an open network, the probability of finding a demand is determined as \( P = PT \). Hence we get

\[
\frac{p_j}{p_0} = \frac{\lambda_j}{\lambda_0} = \alpha_j.
\]

The relative frequency of passing through the interface point \( j \) for \( T = PT \) is equal to \( \hat{p}_j = \frac{n_j}{N} \). \( N \) is the total number of demands, \( n_j \) is the number of demands in the system \( j \). For a sufficiently large time interval \( n_j / n_0 \to \alpha_j \). Thus, the requirements \( \alpha_j \) once pass through the system \( j \) before returning to the source. Therefore, \( \bar{u} = \sum_{j=1}^{M} \alpha_j \bar{u}_j \), where \( \bar{u}_j \) is the average time spent in the system with the number \( j \).

The complexity of calculating networks \( \lambda_i = \alpha_i \lambda_n, \quad i = 1,2,\ldots,M \) is that the simplest flow of demands, which enter the system, at its output will generally have an aftereffect. However, in view of the fact that the summation of flows takes place in multiserver systems, according to CLT (Central Limit Theorem), practically already when 4-5 flows are summed, the total flow loses aftereffect \( \lambda_i = \alpha_i \lambda_n, \quad i = 1,2,\ldots,M \). For such representative networks, there is a steady-state regime, and if for each system \( \lambda_i = \alpha_i \lambda_n, \quad i = 1,2,\ldots,M \) is a superposition of steady-state regimes of systems loaded with sources whose rates \( \lambda_i \) are determined by the relations (2).

The state \( E_{n_1,n_2,\ldots,n_M} \) can be specified by a vector: \( \mathbf{n} = \{ n_1, n_2, \ldots, n_M \} \). The probability of these states in the steady state will be denoted by \( P_{n_1,n_2,\ldots,n_M} \). It is possible to transform this expression as:

\[
P_{n_1,n_2,\ldots,n_M} = P_{n_1} P_{n_2} \cdots P_{n_M} = \prod_{j=1}^{M} P_{n_j}^{(i)}, \quad \text{where} \quad P_{n_j}^{(i)} \text{is the probability, calculated on the condition that this system is loaded with a Poisson source with rate} \lambda_i.
\]

The flow rates can be determined from equations (3) using the transmission matrix \( \lambda_j = \alpha_j \lambda_n, \quad i = 1,2,\ldots,M \), where \( \lambda_n \) is the flow rate in an arbitrarily chosen system \( i_0 \), which in turn is determined by the number.
of requirements in the system. Then, if \( P^{(1)}, P^{(2)}, \ldots, P^{(M)} \) are probabilities, then

\[
P_{n_1, n_2, \ldots, n_M} = \sum P^{(1)}_{n_1} P^{(2)}_{n_2} \cdots P^{(M)}_{n_M} \quad \text{at} \quad n_1 + n_2 + \ldots + n_M = m \quad \text{and} \quad P_{n_1, n_2, \ldots, n_M} = 0 \quad \text{at} \quad n_1 + n_2 + \ldots + n_M \neq m.
\]

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

7. Conclusions

The transition to digital technology is planned for many years. The parameters of this process can be predetermined. Thus, the widespread digital technology learning for the purposes of system management, forecasting, and the transition to advanced economic indicators is the main direction of increasing business efficiency. To solve such a large-scale task, there is already a developed technical base. It is based on digital technologies for the identification of any goods, goods, 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, expire date. Also, without human participation, computer programs support the level of emergent stocks, they predict purchases. Inter-machine synchronization of network nodes today fully provides the level of third-party logistics 3PL. The organizational and technical platform allows integrating the information and physical space.

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