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MODIFIED PETRI NETS IN THE MODELLING OF INFORMATION FLOWS OF AN ONLINE STORE

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ABSTRACT: The article presents an assessment of the impact of information technology and the Internet on the e-commerce sector in Russia and in the world. The analysis of the state of the e-commerce market in Russia, as well as in several other countries leading in terms of the volume of this market, is carried out. One of the possible approaches to modelling material and information flows of an online store is considered. Based on a review of the basic methods for modelling discrete-continuous economic and technical systems, the feasibility of using the apparatus of Petri net structure theory for modelling the operation scheme of an online store is substantiated. It is proposed to use a modification of Petri nets focused on modelling and analysis of discrete-continuous systems by including priority transitions, as well as the delay time of labels in positions and transitions. A model of information flows of the online store in the form of a modified Petri net is built.

Keywords: electronic commerce, business models, online stores, material flows, modelling, information flows, model, modified Petri nets.

INTRODUCTION

In the process of development of the modern economy, new ways of entrepreneurial activity are constantly opening up. The active development of information technology and the Internet creates a fundamentally new environment for business development: the formation of new markets, the emergence of demand for new goods and services, the creation of fundamentally new offers. The widespread use of information technology, along with globalization, is the factor that determines the nature of the development of the modern economy and the problems that need to be studied in the new conditions. Such new phenomena include the development of electronic business, in particular electronic commerce. The concept of "electronic business" currently does not have a clear and universally recognized definition. As an example, we give the definition provided by the Association of Russian Banks (ARB): electronic business (e-business) is a business activity that uses the capabilities of global information networks to transform the main business processes, as well as internal and external relations to generate revenue (Statistical data of research agency “Forrester”). One of the rapidly developing areas of electronic business is electronic commerce (EC).

The EC is defined as a sphere of the economy, which includes all financial and trading transactions carried out using computer networks, and business processes associated with such transactions (Statistical data of research agency “Forrester”). EC includes electronic information exchange, electronic capital flow, electronic trade, electronic money, electronic marketing, electronic banking and electronic insurance services (Statistical data of research agency “Data Insight”). There are over 10 varieties of business models for EC, but the following models are the main and applicable: B2C (business - consumer); B2B (business - business); C2B (consumer - business); C2C (consumer - consumer). The B2C category, which is based on online stores, has historically turned out to be the first applicable model where a commercial enterprise acts as a seller of goods and services, and the customer (consumer) is a private person.

In the B2B model, commercial organizations play the role of both seller and buyer. Attention is paid to the organization of work between companies in the process of production of goods or services. This business model opens up a horizon of new opportunities for companies, such as placing commercial offers, entering into major transactions and contracts, expanding business ties at the international level and increasing activity in the global market. Currently, this sector accounts for a large percentage of all transactions in the EC markets. In the C2B model, the role of the seller is assigned to a private individual, and the company acts as the buyer. This kind of sales organization system allows consumers to set the cost boundaries of goods offered by commercial organizations, thereby independently generating demand for these products. We should note here that this business model is the least applicable of all existing. In the C2C model, individuals are both buyers and sellers. Under these conditions, sites act only as intermediaries between consumers.

Even though the history of EC began back in the 60s of the last century, this type of business has undergone most of the global changes in just the last two decades. Unlike other sectors of the economy, EC development is fast and intensive. The desire of buyers to save time and money leads to the need for businessmen to use the achievements of information technology and the Internet. EC is a means of doing business on a global scale, and the pace of implementation and results indicate the prerequisites for a radical transformation of the sales and procurement system, the transfer of commerce to a

different, global level.

The rapid development of this type of commerce became possible only after the degree of global network distribution exceeded a certain critical level, which led to its accessibility to the masses of the population (Statistical data of research agency “Data Insight”). The level of development and distribution of EC in the world market today depends directly on the level of coverage of the global network in individual countries and regions, as well as around the world. Here is a series of data characterizing the development of EC in Russia and abroad. The volume of the Russian e-commerce market in 2019 amounted to $30.6 billion. These data are presented in the report “Internet Commerce in Russia in 2019” by analysts of the research company Data Insight (9). Currently, the share of EC in the country's GDP is 1.3%. In comparison, in the UK this indicator is 2.8%, and in the USA 2.6%. The Russian EC market is about $170 on a per capita basis. This is incomparably small compared to Western countries. The market soared more than 23% in 2019. This is comparable to growth in Malaysia and higher than, for example, in Canada. Analysts predict a sharp market growth by 2023.

In total, 425 million orders were made in online stores over the year in Russia. It is 41% more than a year ago. Online stores total revenue amounted to 1.6 trillion rubles, which is a quarter more than in 2018. Overall, the market has significantly grown throughout the year, but it slowed down a little in the second half, up to 39% yoy in orders and 24% in rubles. An important trend in recent years is a drop in the average bill with an increase in the number of orders. The average purchase size in online stores in 2019 amounted to 3800 rubles, which is 14% less than a year earlier. The average purchase amount decreases for the third year in a row. It should be noted that there is an increase in competition in certain areas of modern EC. Internet commerce can be especially distinguished; the winner is the one who collects, processes and uses information support more effectively in online stores management.

Information exchange is of great importance in the activities of online stores. Practice shows that often the data stream about the ordered product is lost along the way to the addressee, is distorted or arrives late. For the buyer, this is fraught with the fact that an online store delivery service may not bring him the goods he/she ordered. This can refer to some kind of "insignificant" characteristic - color, mass, size, interface, additional functions. Therefore, important conditions for the effective operation of online stores are: the absence of "bottlenecks" and the correct addressing of information flows. Otherwise, online stores may suffer losses. Online stores are characterized by a complex multi-level structure; therefore, they can be considered as complex economic and technical systems. The effectiveness of the functioning of such systems can be achieved using modern methods of information processing, methods of system analysis of complex objects based on a mathematical description of the process (2.3). Mathematical modelling and computer experiments with an object substitute model are an effective tool that allows one to create management systems, consider the behaviour of an object in emergency situations, evaluate its structure and control laws, and take into account the stochastic nature of disturbing influences.

METHODOLOGY

Modern economic and technical systems, which include online stores, have both structural and behavioural complexity. The existing concept of the level of complexity is determined by the number of elements of one kind or another, their connections and

relationships, “order relations” between them. Behavioral complexity can be associated with the behavior of the system in time and the presence of management processes in economic systems. Currently, the most effective method of studying economic and technical systems is simulation (4). Three main approaches were formed in it: discrete event modelling, system dynamics and agent-based modelling (ABM) (Official site of the International union of telecommunication (MSE, English International Telecommunication Union, ITU)). The system dynamics apparatus usually operates with continuous processes in time, and discrete-event and ABM are used for time-discrete processes. System dynamics suggests a maximum level of model abstraction, discrete-event modelling reflects abstractions of low and medium levels. ABM can be applied at any level of a model of any scale (Official site of the International union of telecommunication (MSE, English International Telecommunication Union, ITU)).

If we associate certain graphic primitives with the abstract representation of the system and connect them with lines carrying certain logic, we get a network - a graphic image of the process. The good thing about the network methods for describing and analyzing processes is that the abstractions used in them are close to intuitive ideas about processes (Official site of the International union of telecommunication (MSE, English International Telecommunication Union, ITU)). One of the popular graphical tools for researching systems is Petri nets (PTs). They allow one to describe and analyze the duration and interaction of operations within processes of different levels to identify bottlenecks of economic-technical systems, as well as determine the magnitude and reserves of reducing the costs of human, financial and other resources for the implementation of these processes. The main advantages of using PTs in modelling are as follows (5): 1. a process defined in terms of PT has a clear and precise view; 2. visualization of the network construction graphics, thanks to which all its definitions and algorithms are easily perceived; 3. the possibility of using various analysis methods.

At the same time, the popularity of PT is due to the successful presentation of various types of objects present in many simulated systems, and the “event-based” approach to modelling. PTs have the best capabilities for describing the relationships and interactions of parallel processes (Official site of the International union of telecommunication (MSE, English International Telecommunication Union, ITU)). PTs are a powerful tool for researching systems due to the ability to describe many classes of discrete, asynchronous, parallel, distributed, non-deterministic systems, the visibility of the presentation of their work, and the developed mathematical and software analysis apparatus. To describe the operation scheme of online stores, we propose the use of N-schemes based on the mathematical apparatus of Petri nets, one of the advantages of which is the possibility of representing the network model both in analytical form, with the possibility of automating the analysis process, and in graphical form to ensure the visibility of the model being developed (5). When analyzing structural and functional schemes, the main limitation of the formalism of N-schemes should be considered, which consists in the fact that they do not take into account the temporal characteristics of the simulated systems, since the transition response time is considered equal to zero. Given these conditions, we propose modified PTs (MPTs) (5):

$C=<P,T,I,O,M,L,\tau_1,\tau_2>$,

where $T = \{t_j\}$ is a finite nonempty set of symbols called *transitions*;

$P = \{p_i\}$ is a finite nonempty set of characters called *positions*;

$I: PxT \rightarrow \{0, 1\}$ is the input function, which for each transition t_i defines the set of its positions $p_i \in I(t_j)$;

O: PxT → {0, 1} - the output function, which displays the transition to the set of output positions $p_i \in O(t_j)$;

M: P → {1, 2, 3 ...} - the function of labelling the network, which associates with each position a non-negative integer equal to the number of labels in this position, which changes during the operation of the network.

The transition triggering instantly changes the labelling M (p) = (M (p_1), M (p_2), M (p_3) ... M (p_n)) to the labelling M / (p) according to the following rule:

$$M'(p) = M(p) - I(t_j) + O(t_j) \quad (1)$$

The equation (1) means that the transition t_j removes one label from each of its input positions and adds one label to each of the output.

L = {c1, c2, ... ck} - the set of colours of the labels.

Labels are interpreted as discrete streams (financial, material or informational).

$\tau 1$: T → N and τ_2: P → N are functions that determine the delay time when the transition is triggered and the delay time in the position.

The dynamics of the implementation of modified PTs is determined by the movement of labels simulating the movement of discrete flows. Thus, the considered modification of Petri nets allows us to solve the following problems (A plastic card as an instrument of payment systems in Russia): 1. Analysis of the functioning of the system elements in emergency situations; 2. Analysis of control switching at the network level; 3. System analysis to ensure a steady state.

DISCUSSION

The topic is the subject of analysis by a fairly limited number of scientists. Bespamyatov G.T., Krotov Yu.A. investigated the maximum permissible concentration of chemicals in the environment, Budyko MI, Drozdov OA, Yudin MI talked about the impact of human activities on the climate. Dolgov S.V. investigated the hydrological consequences of changes in economic activity in the Kursk region, Yu.V. Medvedkov - human and urban environment. Studies of this publication are based on the works of the following scientists: A.A. Dubyansky, V.M. Smolyaninova, N.A. Kravchenko, Yu.V. Mukhina, L.A. Ostrovsky, L.A. Vasilevskaya and others.

RESULTS

In modelling, it is considered that each material flow corresponds to an information flow. Such a correspondence is not always isolated (complete). Often information and material flows occur in different time intervals. The path along which the information flow moves in the general case may not coincide with the route of the material flow. The information flow can be ahead of the material flow, follow along with it or after it. In this case, the information flow can be directed both in one direction with the material, and in the opposite direction (4): leading information flow in the opposite direction contains, as a rule, information about the order; leading information flow in the forward direction - preliminary messages about the upcoming arrival of the goods; simultaneously with the material flow there is information in the forward direction about the quantitative and qualitative parameters of the material flow; following the material flow in the opposite direction, information on the results of the cargo acceptance in terms of quantity or quality, various claims, confirmations can pass.

The option of leading information flows in comparison with material flows is more preferable. This makes it possible to better prepare for the reception of goods. In fact, information flows are far from always ahead of the schedule; often they lag behind the timing of the movement of material flows. Information flows should be adequate to material flows in terms of the characteristics of these flows, but there is not always such a correspondence: in some cases, documents are drawn up that are common for several recipient consumers, and some of information could be redundant for each individual recipient of these resources. Management of information flows of online stores is not an end, but a means of managing material flows, their formation, movement, acceptance. Improper management of information (material, financial) flows can lead to inconsistency in online stores, which can be a strong blow to business organization and lead to significant economic losses.

Mathematical modelling is an effective tool for building control systems. Modelling of material and information flows of online stores based on modified Petri nets is presented in (5). The scheme of an online store considered in the article is simplified - a way of receiving online store payments is cash. A diverse assortment, attractive prices, a user-friendly interface - all this does not contribute to sales, if payment acceptance in online stores leaves much to be desired. It depends on the convenience of the final step, when a potential customer has already made a purchase decision, whether he will make it on your or on a competitor's site. And if there is no convenient payment method on the site, many will prefer to continue searching. Most online stores prefer to combine several options for receiving payments, providing the buyer with two important advantages - the right to choose and comfort.

Fig. 1 presents a scheme of an online store, where the following payment options are considered: cash and bank cards (A plastic card as an instrument of payment systems in Russia). The operation scheme of the online store is described by the following sequence of stages of the purchase of goods:

1. Buyer places an order on the site.
2. The order automatically enters into the Information System.
3. Buyer receives an automatic confirmation of the order on his/her Email.
4. The Sales Service gets an automatic notification about a new order.
5. Request of the Sales Service to the Warehouse Status Information System.
6. Exchange between the Warehouse and the Information System on the current state of stocks.
7. In the absence of the required product in the Warehouse, the generation of a request to the Procurement Service.
8. Notification of the Supplier about the planned purchase.
9. Order delivery to the warehouse.
10. Data entry by the Procurement Service on the procurement.
11. Transfer of the order to the Delivery Service.
12. The delivery service delivers the order to the Buyer and receives the money.

12 (1). Redirecting a request for payment.

12 (2). Entering card data.

12 (3). The electronic payment system sends an authorization request to the traditional payment system - the acquirer bank.

12 (4). The acquirer bank transmits a request for card authorization to the issuing bank, which maintains an online account database.

12 (5). Money transaction.

12 (6). The authorization result is transferred to the payment system.

12 (7). The buyer and the online store receive an authorization result directly from an electronic payment system.

12 (8). Money transaction.

13. Acceptance of the order by the Buyer and signing of documents for the Delivery Service.

14. Return of money and documents by the Delivery Service to the Sales Service.

15. The order is assigned the status “Completed”.

The presented scheme is simplified. It is assumed that an online store has a warehouse and works directly with suppliers. However, such a scheme allows us to say that flow control is an important part of an online store, and almost every department can lose, delay or distort information (13). Based on the described scheme of the online store for managing information flows, a mathematical model is developed in the form of modified PTs, presented in Fig. 1.

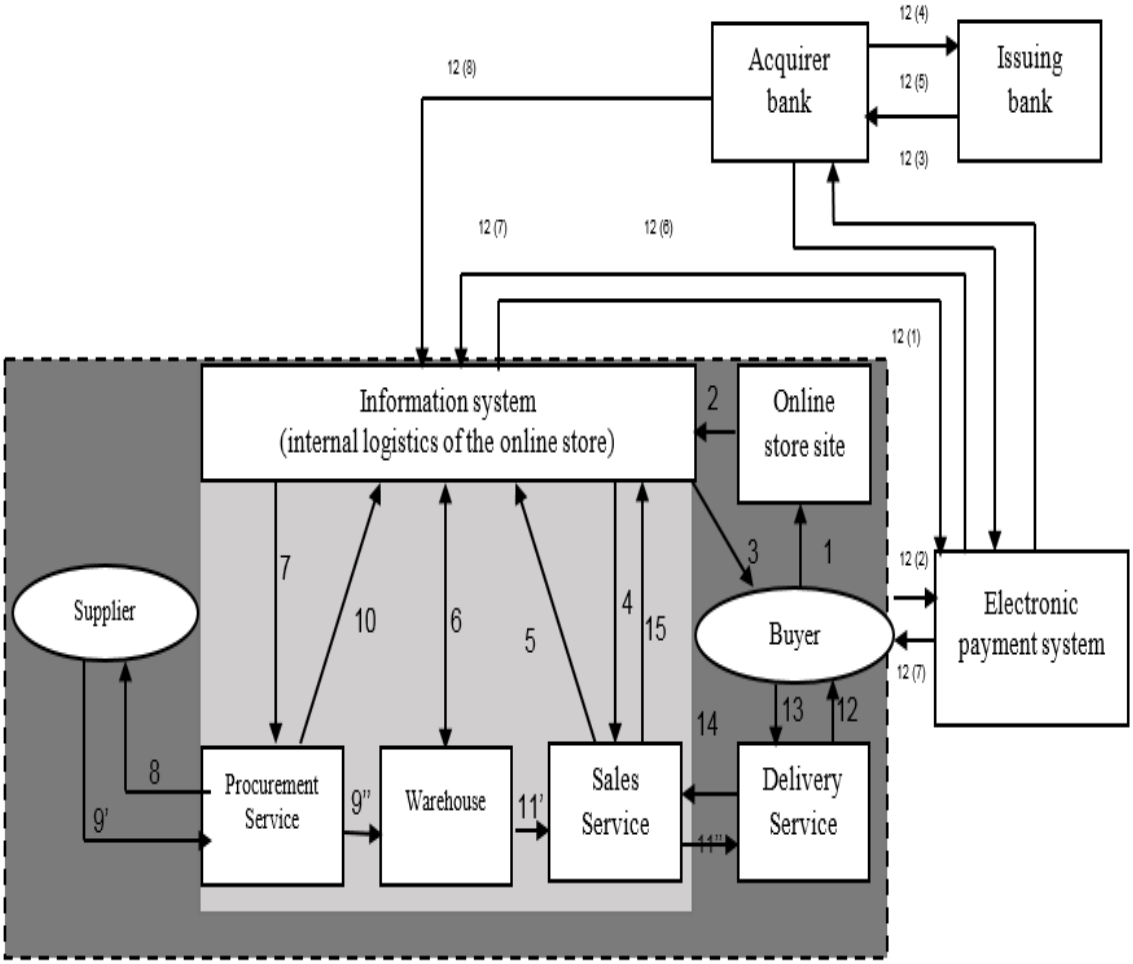
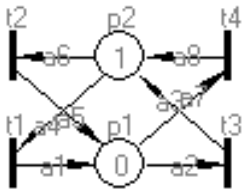
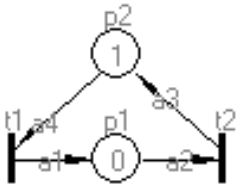
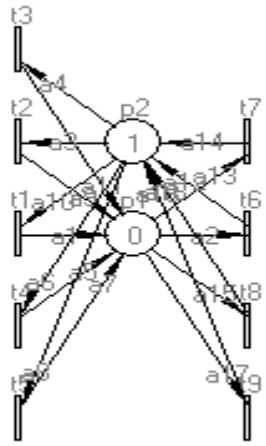
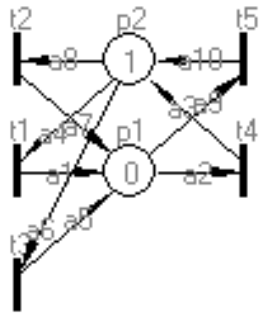
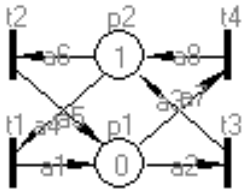
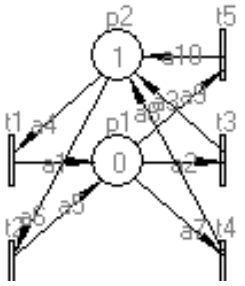
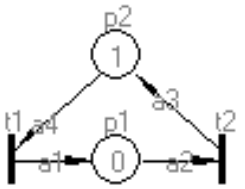
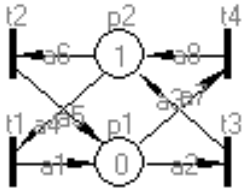
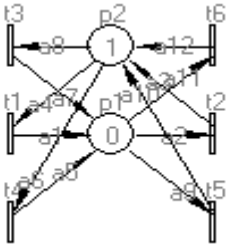


Fig. 1. Operation scheme of the online store

The model allows one to explore systemic relationships and the functioning laws of the system. Models of its basic elements were also constructed using the results (Table 1) (Motameni et al., 2008; Molinillo et al., 2018; Savdur & Kadochnikova, 2016).

Table 1. Models of the main elements of the online store

Graphical description of the models of the basic elements of the online store	Analytical description of the models of the basic elements of the online store		
 a) Buyer	2 Positions 4 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p2} O(t4)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p1} I(t4)={p1}
 b) Online store site	2 Positions 2 Transitions 1 Colour	O(t1)={p1} O(t2)={p2}	I(t1)={p2} I(t2)={p1}
 c) Information system	2 Positions 9 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p1} O(t4)={p1} O(t5)={p1} O(t6)={p2} O(t7)={p2} O(t8)={p2} O(t9)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p2} I(t4)={p2} I(t5)={p2} I(t6)={p1} I(t7)={p1} I(t8)={p1} I(t9)={p1}
 d) Sales service	2 Positions 5 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p1} O(t4)={p2} O(t5)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p2} I(t4)={p1} I(t5)={p1}

 e) Warehouse	2 Positions 4 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p2} O(t4)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p1} I(t4)={p1}
 f) Procurement service	2 Positions 5 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p2} O(t4)={p2} O(t5)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p1} I(t4)={p1} I(t5)={p1}
 g) Supplier	2 Positions 2 Transitions 1 Colour	O(t1)={p1} O(t2)={p2}	I(t1)={p2} I(t2)={p1}
 h) Delivery service	2 Positions 4 Transitions 1 Colour	O(t1)={p1} O(t2)={p1} O(t3)={p2} O(t4)={p2}	I(t1)={p2} I(t2)={p2} I(t3)={p1} I(t4)={p1}
 i) Electronic payment system	2 Positions 6 Transitions 1 Colour	O(t1)={ p1*1 } O(t2)={ p2*1 } O(t3)={ p1*1 } O(t4)={ p1*1 } O(t5)={ p2*1 } O(t6)={ p2*1 }	I(t1)={ p2*1 } I(t2)={ p1*1 } I(t3)={ p2*1 } I(t4)={ p2*1 } I(t5)={ p1*1 } I(t6)={ p1*1 }

Based on the PT models of the main elements, the online store operation scheme was synthesized (Fig. 2).

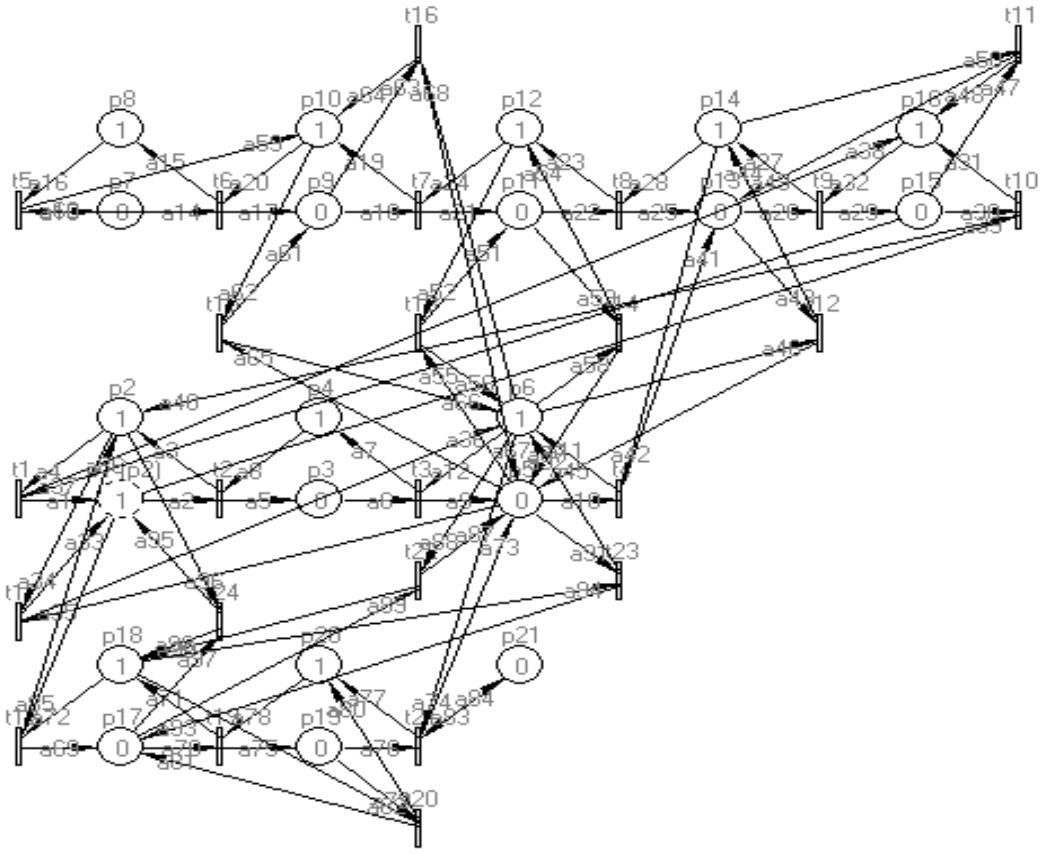


Fig. 2. The model of the scheme of the online store in the form of a modified Petri net

Analytical description of the general Petri net:

21 Positions
24 Transitions
1 Colour

O(t1)={ p1*1 p16*1 }	I(t1)={ p2*1 p15*1 }
O(t2)={ p2*1 p3*1 }	I(t2)={ p1*1 p4*1 }
O(t3)={ p4*1 p5*1 }	I(t3)={ p3*1 p6*1 }
O(t4)={ p6*1 p13*1 }	I(t4)={ p5*1 p14*1 }
O(t5)={ p7*1 p10*1 }	I(t5)={ p8*1 p9*1 }
O(t6)={ p8*1 p9*1 }	I(t6)={ p7*1 p10*1 }
O(t7)={ p10*1 p11*1 }	I(t7)={ p9*1 p12*1 }
O(t8)={ p12*1 p13*1 }	I(t8)={ p11*1 p14*1 }
O(t9)={ p14*1 p15*1 }	I(t9)={ p13*1 p16*1 }
O(t10)={ p16*1 p2*1 }	I(t10)={ p15*1 p1*1 }
O(t11)={ p16*1 p13*1 }	I(t11)={ p15*1 p14*1 }
O(t12)={ p14*1 p5*1 }	I(t12)={ p13*1 p6*1 }
O(t13)={ p11*1 p6*1 }	I(t13)={ p12*1 p5*1 }
O(t14)={ p12*1 p5*1 }	I(t14)={ p11*1 p6*1 }
O(t15)={ p9*1 p6*1 }	I(t15)={ p10*1 p5*1 }
O(t16)={ p10*1 p5*1 }	I(t16)={ p9*1 p6*1 }
O(t17)={ p1*1 p6*1 }	I(t17)={ p2*1 p5*1 }
O(t18)={ p17*1 p2*1 }	I(t18)={ p18*1 p1*1 }
O(t19)={ p18*1 p19*1 }	I(t19)={ p17*1 p20*1 }
O(t20)={ p20*1 p17*1 }	I(t20)={ p19*1 p18*1 }
O(t21)={ p20*1 p5*1 p21*1 }	I(t21)={ p19*1 p6*1 p21*1 }
O(t22)={ p5*1 p18*1 }	I(t22)={ p6*1 p17*1 }
O(t23)={ p6*1 p17*1 }	I(t23)={ p5*1 p18*1 }
O(t24)={ p1*1 p18*1 }	I(t24)={ p2*1 p17*1 }

Based on the developed modified PT model, it is advisable to create a software package that allows one to analyze information flows and predict the development of emergency situations of online stores.

SUMMARY

In the analysis of economic and technical systems, the main limitation of the formalism of N-schemes is established, which consists in the fact that N-schemes do not take into account the time characteristics of the simulated systems. This leads to the need for using the PT modification, oriented on modelling and analysis of discrete-continuous economic and technical systems, by including priority transitions, as well as the delay time of labels in positions and transitions. The modified PT model of online stores developed by us allows us to study systemic relationships and rules of functioning of the system.

CONCLUSIONS

We have analyzed the state of the EC market in Russia and several leading foreign countries. The intensive development of the retail sector of EC is indicated, the basis of which is online stores. The importance of the task of managing information flows for the effective operation of the online store is noted. In this regard, a model of information flows of the online store is constructed in the form of a modified Petri net. Practical implementation of the model will allow to increase the level of rationality of managing information flows of the online store.

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