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DYNAMIC SIMULATION BASED OPTIMIZATION OF INFORMATION FLOW IN EXTENDED ENTERPRISE AND ITS IMPACT ON BUSINESS PARTNERS PRODUCTION EFFICIENCY AND STOCK REPLENISHMENT

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Summary

Contemporary firms organize their activities in the form of extended enterprises. Extended enterprise is the concept that a company does not operate in isolation because its success is dependent upon a network of partner relationships established in the whole supply chain. These relationships are used for coordination of activities done by firms, every business partner focuses on specific area it operates the best with regard to costs or efficiency and therefore extended enterprise can optimize its operations as a whole. However, the scale of activities conducted and problems with information flow organization makes the whole business structure more vulnerable to demand fluctuations, what leads to bullwhip effect problem. The paper presents dynamic simulation approach to information flow optimization and shows how it can positively impact a production efficiency and stock replenishment. Simulation experiment has been designed with two models of supply chain – standard and with improved information flow organization. Models have been developed, simulation experiment planned and conducted with the use of system dynamics approach methods and techniques.

Keywords: system dynamics method, supply chain simulation modeling, extended enterprise operations optimization

Symulacja dynamiczna w procesie optymalizacji przepływu informacji w przedsiębiorstwie rozszerzonym i jej wpływ na efektywność działań produkcyjnych i zarządzanie zapasami

Streszczenie

Współczesne firmy organizują swoją działalność w formie przedsiębiorstwa rozszerzonego (ang. Extended Enterprise). Rozszerzone przedsiębiorstwo oznacza, że utworzona organizacja funkcjonuje w określonym ekosystemie. Jej sukces w dużej mierze zależy od ustanowionych relacji z partnerami biznesowymi w ramach całego łańcucha dostaw. Relacje te stanowią sieć wzajemnych powiązań, wspieranych technologiami informacyjno-komunikacyjnymi, i są wykorzystywane przy koordynacji wspólnych działań. Każdy partner działający w ramach przedsiębiorstwa rozszerzonego skupia swoją aktywność na wybranym obszarze, w którym jest liderem (kosztowym lub efektywnościowym). Pozwala to na optymalizację funkcjonowania całej utworzonej struktury biznesowej. Często jednak zakres wykonywanych czynności oraz problemy z odpowiednią organizacją przepływu informacji powoduje, że przedsiębiorstwo rozszerzone jest wrażliwe na zmiany rynkowe (np. okresowe fluktuacje popytu). Powoduje to pojawienie się problemów związanych z efektem „byczego bicza" (ang. Bullwhip Effect). W pracy przedstawiono rozwiązanie tego problemu z wykorzystaniem symulacji dynamicznej. Celem symulacji jest optymalizacja organizacji przepływu informacji w rozszerzonym przedsiębiorstwie. To

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z kolei prowadzi do poprawy efektywności działań operacyjnych partnerów biznesowych, także w zakresie zarządzania zapasami. Opracowano dwa modele łańcucha dostaw – model standardowy oraz z ulepszoną strukturą przepływu informacji. Symulację numeryczną realizowano z zastosowaniem metod dynamiki systemowej (ang. System Dynamics).

Słowa kluczowe: metoda dynamiki systemów, modelowanie i symulacja numeryczna łańcucha dostaw, optymalizacja funkcjonowania przedsiębiorstwa rozszerzonego

1. Introduction

Nowadays firms organize their activities in the form of extended enterprises that have flexible, dynamic and more extensive boundaries than ever. Because of inherent complexity of today's business, organizations must focus on whole processes, reaching out to business partners, suppliers and customers. Modern business architectures must be agile, otherwise they will not be able to cope with constant market changes. Therefore extended enterprise is a loosely coupled, self-organizing network of firms that combine their economic output to provide product and service offerings to the market. Firms in the extended enterprise may operate independently or cooperatively [1]. Such alliance enables business partners to focus on their core competencies, act more flexible and at lower costs, while providing consumers with high quality products or services. Unfortunately the scale of operations and problems with proper information flow organization among partners, makes the whole business structure more vulnerable to demand fluctuations. When demand for merchandise or level of stock start to change randomly, the behavior of whole extended enterprise becomes very complex. One of the main problems is so called bullwhip effect. It refers to increasing swings in inventory in response to shifts in customer demand. The bullwhip effect was named for the way the amplitude of a whip increases down its length. The problem is that forecast accuracy decreases as move upstream along the supply chain. The bullwhip effect is mainly caused by three underlying problems: a lack of information or bad information flow organization, the structure of the supply chain and a lack of collaboration. According to Malonie and Carter [2] the elimination of bullwhip effect can increase profits by 10-20% and if enterprise is able to reduce this effect it could be possible to increase profits by 5-10%. These possible improvements are the main rationale for many research considerations in the area of extended enterprises management. Modeling of bullwhip effect was first made by Metters [3]. He has developed a stochastic model to discuss the fluctuations. Other stochastic modeling of the effect was done by Cachon [4], Kelle et al. [5], Chen et al. [6] and Machuca et al. [7]. Chen et al. [6] have explicitly proven that variation ratio of demand and manufacturing is strictly greater, than one, i.e. the fluctuations are increasing along the supply chains.

The main assumption that has driven work which results have been presented in this paper is that one of the ways to be prepared for such risky situations and make informed decisions is to use the simulation model, which becomes the workbench for extended enterprise. Simulation model in this approach is used in the process of analyzing the characteristics of the real system and finally provides hints on how to better organize information flow among business partners that operate in extended enterprise. As will be shown in the paper, such optimization of information flow organization can positively affect production effectiveness and set the stock at optimal levels.

2. System Dynamics Approach to Extended Enterprises Modeling

System Dynamics is a method used for analysis of weakly structured problems with many interrelationships among problem space elements. It provides comprehensive approach to business systems analysis where dynamic relationships among system's elements generate value added and it would not be well visible when system is considered as a monolithic structure. System Dynamics is a continuous simulation methodology and set of techniques developed by Jay W. Forrester from MIT Sloan School of Management in late 50' of twentieth century. The approach has carefully been described in his paper "*Industrial Dynamics – A Major Breakthrough for Decision Makers*" published in Harvard Business Review [8] as well as seminal textbook "Industrial Dynamics" [9]. System Dynamics approach enables to model complex systems with regard to their structure and behavior (internal processes). The basis of the method is the recognition that the structure of any system, the many circular, interlocking, sometimes time-delayed relationships among its components, is often just as important in determining its behavior as the individual components themselves.

According to Sterman [10] there is no modeling recipe that guarantees the development of valid model and its full usability. Modeling is a creative process in its nature and usually modelers exhibit different goals and approaches. However using system dynamics technique requires following specific process. In the first stage problem has to be formulated and modeling goals properly set. Next, key factors related to problem space, feedback and system's scope should be determined. These constitute an input to problem domain textual description and diagrams showing main relationships among modeled system's elements. After all these elements are in place, analytical model is developed which is used during simulation. Simulation results from the first replication (*base replication*) are compared with characteristics of real system what forms a basis for model verification and validation. Model is tuned up to satisfying level of accuracy. After model is verified and validated experiments may take place. Usually decision variables and model parameters are changed in order to check how it will affect the system's behavior expressed with *performance measure*. The comparison of base simulation replication results with results generated with the model after changes enables to determine how changes have affected the characteristics of the system under consideration. The essence of simulation modeling is implementation of changes in the real system based on guidelines provided by simulation experiment results analysis.

Analytical modeling in system dynamics approach uses the following building blocks:

- *stock* – temporary quantity describing the state of specific system's element,
- *flow* – stream determining a velocity of levels changes,
- *decision variables* – values responsible for regulation of flows based on temporary system's states.

All elements presented above are used for description of system's structure that enables to understand complex nonlinear interrelationships existing among the system's components. Depending on needs this structure may represent causal influences related to feedbacks (*causal loop diagrams*) or stocks and flows showing the system's state in a given moment in time (*stock and flow diagrams*). There are many software environments for system dynamics simulation available (e.g. *AnyLogic*, *Powersim*, *Vensim*, *Stella* and *IThink*). All simulation experiments presented in this paper have been developed with Vensim 6.6 D software environment, PLE version. Detailed description of the development process of casual loop and stock and flow diagrams has been published in many works [9--11]. Diagram (Fig. 1). presents production line module with one stock (*production materials*) and two flows (*supply of materials* and *production*). The *stock* may denote any store of elements that are processed and flows represent the processing of these elements that increases or decreases the stock level.

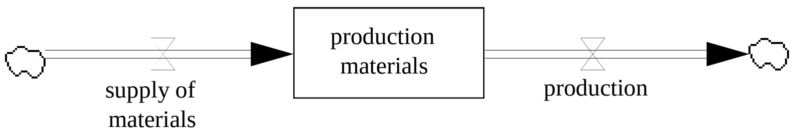


Fig. 1. Stock and flow diagram for hypothetical production process

The level of materials in a given time moment is modeled with the following equation:

$$pm_t = \int_{t-1}^{t} (sm_t - p_t)\mathrm{d}t + pm_{t-1} \tag{1}$$

where: dt – time interval between t and t–1, pm_{t-1} – production materials level at time t–1, sm_t – supply of materials in dt time interval, p_t – production in dt time interval.

System dynamics has become very popular approach to simulation modeling of complex and dynamic systems of different type. Many areas of applications may be listed such as mechanics, mechatronics, thermodynamics, energetics, logistics, biology, health care and dynamic decision making.

The application of system dynamic approach to simulation modeling of supply chains is deeply entrenched in seminal work of Forrester [8]. Forrester's model representing production and distribution system has been composed of six key flows: information, materials, orders, cash flows, manpower and capital equipment. In 1961 Forrester has developed simplified model that has been used in more detailed analyses and became usable for education purposes [9]. Model which is commonly known as Forrester Supply Chain includes such components as producer, factory store, distributor and retailer. Two main flows were incorporated – orders flow (from retailer to factory) and deliveries flow (from factory to retailer). Extensive review of system dynamics applications to supply chain management has been presented in [12], including such domains as: inventory management, demand amplification, supply chain reengineering, supply chain planning and design as well as international supply chains modeling.

3. Supply Chain Model

Simulation experiments described in this paper use modified version of Forrester's Supply Chain including such components as: supplier, producer, retailer and market (customers). The structure of modeled supply chain is presented on Fig. 2.

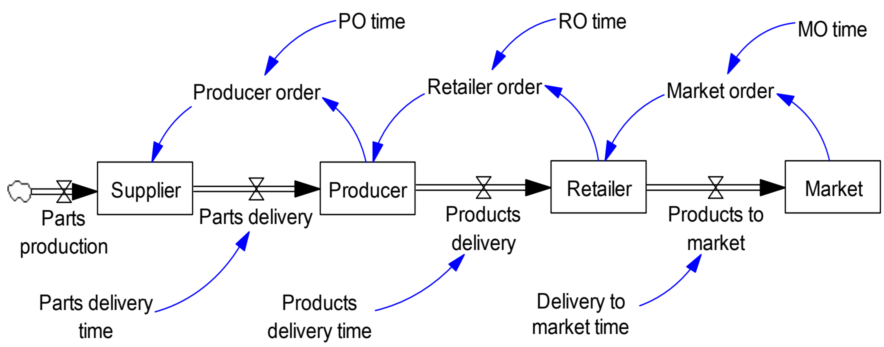


Fig. 2. The structure of supply chain used in simulation experiments

Supplier responsibility is to produce and deliver parts needed for product development. Producer uses these parts as an input to production process. Retailer acquires products from producer and markets them to customers. The main function of market is to generate demand and buy products from retailer. One of the main improvements proposed in the model is to introduce the policy of stock replenishment for all supply chain business partners. It is assumed that demand in the next period of time (day) will be the same as it is in the current period. This means that if the total demand for specific supply chain partner equals *n* and the current stock level equals *q*, then the optimal quantity for an order will be *2n-q*. Such policy ensures that after current orders are fulfilled, firm has at its disposal enough quantity of product items to satisfy the demand in the next period of time. Firm replenishes its stock only in case when the stock level falls below the threshold that has been set in advance. The advantage of such approach is without a doubt its application's simplicity (including simulation experiment) but there are also some disadvantages. This policy assumes steady demand level without any fluctuations, what is quite rare in real market environment. Therefore it could be the source of some problems when the demand in the next period will decrease, the stock levels in whole supply chain (all business partners) will increase, what may significantly affect production and warehousing costs. There could also be the situation where the demand level in the next period is higher than at the current one and stock levels have to be higher in order to keep up with such demand. These problems will appear more often in the cases of high demand fluctuations. This fact justifies the usage of replenishment policy presented above in the simulation experiments and the bullwhip effect analysis in the context of high demand fluctuations.

4. Simulation experiment

Simulation experiments have been based on two supply chain models with components presented on Fig. 2. The former describes the flows of materials, products and orders. Materials and products flows from supplier to market are related to such stocks as suppliers components, producer components, producer products, retailer products and products on the market. In the flow of orders from market to supplier the following stocks have been defined: market's orders for products, retailer's orders for products, producer's orders related to operations, producer's orders for components, supplier's orders for components required by producer. The retailer replenishment business logic has been modeled with the following formula:

```
IF THEN ELSE(2*market orders-retailer prod level>0,
2*market orders-retailer prod level , 0 )/(rord in time)
```
(2)

where: *market orders* – market's order quantity, *retailer prod level* – current retailer's products stock level, *rord in time* – time needed for completing the order by retailer.

Important characteristic of this model is that orders are collected by every business partner in supply chain. The number of orders in every time period is determined with the replenishment formula presented above and information about number of fulfilled orders (products and components). The structure of supply chain is presented on Fig. 3.

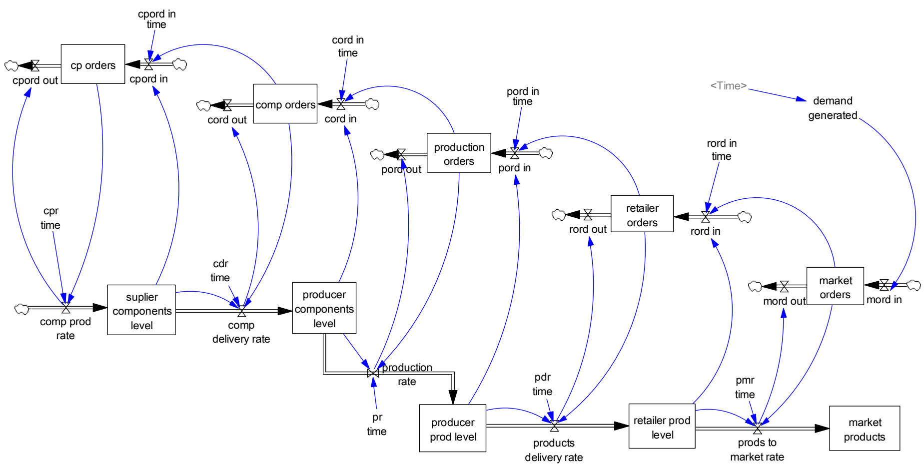


Fig. 3. Stock and flow diagram describing supply chain

The second supply chain model developed for simulation experiments includes the same flows as the first one but differs from the former in the way orders are processed. There is only one stock that stores market's orders and its main responsibility is to ensure that market demand will be met, in case where there is lack of products in retailer store, part of an order that has not been fulfilled is moved to next period when replenishment is done. The number of items in orders generated by other supply chain business partners are determined according to presented replenishment policy based on current number of market's orders. The formula used for calculation of retailer's orders level is presented below.

```
IF THEN ELSE(2*market orders-retailer prod level>0,
     2*market orders-retailer prod level, 0 );
```
(3)

where: *market orders* – orders generated by market, *retailer prod level* – retailer's products' stock level

Figure 4 presents stock and flow diagram for modified supply chain model.

All calculations have been made with the use of Euler's method. As a base unit of time 1 hour was adopted. An integration step was set to 1/8 of an hour (according to Forrester's model settings). Simulation experiment incorporated 300 replications, where each replication had a 10 hours timespan. During first hour of every simulated workday market demand was generated according to normal distribution with the following parameters: max = 1.25, min = 0, mean = 0.625, stdev = 0.25. In case of bullwhip effect simulation the demand (in 30 days cycle) was set to constant value increased by 5 units.

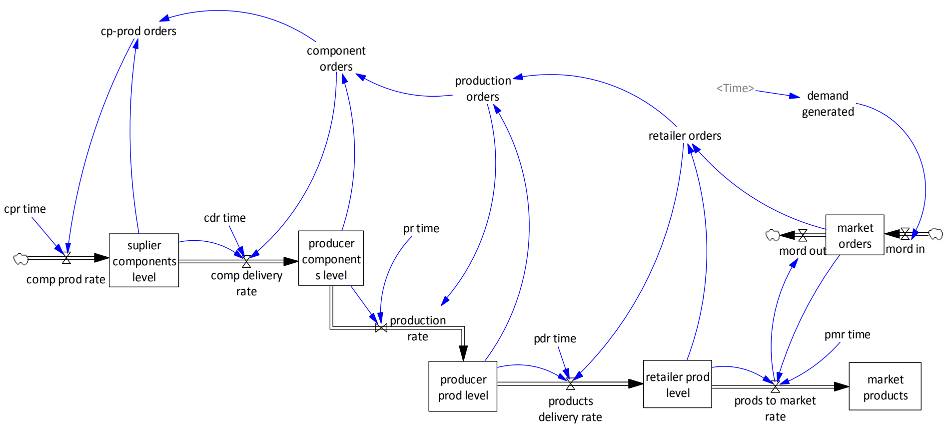


Fig. 4. Stock and flow diagram for modified supply chain model

5. Simulation Results Analysis

5.1. Simulation Results for Standard Supply Chain Model

In order to determine the influence of bullwhip effect on supply chain effectiveness simulation experiments have been run with normally distributed demand and its periodic fluctuations characterized by higher than normal demand level. Experiments were conducted for standard supply chain model as well as supply chain model with modified information flow. Both models had the same demand levels set to 3259 units in simulation experiment without bullwhip effect and to 3364 units in simulation experiment with bullwhip effect.

During every simulation replication stock levels, revenues and orders fulfillment times have been recorded. Results are presented in Tables 1-4.

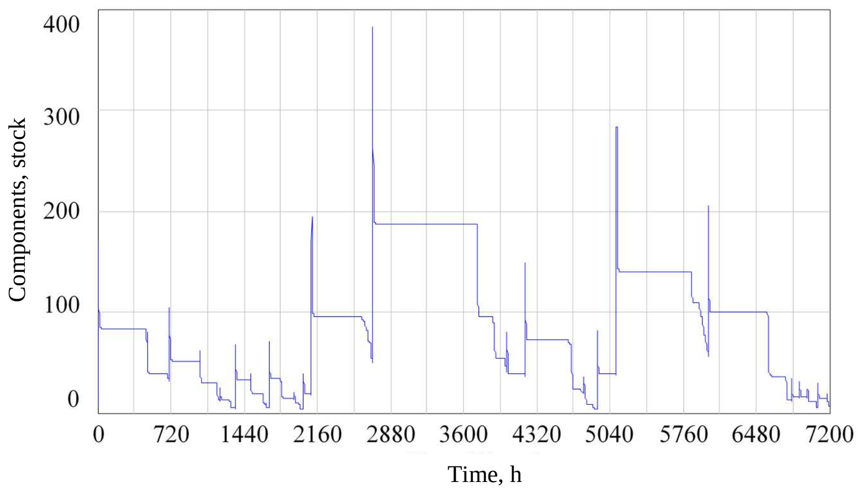
Table 1. Average and maximum stock levels – without bullwhip effect

Stock levels	Parts at supplier	Parts at producer	Products at producer	Products at retailer
Average	42,2024	40,11966	13,30338	3,055301
Maximum	212,6794	167,3231	82,97198	11,81023

Table 2. Average and maximum stock levels – with bullwhip effect

Stock levels	Parts at supplier	Parts at producer	Products at producer	Products at retailer
Average	84,22624	83,1953	22,7385	3,825223
Maximum	382,6921	304,3068	157,0445	28,65905

a)



b)

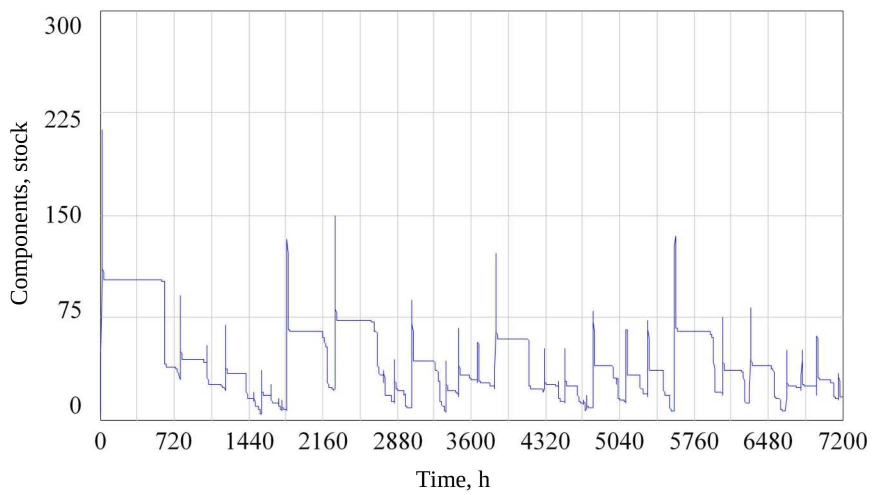


Fig. 5. Supplier's components stock level with bullwhip effect (a) and without bullwhip effect (b)

Results in Tables 1 and 2 show evidently higher stock levels for experiment with bullwhip effect. Average and maximum levels figures for bullwhip effect simulation are almost twice as big as figures for simulation without bullwhip effect. Results' visualizations are presented on Fig. 5. Components stock at supplier is the most distant from demand source and therefore is characterized by biggest fluctuations of stock levels. It is best visible for simulation results with bullwhip effect (Fig. 5a.).

The model of supply chain includes two production systems: supplier of components and producer of products. The production levels for both systems are determined by number of orders placed. Table 3 presents average and maximum efficiency and working times for production systems measured during simulation experiment.

Table 3. Efficiency and working times for production systems

Key indicators	**Production of components**		**Production of products**	
	Without bullwhip effect	With bullwhip effect	Without bullwhip effect	With bullwhip effect
Maximum efficiency, items/h	90,99913	160,0793	28,01105	55,25058
Working time, h	246	181	1754	1517

Figures presented in Table 3. show that in case of bullwhip effect efficiency had almost twofold increase. It means that in situations with demand fluctuations production systems should be significantly extended in order to fulfill increased number of orders.

The results of simulation experiment have also shown negative impact of bullwhip effect on stock levels (*overstock*) in the whole supply chain. It has also been proven that demand fluctuations are the source of problems in supply chain operations organization and coordination.

5.2. Simulation Results for Modified Supply Chain Model

In order to reduce negative impact of bullwhip effect the information flow in modeled supply chain has been modified. In improved model all business partners forming supply chain have an access to up-to-date information about retailer's orders level (Fig. 4.). Data on orders that have not been completed is stored only by retailer and used to determine orders levels for all business partners in supply chain. During simulation experiment all stock levels have been recorded and selected final results presented in Table 4 and Table 5.

The results presented in Table 4 and Table 5 show the increase of stock levels for all business partners in supply chain, but what is important, the levels are three times lower than in case of standard model (see Fig. 6 for visualization). Fig. 6 b shows that stock level in simulation without bullwhip effect fits in the range of 25-45 items. In simulation experiment with bullwhip effect, the fluctuation range is comparable to the former one, with higher stock levels in cycles with increased demand levels.

Table 4. Average and maximum stock levels – without bullwhip effect

Stock levels	Components at supplier	Components at producer	Products at producer	Products at retailer
Maximum	51,12726	5,20832	9,93876	5
Average	32,54725	2,377413	6,18859	0,462647

Table 5. Average and maximum stock levels – with bullwhip effect

Stock levels	Components at supplier	Components at producer	Products at producer	Products at retailer
Maximum	89,74049	9,10039	17,14337	5
Average	41,85203	2,515671	6,626543	0,479895

Figures summarized in Table 6. imply that maximum efficiency has increased only in the case of final products production process. However, what is important to note, the values are many times lower than in information flow existing in not modified model.

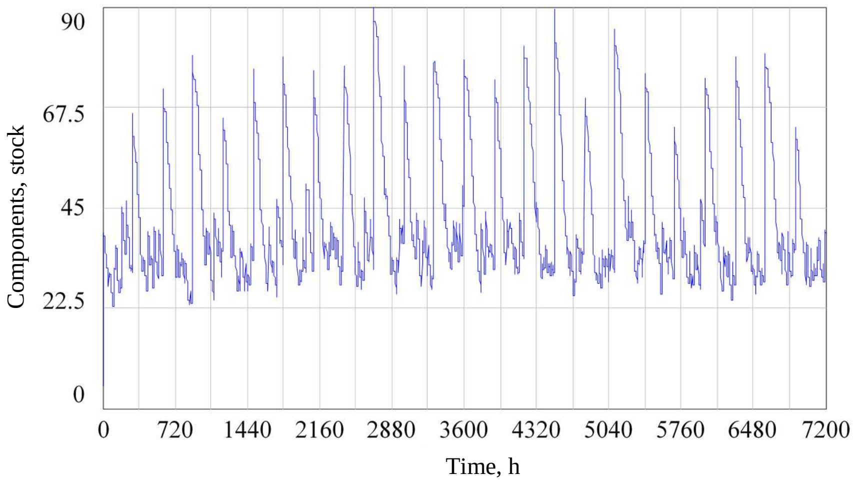
Table 6. Efficiency and working times of production processes

	Components production process		**Products production process**	
	Without bullwhip effect	With bullwhip effect	Without bullwhip effect	With bullwhip effect
Maximum efficiency, items/h	88,8866	88,88658	4,64948	8,54794
Working time, h	417	303	1468	1441

6. Conclusions

The simulation experiments results have confirmed the importance and validity of supply chain information flow organization modification. Centralization of information about orders in one data store available to all business partners forming supply chain has reduced bullwhip effect and its influence on stock levels as well as production processes efficiency. The next stage of the research that has been planned concerns the simulation modeling of economic viability of extended enterprise with regard to costs of stock management as well as economics of replenishment policy.

a)



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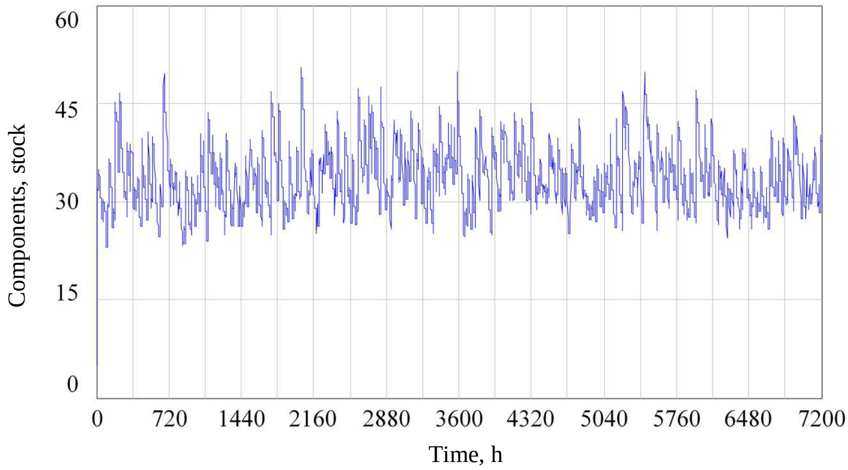

Fig. 6b. Supplier's components stock level: a) with bullwhip effect,
b) without bullwhip effect

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