МАТЕМАТИЧНІ МЕТОДИ ТА МОДЕЛІ В ЕКОНОМІЦІ

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APPLICATION OF SYSTEM DYNAMICS FOR ASSESSMENT OF CHANGES OF THE LEVEL OF STOCK AFTER INTRODUCTION OF ERP SYSTEMS

Application of information management system is an important element of ensuring business effectiveness for any modern enterprise. However, the permanent growth of the cost of such systems requires application of new approaches to assessment of influence of complex information systems upon the level of stock. The article describes a structure of the model and specifically those elements that allow assessment of reduction of delays connected with automation. It offers to assess a change of the stock level with the use of methods of system dynamics. The results are based on imitation experiments of the stock level in the production and sales system with the use of the AnyLogic software system.

Key words: ERP system, system-dynamic modelling, stock management

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ПРИМЕНЕНИЕ СИСТЕМНОЙ ДИНАМИКИ ДЛЯ ОЦЕНКИ ИЗМЕНЕНИЙ УРОВНЯ СКЛАДСКИХ ЗАПАСОВ ПОСЛЕ ВНЕДРЕНИЯ ERP-СИСТЕМ

Применение информационных систем управления – важный элемент обеспечения эффективности бизнеса для любого современного предприятия. Однако постоянный рост стоимости таких систем требует применения новых подходов к оценке их эффективности. В данной статье описана модель для оценки влияния комплексных информационных систем на уровень складских запасов. В работе описана структура модели и в особенности те ее элементы, которые позволяют оценить снижение задержек, связанных с автоматизацией. Изменение уровня запасов предлагается оценивать с использованием методов системной динамики. Результаты основаны на имитационных экспериментах уровня складских запасов в производственно-сбытовой системе с использованием программной системы AnyLogic.

Ключевые слова: ERP-система, системно-динамическое моделирование, управление складскими запасами

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ЗАСТОСУВАННЯ СИСТЕМНОЇ ДИНАМІКИ ДЛЯ ОЦІНКИ ЗМІН РІВНЯ СКЛАДСЬКИХ ЗАПАСІВ ПІСЛЯ ВПРОВАДЖЕННЯ ERP-СИСТЕМ

Застосування інформаційних систем управління – важливий елемент забезпечення ефективності бізнесу для будь-якого сучасного підприємства. Однак постійне зростання вартості таких систем вимагає застосування нових підходів до оцінки їхньої ефективності. У даній статті описана модель для оцінки впливу комплексних інформаційних систем на рівень складських запасів. У роботі описано структуру моделі і особливо ті її елементи, які дозволяють відстежити зниження затримок, які пов'язані з автоматизацією. Зміни рівня запасів пропонується оцінювати з використанням методів системної динаміки. Результати засновані на імітаційних експериментах рівня складських запасів у виробничо-збутовій системі з використанням програмної системи AnyLogic.

Ключові слова: ERP-система, системно-динамічне моделювання, управління складськими запасами

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Introduction

Currently, no one has any doubts about the need for the implementation of information systems. Information systems and technology are applied in all enterprises but functionality of these systems may be very different. It may vary from using the spreadsheets to automate the solution of particular problems and traditional accounting computer systems to implementation of integrated information systems that cover all stages of the product life cycle.

In the last decade the development of information technology has led to more extensive and expensive enterprise information systems which require special approach to the efficiency assessment.

There are many different methods for such estimation. Some of these methods take into account only the cost of the purchase and implementation of the systems; others include some results of the implementation. However, most experts believe that identification and estimation of the effects that are really related to implementation of information systems and technology is very difficult. The authors propose a method to estimate these effects on the basis of reduced inventory levels.

Literature review

Most researchers of the problems focus on reducing inventory and correspondingly cost optimization. For example, Barua [1] have shown that the implementation of IT has a positive effect on the turnover of stocks; Mukhopadhyay [2] have substantiated a positive dependence between the complex information systems implementation and reduced inventory. Various sources publish data of statistical research about the results of the information systems implementation on different levels in enterprises from different industries and of different sizes. Inventory level is reduced on average by 10–20%. But Lai, Xu, and Zhu [3] doubt that there is a direct correlation between the increasing investment in information technology and reduction of stocks. They assume that this relationship may be more complicated. According to these authors inventory reduction cause the following reasons.

1. IT implementation is accompanied by other processes. For example, there is a re-engineering of business processes, the transition to modern supply chain management, etc. They can cause the observed effect.
2. Now classic models of inventory management are not applied to individual inventory positions, but to the level of integrated warehouse management the whole company. (Rumyantsev and Neteshin [4]).

The big-scale study of more than 8,615 companies for over 7 years has been described in work [3]. The authors make some very interesting conclusions about the results of the investment in information systems impact on the inventory level. Investments in information systems impact the reduction of inventory levels negatively for the production level, neutral for the wholesale supply management, and positive for the retail value chain. This is consistent with the theory that stocks are reduced by reducing the information distortion. These distortions are enhanced to the top level companies upstream.

Opposing data is presented in [5; 6]. Mitra, Anderson and others publish the data about growing inventories after implementation of information systems, including class ERP. It may be due to the fact that the implementation of corporate information systems encourages enterprises to develop business and allows increasing the nomenclature of manufactured products.

So, there are many opinions and approaches to assess the impact of information systems and technologies on the level of enterprises' stocks, however, these approaches often give conflicting and controversial results. In this paper, we propose to apply the system dynamics to the analysis of these processes.

System Dynamics is an approach that allows us to understand the structure and dynamics of complex systems. Modern enterprise certainly is a complex system with a lot of feedbacks.

Basic methods of system dynamics were described in the papers by Forrester [7]. Namely, in the system dynamics cyclical changes in complex systems and feedback effects can be taken into account. These approaches to the analysis of the objects of interest have been developed in the works Lau [8], Caballini and Revetria [9], Chou [10], Venkateswaran and others [11]. System Dynamics offers to consider the operation of any complex system as an interaction of such elements as the «levels» and «flows». Inventory levels at a certain point of time can play the role of the «level» concept in our research. Items that are received at the warehouse or shipped from it can be considered as an example of «flow».

To construct a model, we also used the concept of «delay». According to Forrester, delay is an important component of complex systems. Delays have a significant impact on the system state. These delays can be separated into the following types: informational delays and time delays of material nature. The first type of delays may be caused by the time which is the necessary for transferring the information and making decisions. The second type is usually associated with the need for time-consuming movement of material resources or logistics operations.

The purpose of the research is to investigate the connection between the implementation of an integrated information system and reduced inventory levels of the firm. As a basic research tool, the authors use the system dynamics.

Description of the model

The first task of the study is to identify the delays, which can be reduced after the implementation of ERP-systems.

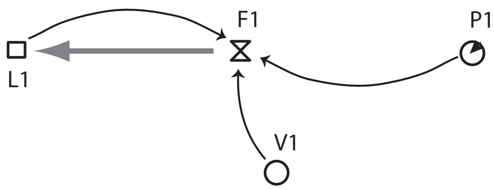
So, in the simplest case, we can consider the delays which are associated with the transportation of goods to the retail store, delays which are associated with the necessary time to organize shipments from retail store to customers, delay of necessary time to communicate with the client at service, necessary time for a decision on the formation and replenishment orders to the next distribution level. Obviously traffic delay depends least of all on the automation of the business processes.

Such delays can be observed in the system of distribution, which consists of several levels (retail, wholesale, manufacturing).

Positive and negative feedback are reflected in the model, which is based on Forrester's and Sterman's works [7; 12], but with changes and additions associated with innovative approaches to management.

The model describes the interaction of the three units. These are the retail store, the wholesale and the manufacturing.

Next, consider the model of retail warehouses. The model contains three main blocks. The first block deals with the formation of the expected level of orders from a customer to a retail warehouse. It is presented in picture 1, which contains the following elements.



Picture 1. Formation of the expected flow of orders (created by AnyLogic system)

*L*1 – the element which forms the expected level of orders. Its value is given by:

$$dL1/dt = F1 \quad (1)$$

*V*1 – the variable which determines the number of clients;

*F*1 – the flow rate (number) of clients per unit of time;

$$F1=(V1 - L1)/P1 \quad (2)$$

*P*1 – the parameter that defines the time (in units of time), which is necessary to serve one customer.

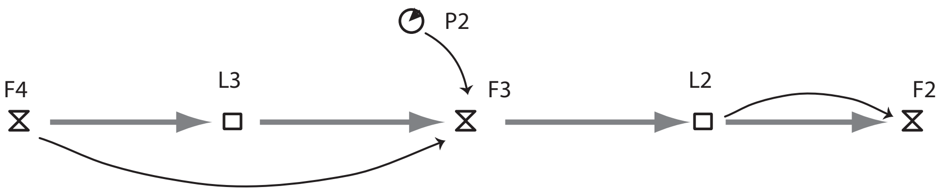
So we can adjust the expected level of new orders in the feedback system with the time of processing.

Second block (picture 2) defines the level of stock at retail stores. We take into account that the transportation of goods from the wholesale to the retail store takes some time. So, the flow of shipments from the warehouse must be restricted.

*L*2 – the level of the warehouse stock of goods;

$$dL2/dt = F3 - F2 \quad (3)$$

*F*3 – the value of the flow of goods which were received at the retail store during the period of time;



Picture 2. Simulation of inventory levels at retail stock (created by AnyLogic system)

*F*2 – the value of the goods flow which were shipped from the retail store during the period of time;

$$F2 = \min(L2, L1) \quad (4)$$

*L*3 – the level of goods that have been shipped from the warehouse, but haven't released to retail yet;

$$dL3/\mathrm{dt} = F4 - F3 \quad (5)$$

*F*4 – the flow of goods that have been delivered to the retail link (its size will be justified later);

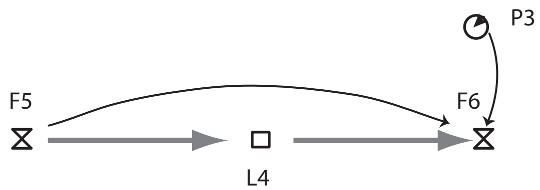
*F*3 – the flow of goods that come to retail warehouse link after transportation or after others delays en route. This stream can be defined as a flow F4 delayed for a period of necessary time for transportation.

$$F3 = \mathrm{delay}(F4, P2) \quad (6)$$

*P*2 – parameter that characterizes the average period of the transportation of goods in terms of time.

Third block describes the process of making a decision about the size of the order of goods for supply from the wholesale sector.

*L*4 – the level of orders for the wholesale sector in the process of registration;



Picture 3. Modeling the flow of orders to the wholesale warehouse (fragment model created by AnyLogic system)

$$dL4/dt = F5 - F6 \quad (7)$$

*F*5–the flow of orders that is generated to the wholesale sector per unit of time;

$$F5 = \max(L1 + V2, 0) \quad (8)$$

*V*2 – the variable that defines the rate of replenishment of the stock

$$V2 = (V3 - L2)/P4 \quad (9)$$

*V*3 – the variable that characterizes the ideal level of inventory in the warehouse.

It is determined by the level of client requests for a given period of time and some parameter of inventory control (*P*4).

$$V3 = L1*(P5 + P6) \quad (10)$$

*P*5 – the parameter that characterizes the minimum time to complete a business process of the shipment of goods from the warehouse;

*P*6 – the parameter that defines the time to ensure the safety stock of goods.

*F*6 – the flow of orders that come in the wholesale sector per unit of time. It is determined by the flow F5 with delay that is calculated with parameter P3.

$$F6 = \text{delay}\,(F5, P3) \quad (11)$$

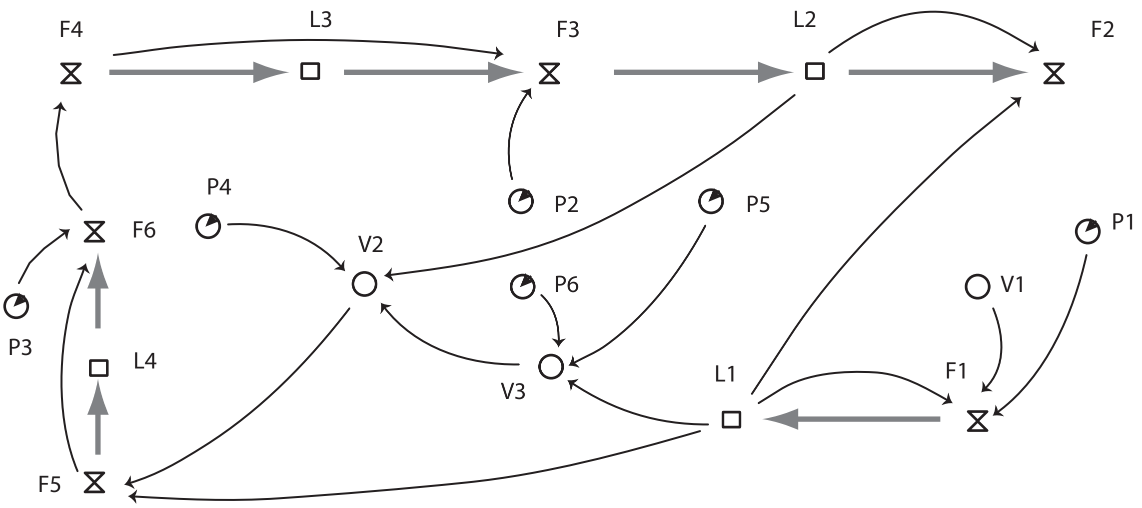
*P*3 – the time it takes to place an order in the wholesale sector.

The result is a model for the analysis of inventory levels (picture 4).

This model can be used to assess the impact of the automation of warehouse operations process.

We assume that the implementation of information systems leads to the information delays reduction in business processes. Next, we consider the delay information in this model. First of all, there are delays in customer service and the formation of the order to the next level of distribution delays. These are the parameters *P*1 and *P*3. Furthermore, it can be expected that the application of an integrated inventory management system will reduce: the time delays associated with registration of shipment from the warehouse (*P*5), time to organize the necessary safety reserve (*P*6) and the time necessary for adjustment of the inventory (*P*4)

The constructed model can be used for the analysis of stocks in the following situations:



Picture 4. The model for analysis stock level in the retail stores (created by AnyLogic system)

*S*1: Number of clients V1 is a constant 200, and all requests in the wholesale sector are performed immediately. Parameters P1-P6 set equal to 1.

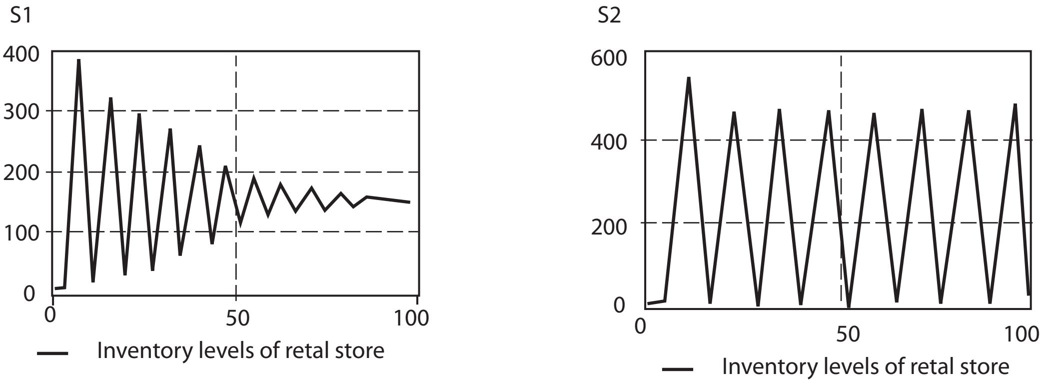
*S*2: Number of requests from customers which enters the system is a random variable that fluctuates between 150 and 250 with a mean of 200; the parameter P1, which characterizes the time of making client's request, is reduced to 0.05; the parameter P3, which displays the time of ordering in the wholesale sector, is reduced to 0.5; the

parameter P5, which takes into account the time for business process of shipment, is reduced to 0.1; the parameter P6, which characterizes the minimum time for the business process of ensuring product safety stock, is set at 0.15; wholesale segment carries the requests from retail level not immediately, but with a delay of 2 periods.

Graphical results of the simulation are shown in the picture 5. Model time (time unit is 1 week) is displayed on the X axis and goods items displayed on the Y axis in this and subsequent figures on this and next graphs.

Therefore, one can make the following intermediate conclusions.

1. The random distribution of customer number in the model does not significantly affect the inventory level. This is because the number of requests is controlled by the current state of the system.
2. Parameter P1, which displays the time of client requests formation, must influence the stock-level by reducing the delay of information. But if the level request for services is adjusted according to the requests that have not been fulfilled in prior periods, parameter that characterizes the fulfillment time of requests won't have a significant impact on the stock level.
3. Reduction of the time for the client's request formation most significantly influences the inventory levels in a single retail department.
4. The parameters that characterize the delays associated with the business processes of shipping and safety stock formation also impact the inventory levels.



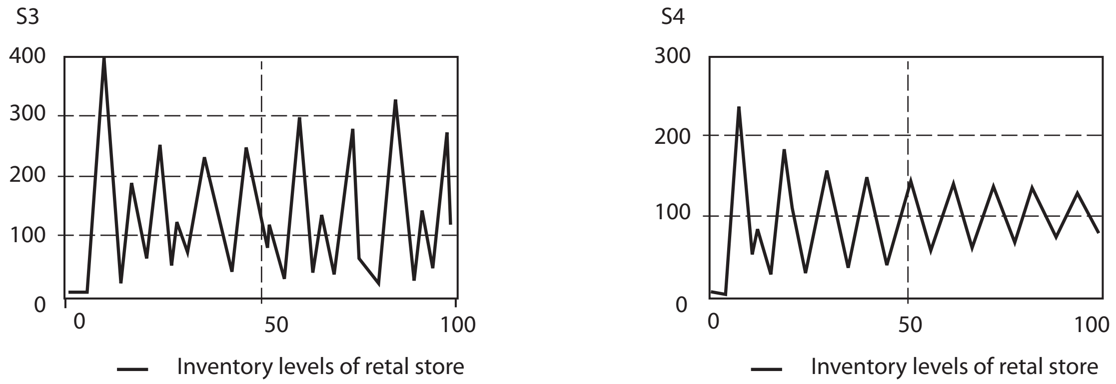
Picture 5. Results of the simulation for the retail store

5. The situation varies most strongly when the model takes into account the time delay for requests execution by the wholesale sector. In this case the fluctuations of the stock level do not decrease as in all previous cases. Therefore, we should consider this situation in more detail.

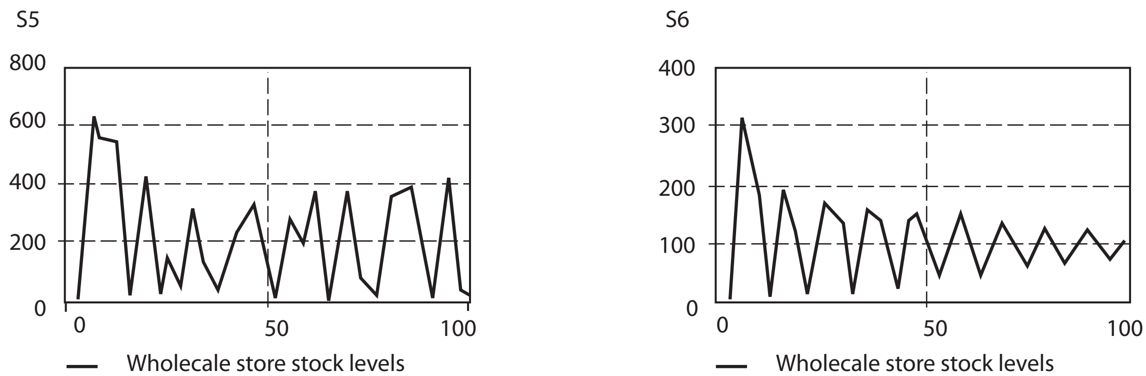
Next, we supplement the retail store model with a fragment, which will simulate the wholesale warehouse. Results are shown in pictures 6–7.

Analysis of the results leads to the following conclusions.

After adding the wholesale level fragment model mutual influence of two levels starts to bring additional disturbance to the system. As a result, the average stock level increases at all distribution levels. However, when the parameters that reflect the trends associated with the enterprise information systems implementation change, the average stock level in the retail and wholesale sector reduces.



Picture 6. The reduction of inventory levels at the retail warehouse before (S3) and after (S4) the implementation of information systems, taking into account the influence of the wholesale sector delays



Picture 7. Results of simulation of the stock level in the wholesale sector with the reduction of delays associated with some business processes automation

Next, we have to add the manufacturing level to the model. This level will be used to estimate the delays of the ordering between the wholesale sector and the manufacturing sector more precisely.

The generalized model created by AnyLogic system is shown in Picture 8. This model has been used to assess the impact of delays in the manufacturing level on the stock level.

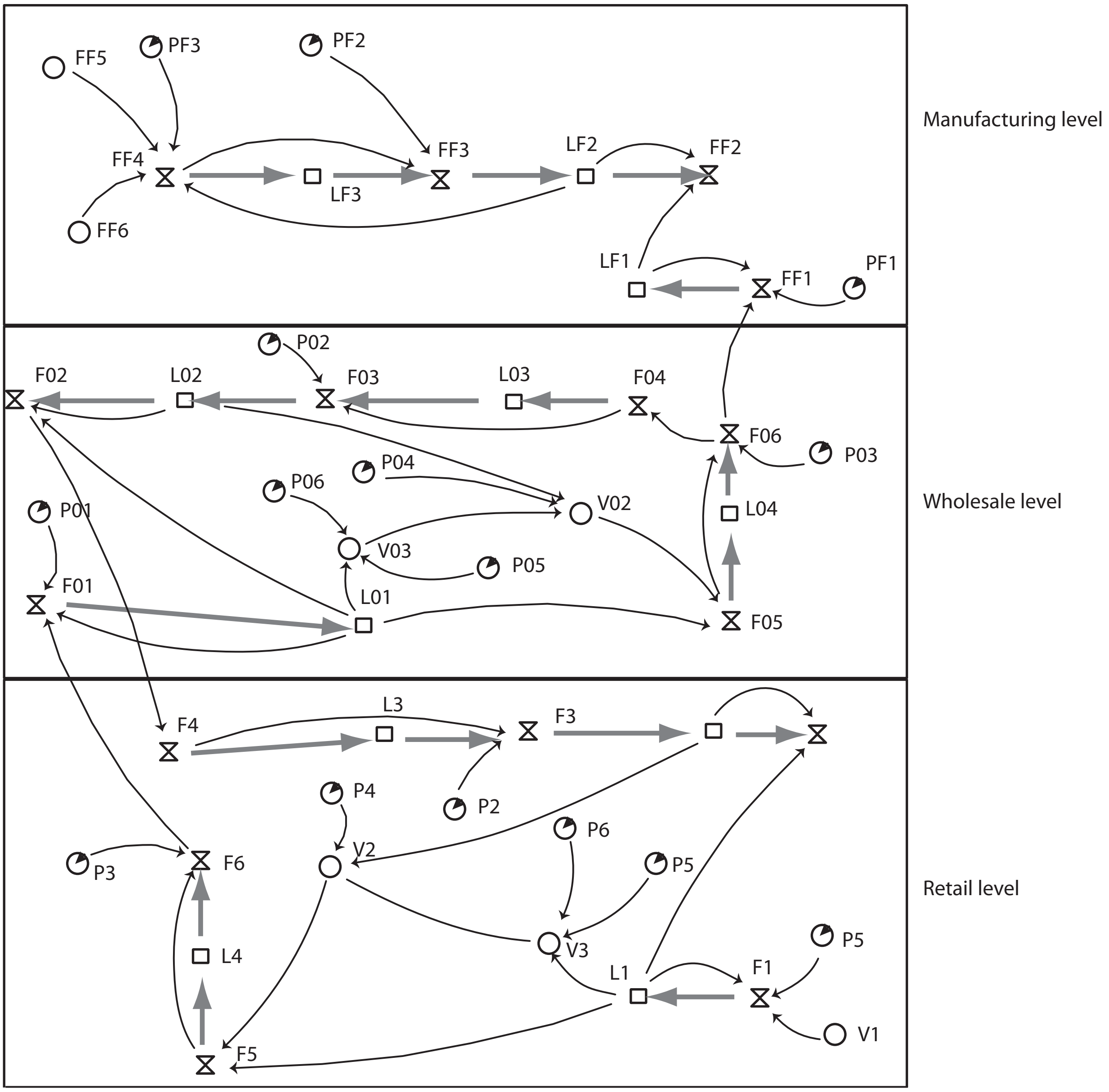
Using technologies MRP and CRP is one of the most effective techniques of the modern systems for enterprise management. In this context, their application allows to expect the reduction of PF3 – the time which is necessary to form the flow of production orders (mostly) and PF2 (the parameter that determines the duration of the production cycle).

To confirm this hypothesis, simulation of the following situations has been performed.

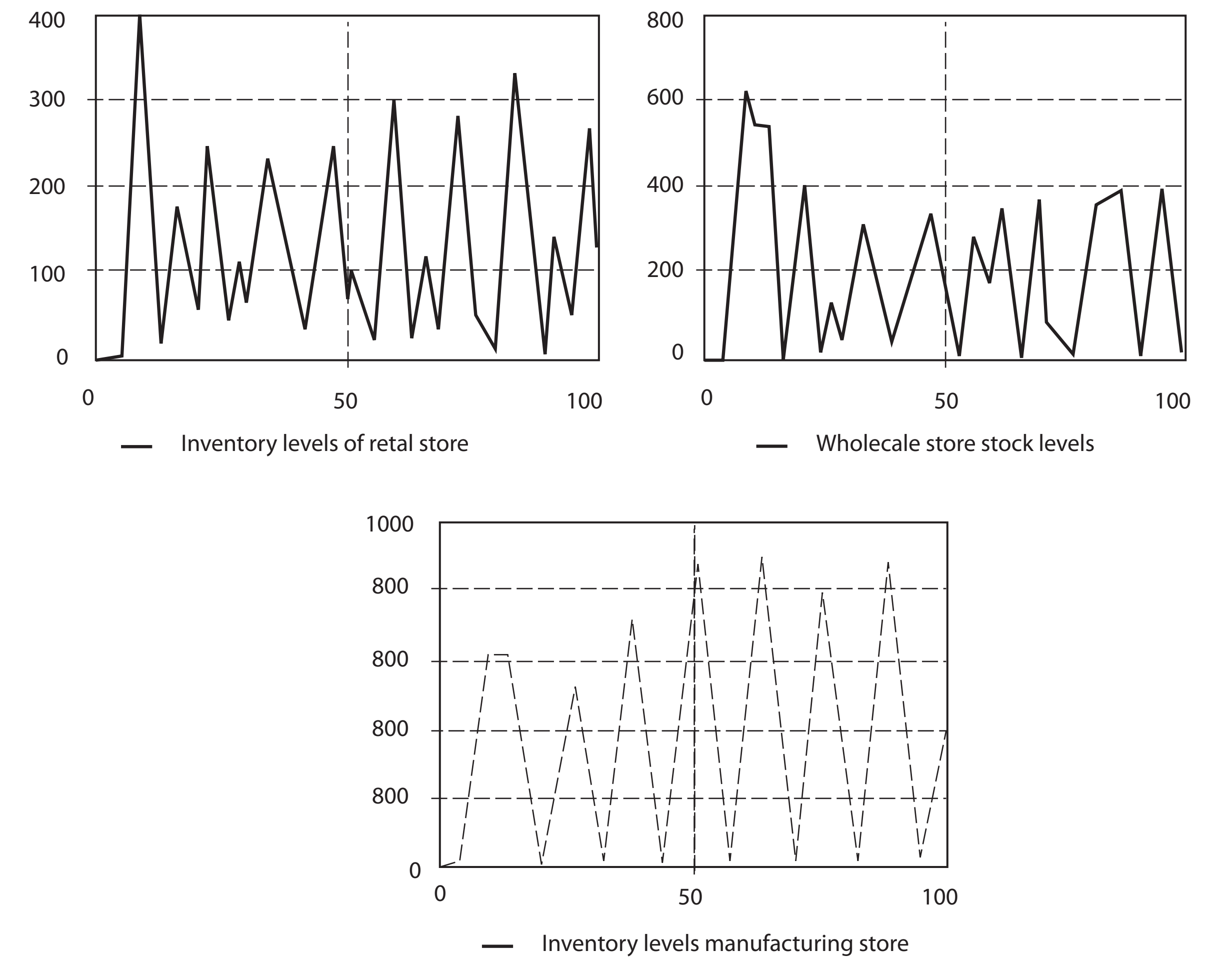
The pictures 9 and 10 show the effect of reduction parameters *P*1, *P*3, *P*5, *P*6, *PO*1, *PO*5, *PO*6, *PF*1, *PF*2, *PF*3 on inventory levels. The values of these parameters are less in Picture 10.

As can be seen from the analysis of these graphs, the reduction of inventory levels is observed in each of the warehouses. In this case, a clear tendency to the stabilization of inventories at a certain level in the wholesale and retail warehouses can be observed.

Furthermore, the change of the aggregate stock level in the system was considered in the situations S7 and S8 (picture 11).



Picture 8. Three-level model «Manufacturing-Sales» created by AnyLogic system



Picture 9. Stock level in the system

As we can see the aggregate level of inventories in the system not only reduces, but also tends to get stabilized.

Conclusions and questions for discussion

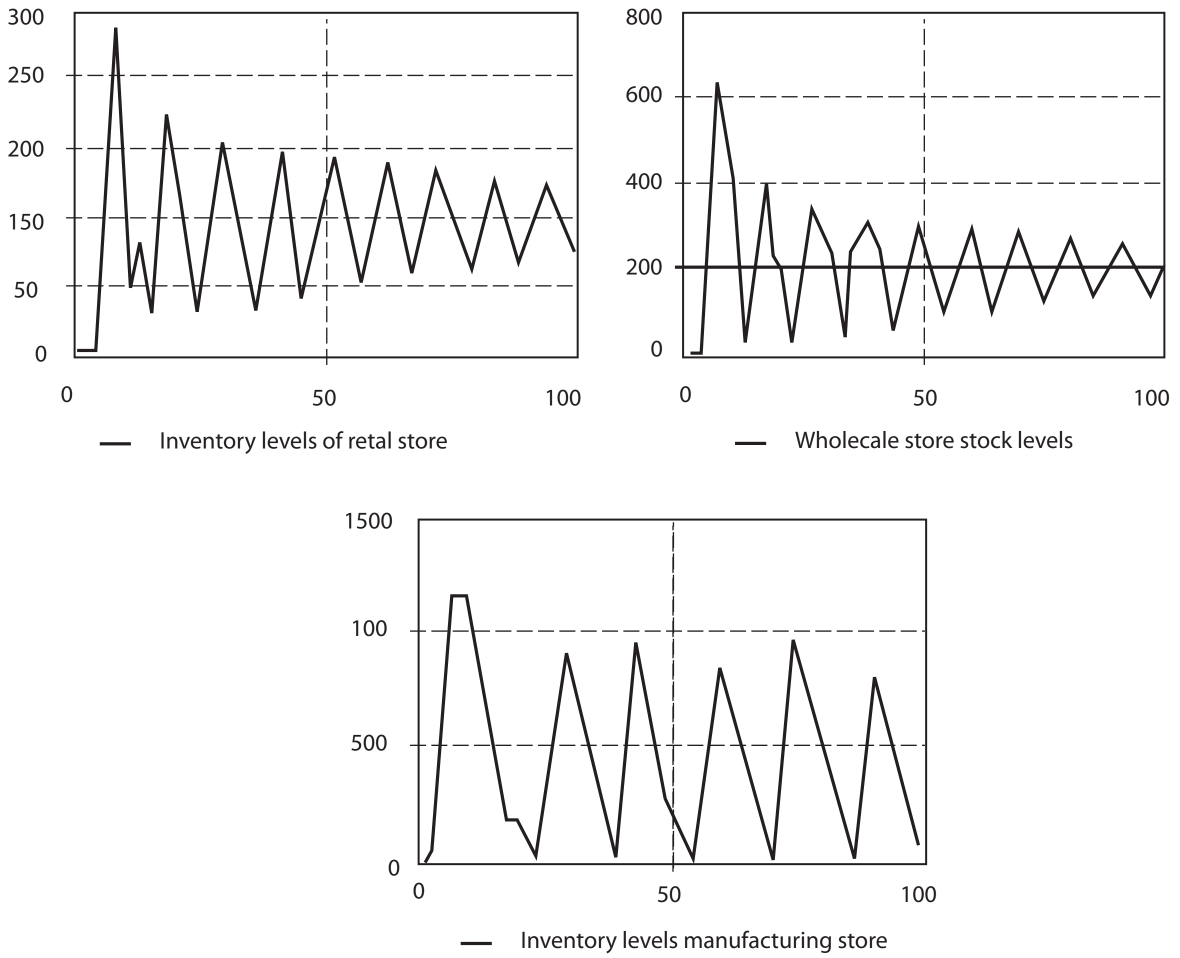
Results of the study suggest the following conclusions.

1. System dynamics approach can be used to assess the changes in the status of the system that are associated with the implementation of information systems and technology.
2. To model these changes, the parameters which can reduce delays in the system after automation of business processes should be included to the simulation model.
3. The proposed approach allows us to assess the dynamics of stocks in complex systems which consist of several interdependent levels of distribution.
4. It can be argued that the implementation of information systems and technologies reduces the inventory levels. This is due to the fact that automation can reduce the time delay in the performance of certain business processes.
5. The simulation results allow us to conclude about the most powerful influence on the reduction of the inventory levels when complex integrated information systems are implemented.

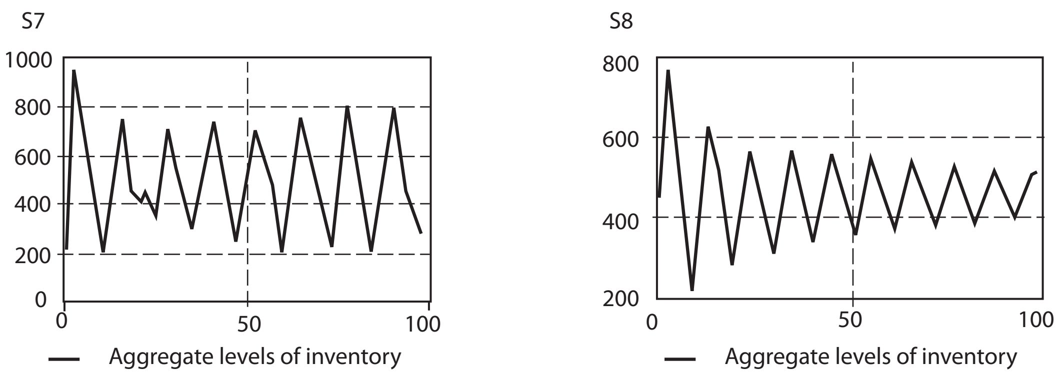
At the same time, there are several issues to be studied further.

1. Is it true that an information system implementation has the highest impact on the reduction of stocks in the lower (retail) level, and the lowest in the production? This thesis is controversial in view of the existence of effective technologies of production planning.
2. How does an information system influence the change of time delays associated with the movement of material flows?

These and other issues require further clarification of the proposed model and the use of statistical approaches to data analysis.



Picture 11. Stock level in the system after ERP implementation



Picture 12. Changes in the total level of inventories at three warehouses of the system before (S7) and after (S8) business processes automation

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