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A Dynamic System of Material Flows in Wood Industry Companies

Dinamički sustav tijekova materijala u drvnoindustrijskim tvrtkama

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SUMMARY • *The plan is the strategy for action. Planning involves choosing a plan by considering alternative plans and reasoning about their consequences. The correct planning will result in a higher system of efficiency. To enable the planning the following resources have to be available: material, staff, money, facilities, information and time. Unreliable suppliers force manufacturers to buy and to store materials to ensure the appropriate stocks. The consequence of such a policy results in increased expenses and a big turnover of the investment capital. The purpose of an inventory is security. Therefore, the managing with the material flows must establish the product quantities when other sources are not sufficient. The paper presents the modelling-learning simulation that can help a decision maker to optimize the inventories in a small wood industry company. The research resulted in a model that simulates material flows in a way of intelligent decision support. The model includes a manufacturer, suppliers and mathematical methods that provide inventory simulation. The simulation has been based on data collected from a wood industry company. The simulation results have been compared with the data from a real system. The comparison shows that the modelling-learning approach in combination with system dynamics could yield better results than the other methods do. When the stocks are lower the invested turnover capital is lower too. The model that has been developed could be successfully applied in wood industry companies. This enables intelligent decision support that will result in profitable business.*

Key words: *wood industry, business management, manufacturing management, inventories, intelligent decision support, modelling, simulation, dynamic programming*

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SAŽETAK • *U radu je prikazan sustav dinamičke kontinuirane simulacije količina zaliha materijala s ciljem optimiranja ukupnog poslovnog procesa drvnoindustrijske tvrtke. Izvršeno je projektiranje i simuliranje ponašanja dinamičkog simulacijskog modela tijekova materijala u drvnoindustrijskoj tvrtki. Izvršena je simulacija s realnim podacima elemenata zaliha materijala i dobavljača. Uspoređena su stanja realnog sustava i rezultata dinamičke simulacije. Dobiveni rezultati ukazuju da je sustav dinamičke simulacije za taj promatrani slučaj dao bolje rezultate; niže količine zaliha i niži uloženi obrtni kapital na njih za to razdoblje. Dinamička simulacija modela upravljanja količinama zaliha materijala s uspjehom se može primijenjivati u drvnoindustrijskim tvrtkama. Ti modeli čine inteligentnu sustavnu podršku u procesu odlučivanja uz kompjutersku podršku.*

Ključne riječi: *drvna industrija, upravljanje poslovanjem, upravljanje proizvodnjom, upravljanje zalihama, inteligentna podrška odlučivanju, modeliranje, simulacija, dinamičko programiranje*

1. INTRODUCTION
1. Uvod

Many models and methods to manage inventories have been developed. Most of them use different techniques that optimize material flows. However, there are no general solutions. Each task requires a specific technique to determine material quantity. In the research we used the continuous system dynamic simulation method. We believe it is a suitable answer for solving the inventory problem. Moreover, we are convinced that the method is more than appropriate to forecast the future material requirements, too.

Jay Forrester (1961) created the enviroment at M.I.T. that allowed others to discover and share his insights about feedback systems, modelling and simulation. It is amazing that many ideas are now generating excitement in modelling and computer-based learning.

System dynamics is a framework for thinking about how the operating policies of a company and its customers and suppliers interact to shape the company's performance over a period of time. System dynamics builds up on information feedback theory which provides symbols for mapping business systems in terms of diagrams and equations, and a programming language for making computer simulations. System dynamics is a scientific discipline with its own scientific methodology of investigating the behaviour dynamics, modelling, simulation and optimization of primarily the most complex dynamic systems that have been scientifically studied and determined by real continued models, i.e. by a group of linear and/or nonlinear differential equations. It is also an actual application of the "System Thinking" to the processes of management of complex, dynamic, natural, tehnical and organization systems. This paper demonstrates the philosophy of the system dynamics continuous computer simulation of the behaviour dynamics in the production and business managemet of the wood industry company. The system dynamic models are not based on any mass data processing but on the smallest quantity of data that yield most information on the studied laws of behaviour dynamics in the organizational business systems.

Learning from modelling and simulation, illustrates developments in the model--supported case studies and workshops. It also describes the efforts now being made to understand the obstacles to group learning and to measure (objectively) the improvements in learning that derive from the use of models and gaming simulators. These methods are intelligent system support.

It is important to collect data from history. In such a way the company will be prepared for the future. Traditional methods for solving the inventory problem have no forecasting abilities. To enable forecasting different methods could be used: time series, ARMA, ARIMA, etc. The problem is how to incorporate them in a simple and exact model of a real system. It is because simulation uses traditional techniques. Furthermore, the model has to be suitable, neither too simple and nor too complex. It is the modelling theory, practice and way to use the obtained results in the future. The future is always uncertain-only the disturbances are certain. That is why we are convinced that the new intelligent modelling-learning approach could be the right way to solve the inventory problem. Moreover, the experimental results that will be given in the paper support the reason why we should use system dynamics. Simple but adaptable models have to be made to enable the qualified models that could help the decision makers.

The data we have used in the experimentation have been collected from a real system. Such approach enables the comparison of forecasting given by the model with the results obtained in the real system. The aims in the research were:

- to analyze the current state of inventories in the real wood industry company,
- to establish the influence factors in material flows,
- to define the optimization criterion,
- to develop the models capable of simulating the material flows in a real wood industry company,
- to select the most appropriate simulation model, and
- to show that by minimizing the inventory stocks and the invested turnover capital it is possible to improve the business- and manufacturing management processes in wood industry.

The decision is impossible without alternatives. To analyze the alternatives ensures a good decision. Traditional methods are suitable to determine the outputs in inventory management. In contrast to the forecasting methods, the modelling-learning offers a great advantage-it could join different methods and combine them in a powerful decision support. No other method is capable of doing it in such an amazing way. Therefore, the system dynamics provide a frame of how to solve a problem intelligently, it is an intelligent tool that enables modelling and learning games. Another advantage is that it enables parallell simulation of both business and manufacturing processes. By building such a complex model, the decision maker can validate the inventory model in the context of business and manufacturing system and the related environment. Experimenting with different scripts that could simulate the future enables the future to be more predictable. To summarize, whatever simulates the future, the management will know the best solution. It is because they know the short and middle-term consequences of their decisions. Therefore, they will be able to make good decisions and to keep the company in a near-optimal condition according to the material resource plan to maximize the invested turnover capital. It would, thus, be convenient to for the whole business in a company.

The paper is organized as follovs. Section 2 describes a model that has been developed to simulate inventories. The model is organized in such a way to be an intelligent agent adaptable in a very complex human-computer decision support. Section 4 summarizes the research and gives the perspective of the further research.

2. THE MODEL
2. Model

The research promotes a modelling-learning simulation model that optimizes inventories in the wood industry company. Therefore, it is a novelty in solving the inventory problem-we did not find any research that uses such an approach in solving the inventory problem.

The model we developed uses data that have been calculated by a deterministic mathematical model. To get a sufficient amount of data to study the material-flow principle, the minimal amount of data processing has been used. In many cases the mass data processing could be approximate. It is because the improved behavior in a wood industry company depends on its structure, business policy, vitality and economic conditions in behavior. The structure of a manufacturing system is complex whether the company is 'small' or 'big'. Therefore, it is reasonable to look at the system through different, small but self-sufficient, sub-systems. It is close to the tendency of using artificial intelligence (AI) in principle and practice of building computer-based models. The essence in such an approach is to build a model of the system that consists of intelligent agents. The agent is the unit that solves a specific task or group of tasks during the process of decision making according to the goal of a system. It has a limited amount of memory and a knowledge of environment, a limited knowledge of constraints and intentions of other agents and a limited amount of resources. The agent produces a solution.

The material supply system is important for each wood industry company. The aim of the system is to estimate the accumulations in the physical values of the goods. The material-flows connect the facilities that build a manufacturing process. The management policy applies material and information flows to determine the business policy and to keep the company in a good condition. The state of the materials used the manufacturing process implies the supply periods that require a material and production cycle such as rate of materials used to accomplish the manufacturing process. When the model of material supply system is an instance in some more complex human-computer decision making system, the model in Figure 1 could be an example of an intelligent agent. Figure 1 describes the system that delivers material in short terms using the positive (+) cause-and-consequence link. The shorter the production cycle is, the smaller the material stock is. Therefore, the negative (-) cause-and-consequence link must be established, too. The model that simulates a management policy uses different values of delivery time between a manufacturer and suppliers. The different scripts are of essence when simulating an acceptable management policy to design an inventory behavior and to study its influence on the business and manufacturing processes. To calculate the variable of level the following expression has been used:

$$L \quad L.K = L.J + DT \times (RA.JK - RS.JK) \quad (1)$$

where L.K is a new system-level at K-th moment, L.J is an old system-level at J-th moment, DT is an interval between two consecutive calculations (J-th, K-th and time-axe t), RA.JK is a change in material flows through JK-th period and RS.JK is a change in material flow level at JK-th period.

The expression (1) presents the main interaction. It is the only instance in the computer-based support system that has to be adopted depending on the specific case. Other instances are common for all cases.

Figure 1. *Causal loop diagram (26) • Uzročno posljedični dijagram (26)*

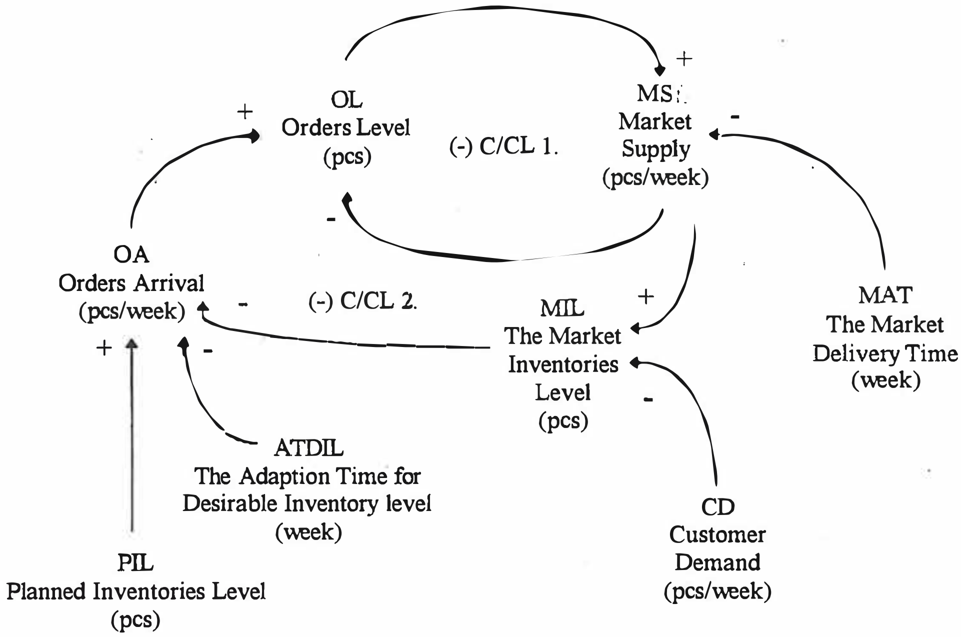
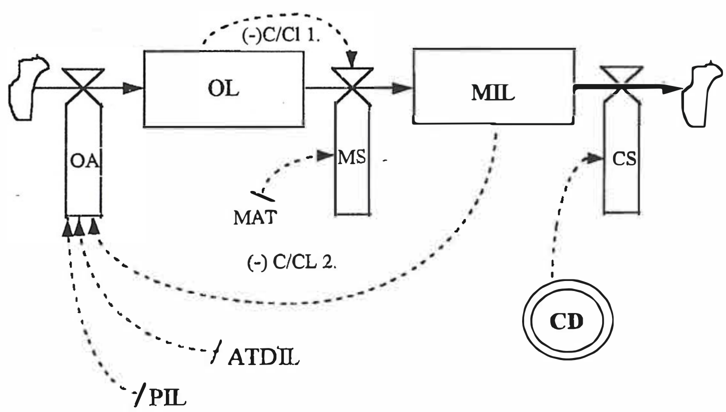


Figure 2. *Flow diagram (26) • Dijagram tijekova (26)*



Legend: OA-Orders Arrival (pcs/week), ATDIL-The Adaption Time for Desirable Inventory Level (week), MIL-The Market Inventories Level (pcs), PIL-Planned Invetories Level (pcs), OL-Orders Level (pcs), MS-Market Supply (pcs/week), MAT-The Market Delivery Time (week), CS-Customer Supply (pcs/week), CD-Customer Demand (pcs/week), C/CL-Cause/Consequence link

Legenda: OA-brzina pristizanja narudžbi (komada/tjedno), ATDIL-vrijeme prilagodbe željenoj razini zaliha (tjedan), MIL-stanje zaliha proizvoda u prodavonicama (komada), PIL-planska razina zaliha (komada), OL-stanje narudžbi (komada), MS-brzina isporuke proizvoda prodavaonicama (komada/tjedno), MAT-rok isporuke gotovih proizvoda prodavaonicama (tjedan), CS-brzina prodaje proizvoda kupcima (komada/tjedno), CD-prodaja proizvoda kupcima (komada/tjedno), C/CL-uzročno posljedična veza

The model given in the Figure 2 is capable of adopting input and output material flows using non-linear interdependence. The simulation with the modelling-learning approach is interactive and takes care of all the relations between the model and the system, their resources and the environment. The simulation follows part time period and DT element sum changes in the individual material-flows. Therefore, the properties of the entire, interactive and self-repeating process, are obtained and suitable business results could be established.

In the research DYNAMO simulation language has been used. The computer-based simulation model was made in BASIC programming language and SYSDYNS system dynamic SW package. The HW equipment was an IBM PC compatible computer. The reason for using DYNAMO is its high symbolic value suitable for building models of continuous complex dynamic systems. The basic elements in DYNAMO respect system dynamics and enable efficient computer simulation.

Mathematical model in DYNAMO compiler:

```
1,R     OA.KL=(1/ATDIL) x
        (PIL-MIL.K)              (2)
1.1,C   ATDIL=5                  (3)
1.2,C   PIL=1000                 (4)
```

OA-Orders Arrival (pcs/week)
ATDIL-The Adaption Time for Desirable Inventory Level (week)
PIL-Planned Inventories Level (pcs)
MIL-The Market Inventories Level (pcs)

```
PIL-MIL=DISCREPANCY              (5)
2,L     OL.K=OL.J+(DT) x
        (OA.JK-MS.JK)            (6)
2.1,N   OL=100                   (7)
```

OA-Order Arrivals (pcs/week)
OL-Order Level (pcs)

```
3,R     MS.KL=OL/MAT             (8)
3.1,C   MAT=1                    (9)
```

MS-Market Supply (pcs/week)
OL-Order Level (pcs)
MAT-The Market Delivery Time (week)

```
4,L     MIL.K=MIL.J+(DT) x
        (MS.JK-CS.JK)            (10)
4.1,N   MIL=100                  (11)
```

MIL-The Market Inventories Level (pcs)
MS-Market Supply (pcs/week)
CS-Customer Supply (pcs/week)

```
5,R     CS.KL=CD.K               (12)
```

CS-Customer Supply (pcs/week)
CD-Customer Demand (pcs/week)

```
6,A     CD.K=1000                (13)
```

CD-Customer Demand (pcs/week)

3. THE SIMULATION
3. Oponašanje

Following section reports on simulation results. The model that has been build for the simulation experiments uses data collected from a real system such as:

- the material delivery time,
- the inventory level,
- weekly demands, and
- market demands.

The management policies were selected accoring to material resource plan. It is because the primary goal in the research was to study product inventories and market demands.

Let us now give some general observations. They have been establised through simulation experiments.

1. The inventory level depends on demands, material delivery-time and the manufacturing cycle in which final products has to be delivered. If the material delivery time is shorter, the stocks will increase up faster. If the manufacturing lead time decreases, the stocks will decrease faster and the product demands will be met in a shorter time. In this case the supply time is of significant influence.

2. If delays in supply are build in to the simulation model considerable disturbances will be met. Stocks accumulate at slower rates, production cycles are longer and the final product inventories are lower. The entire production cycle is longer.

There are two typical cases that deserve more careful explanation. The first one relates regular product demands and the second one has been obtained when the product demands are impulsive.

3.1. Regular demands and delivery time
3.1. Scenario konstantnih zahtjeva za isporukom

Furthermore, the details of case with regular product demands will be discused. The information/material flow and delivery time are balanced within a very short response time.

The model includes the factor of reinforced material with the purpose to increasing orders if the inventories are lower than desirable. The following inventory principle has been identified:

If the inventories recch a desirable level, the reinforcement factor of the orders is smaller than - 1 and vice-versa. This factor has been identified as an improvement in the product inventory management.

The desired inventory level is sufficient to regulate the duration of the invenories. Therefore, the manufacturing cycle is shorter. The desired stock level reduces faster. The longer duration of material stocks maintains the desired inventory level. This obviously enables continual manufacturing to meet the demands. It means that the product demand and supply in a real system are known.

3.2. Impulsive disturbances and delivery time
3.2. Scenario neočekivanih zahtjeva za isporukom

The general conclusion for the case where changes in product demands are impulsive is that the system states adapt slowly due to a delay in information and material flows. The simulation experiments were accomplished to analyze the delivery time under two circumstances.

The first circumstance was high inventory levels. The delivery time oscillates and meets the demands within significant delays. The sudden changes stabilize the inventories and bigger orders in the periods when demands are higher. That indicates that product demands forecasting is important for a company.

Table 1.
Results of the model with regular product demands (1,000 pcs/week) • Rezultati modela sa kontinuiranom potražnjom proizvoda (1000 komada/tjedno)

Week Tjedan	Orders Level Stanje narudžbi pieces/ week komada/tjedno	Market Invetories Level Stanje zaliha proizvoda pieces komada	Customer Demand Prodaja proizvoda pieces/ week komada/tjedno
1	-100	-800	1000
2	800	-1900	1000
3	1900	-2100	1000
4	2100	-1200	1000
5	1200	-100	1000
6	100	100	1000
7	-100	-800	1000
8	800	-1900	1000
9	1900	-2100	1000
10	2100	-1200	1000
11	1200	-100	1000
12	100	100	1000,
13	-100	-800	1000
14	800	-1900	1000
15	1900	-2100	1000
16	2100	-1200	1000
17	1200	-100	1000
18	100	100	1000
19	-100	-800	1000
20	800	-1900	1000
21	1900	-2100	1000
22	2100	-1200	1000
23	1200	-100	1000
24	100	100	1000
25	-100	-800	1000
26	800	-1900	1000
27	1900	-2100	1000
28	2100	-1200	1000
29	1200	-100	1000
30	100	100	1000
31	-100	-800	1000
32	800	-1900	1000
33	1900	-2100	1000
34	2100	-1200	1000
35	1200	-100	1000
36	100	100	1000
37	-100	-800	1000
38	800	-1900	1000
39	1900	-2100	1000
40	2100	-1200	1000
41	1200	-100	1000
42	100	100	1000
43	-100	-800	1000
44	800	-1900	1000
45	1900	-2100	1000
46	2100	-1200	1000
47	1200	-100	1000
48	100	100	1000
49	-100	-800	1000
50	800	-1900	1000
51	1900	-2100	1000
52	2100	-1200	1000

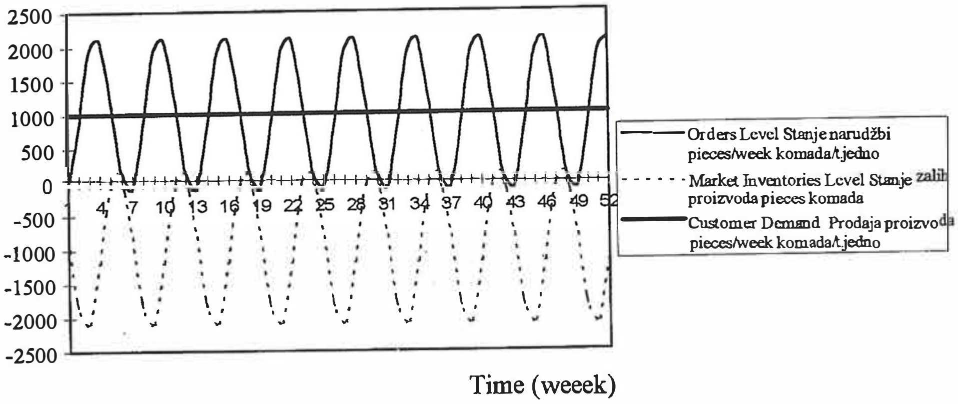


Figure 3. *The model with regular product demands (1,000 pcs/week) • Model sa kontinuiranom potražnjom proizvoda (1000 kom./tjedno)*

The second circumstance was low inventory levels. The simulation results are the same as in case of high inventory.

3.3. The influence of management policies
3.3. Utjecaj poslovodne politike

The business policy is the key to success. The simulation has formed some interesting conclusions valuable for the business policy, too.

The necessity to coordinate the inventory management and the purchasing has been identified due to simulation results in different management policies. The time-delays in the information/material flows have to be eliminated, too. Furthemore, it is good to reduce the delivery time and to forecast the future demands.

The improvement in the information/material flows between a supplier, a manufacturer and a customer favorably meets requirements.

Table 2. *Results of the model with impulsive changes in product demands throught ten weeks • Rezultati modela sa odskočnom promjenom potražnje proizvoda u tijeku deset tjedana*

Week Tjedan	Orders Level Stanje narudžbi pieces/ week komada/tjedno	Market Invetories Level Stanje zaliha proizvoda pieces komada	Customer Demand Prodaja proizvoda pieces /week komada/tjedno
1	-100	200	0
2	-200	100	0
3	-100	-100	0
4	100	-200	0
5	200	-100	0
6	100	100	0
7	-100	200	0
8	-200	100	0
9	-100	-100	0
10	100	-200	0
11	200	-100	0
12	100	100	0
13	-100	200	0
14	-200	100	0
15	-100	-100	0
16	100	-200	0
17	200	-100	0
18	100	100	0
19	-100	200	0
20	-200	100	1000
21	-100	-100	1000
22	100	-1200	1000
23	1200	-2100	1000
24	2100	-1900	1000
25	1900	-800	1000
26	800	100	1000
27	-100	-100	1000
28	100	-1200	1000
29	1200	-2100	1000
30	2100	-1900	0
31	1900	-800	0
32	800	1100	0
33	-1100	1900	0
34	-1900	800	0
35	-800	-1100	0
36	1100	-1900	0
37	1900	-800	0
38	800	1100	0
39	-110	1900	0
40	-1900	800	0
41	-800	-110	0
42	1100	-1900	0
43	1900	-800	0
44	800	1100	0
45	-1100	1900	0
46	-1900	800	0
47	-800	-1100	0
48	1100	-1900	0
49	1900	-800	0
50	800	1100	0
51	-110	1900	0
52	-1900	800	0

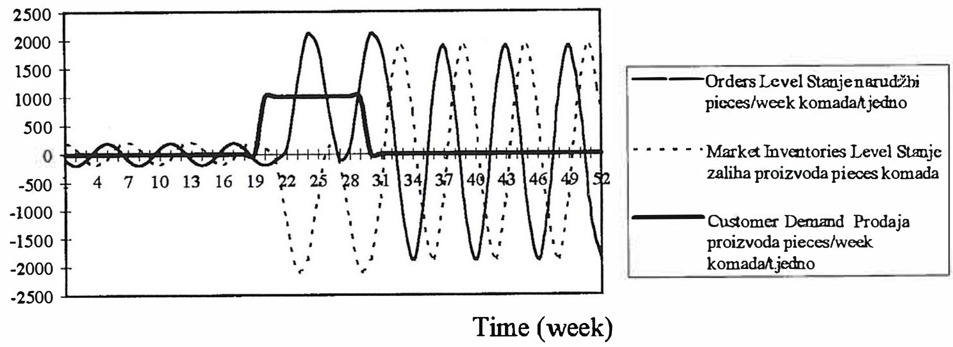


Figure 4. *The model with impulsive changes in product during ten weeks • Model sa odskočnom potražnjom proizvoda u tijeku deset tjedana*

4. THE CONCLUSION
4. Zaključak

The inventory problem is significant in wood industry companies. Inventories have effect on the manufacturing and business resuts. Therefore, an improvement in the material flows managements is a way to extent business results. The research presented in the paper promotes intelligent modelling-learning approach. The approach uses the continous system dynamics method. The use of the system dynamics simulation approach has indicated that an improvement in the material flow management is possible and profitable. The conclusions are:

1. the product demand is the most significant factor in the inventory management

Table 3. *Results of the model with periodical changes in product demands • Rezultati modela sa periodičkom promjenom potražnje proizvoda*

Week Tjedan	Orders Level Stanje narudžbi pieces/ week komada/tjedno	Market Invetories Level Stanje zaliha proizvoda pieces komada	Customer Demand Prodaja proizvoda pieces/ week komada/tjedno
1	-100	-800	1060
2	800	-1960	1119
3	1960	-2279	1177
4	2279	-496	1232
5	1496	-449	1283
6	449	-236	1331
7	236	-1118	1374
8	1118	-2256	1411
9	2256	-2549	1442
10	2549	- 1735	1467
11	1735	-653	1496
12	653	-403	1496
13	1246	-246	1500
14	1246	-2342	1496
15	2342	-2592	1485
16	2592	-735	1467
17	1735	-610	1442
18	610	-317	1411
19	317	-1119	1374
20	1119	-2175	1332
21	2175	-2388	1284
22	2388	-497	1232
23	1497	-341	1177
24	341	-22	1120
25	22	-800	1061
26	800	-1839	1000
27	1839	-2039	940
28	2039	-1140	881
29	1140	17	823
30	-17	334	768
31	-334	-453	716
32	451	-503	669
33	1503	-1720	626
34	1720	-844	589
35	844	287	557
36	-287	574	532
37	-574	-246	514
38	246	-1335	503
39	1335	-592	500
40	1592	-757	503
41	757	331	514
42	-331	574	532
43	-574	-288	556
44	288	-1420	587
45	1420	-1719	624
46	1719	-923	667
47	923	128	714
48	-128	337	666
49	-137	-557	821
50	557	-1715	878
51	1715	-2037	938
52	2037	-1259	998

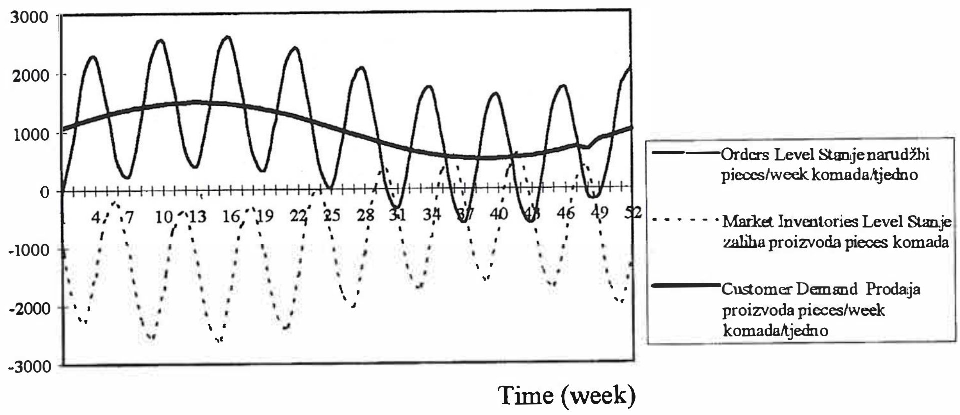


Figure 5. *The model with periodical changes in product demands • Model sa periodičkom potražnjom proizvoda*

system model.

2. if the changes in demands are unexpected, the fluctuation in material flow reduces high inventoris.

3. the factor of enhanced material orders was integrated in the model. The simulation has shown that it is a good rule for material flow management in cases where product demands are unexpected.

4. if the demand is continuous the material flow meets product demands in a very short time.

5. the research has promoted intelligent techniques in demands monitoring, material management and supplier control in the material flow management. Those techniques are an improvement on exisitng ones. They could bring benefits not only in the inventory management but also in invested turnover capital. In such a way the entire business of wood-processing company could be more valuable.

6. the selection of the supplier must be carefuly. The supplier has to be reliable regard, to quantity, quality and terms (just-in-time manufacturing philosophy). This is the way, to cut down the inventories and to reduce turnover capital.

To be intelligent in business and management means reasoning to ponde on about management in business and manufacturing. The tasks, such as the inventory problem, have to be solved intelligent. The way to do it is to use the principles of intelligence and appripriate intelligent techniques. The modelling-learning combined with the system dynamics and simulation is the intelligent way to do it. The tool to realize it is to develope an intelligent agent. The agent has task to enable 'what if' analyses and simulation to help a decision maker to improve on the business results. The research developed the intelligent agent that enables suppliers and material orders to be monitor. The goal of the intelligent computer-based program, that has been developed, is to find a strategy to minimize stocks and maximize the turnover capital that has been invested in the inventories. The intelligence is in primary the property of humans. The computer system that pretends to be an intelligent one has to support and to improve human capabilities. It would improve the entire business significantly in wood industry company.

The perspective of the further research is to develope simillar intelligent solutions for other business and manufacturing mamagement problems and tasks. In such a way it will be possible, step by step, to improve the business and manufacturing processes to make them more rational than before. The intelligent way to do it is to coordinate the use of human and computer resources and to improve the efficiency of both. It requires so little and offers so much.

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