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SIMULATION OF PRODUCTION-SALE DECISION-MAKING WITH MULTIOBJECTIVE OPTIMIZATION BY VENSIM LANGUAGE

Summary. The aim of our paper is to present some of the latest results of authors' investigations in the area of sensitivity analysis and optimization on a model of the System Dynamics type. The elementary feedbacks in Production-Sale Decision-Making are presented, and results of simulation experiments (both type: maximization of profit from sale and minimization of cost of production) are illustrated in the form of so called confidence bounds. The visual possibilities provided by the simulation language Vensim were used. Conclusions are formulated at the end of this paper.

Keywords: Production-Sale model, simulation, optimization, System Dynamics

SYMULACJA DECYZJI W MODELU PRODUKCJA – SPRZEDAŻ Z WYKORZYSTANIEM WIELOKRYTERIALNEJ OPTYMALIZACJI W JĘZYKU VENSIM

Streszczenie. Celem pracy jest prezentacja pewnych nowych wyników badań przeprowadzonych przez autorów w obszarze analizy wrażliwości i optymalizacji na modelach typu Dynamiki Systemowej. Podstawowe sprzężenia zwrotne w Modelu Produkcja – Sprzedaż zostały przedstawione wraz z wynikami eksperymentów symulacyjnych (obu typów: maksymalizacji zysków ze sprzedaży i minimalizacji kosztów produkcji). Zilustrowano je tak zwanymi zakresami ufności (confidence bounds), używając możliwości wizualizacyjne języka Vensim. Na końcu sformułowano wnioski z pracy.

Słowa kluczowe: Model Produkcja-Sprzedaż, symulacja, optymalizacja, Dynamika Systemowa

1. Introduction

System Dynamics[1] was developed in the late 1950's and early 1960's at the Massachusetts Institute of Technology's Sloan School of Management by Jay W. Forrester. This approach can be applied to dynamics problems arising in complex social, managerial, economic or ecological systems. The main purpose of System Dynamics is to try to discover the "structure" that conditions the observed behavior of the system over time. System Dynamics try to pose "dynamic" hypotheses that endogenously describe the observed behavior of system.

In the area of the System Dynamics method, both in theory and in practice, there have not been much research done with respect to linking simulation and optimization. Although the first trials were sufficiently long ago[2] the fact is that incorporation or embedding simulation to optimization (and vice versa) were not as popular as we believe they should have been. Probably one of main reason for this was the lack of effective tools. Popular software packages, originally used in SD modelling and simulation, didn't have the possibilities of

[1] Bendor T.K., Kaza N.: A theory of spatial system archetypes. „System Dynamics Review", No. 28(2), 2012; Coyle R.G.: Management System Dynamics. John Wiley & Sons, London 1977; Coyle R.G.: Cosmic and Cosmos. User manuals. The Cosmic Holding Co, London 1994; Coyle R.G.: System Dynamics Modelling. A Practical Approach. Chapman & Hall, London 1996; Coyle R.G.: The practice System Dynamics: milestones, lessons and ideas from 30 years' experience. „System Dynamics Review", No. 14, 1998; Coyle R.G.: Simulation by repeated optimization. „Journal of the Operational Research Society", No. 50, 1999; Forrester J.W.: Industrial Dynamics. MIT Press, Massachusetts 1961; Forrester J.W.: Urban dynamics. MIT Press, Massachusetts 1969; Forrester J.W.: World Dynamics. Wright-Allen Press, Massachusetts 1971; Forrester J.W.: Principles of Systems. Cambridge Press, Massachusetts 1972; Goncalves G.: World behaviour modes, pathways and overall trajectories. Eigenvector and eigenvalue analysis of dynamic systems. „System Dynamics Review", No. 25(1), 2009; Hazhir R., Sterman J.D.: Reporting guidelines for simulation – based research in social sciences. „System Dynamics Review", No. 28(4), 2012; Kasperska E.: Symulacja komputerowa dla wspomagania podejmowanych decyzji gospodarczych w przedsiębiorstwie przemysłowym o produkcji ciągłej. Nowe kierunki badań. „Organizacja i Kierowanie", nr 2, 1995; Kasperska E.: Badania symulacyjne na modelu SYMODREAL (model zakłóceń dostaw i produkcji zakładu przemysłowego). Zarządzanie przedsiębiorstwem przemysłowym. Problemy, metody, techniki. Bendkowski J. (eds.). Politechnika Śląska, Gliwice 1995; Kasperska E.: Cybernetic formulation of some functions of management – types of simulation and optimization approaches within the System Dynamics method. Davidsen P.I., Mollona E., Diker V.G., Langer R.S., Rowe J.I. (eds.). Proc. 20th International Conference of the System Dynamics Society, 2002; Kasperska E., Słota D.: Parallel dual problem of optimization embedded in some model type system dynamics. Proceedings of the 24th International Conference of the System Dynamics Society. Nijmegen, Netherlands. Grossler A. (eds.) et al. The System Dynamics Society, New York 2006; Plate R.: Assessing individuals' understanding of nonlinear causal structures in complex systems. „System Dynamics Review", No. 26(1), 2010; Radosiński E.: Systemy informatyczne w dynamicznej analizie decyzji. PWN, Warszawa 2001; Sroka H.: Systemy wspomagania decyzji kierowniczych. Prace Naukowe. Akademia Ekonomiczna, Katowice 1986.

[2] Keloharju R.: System Dynamics or Super Dynamics. „Dynamica", No. 4, 1977; Keloharju R.: General frame of resources structure and trade off. „Dynamica", No. 6, 1980; Keloharju R.: Archiving structural sensitivity by automatic simplication. „Dynamica", No. 9, 1983; Winch G.W.: Optimization experiments with forecast bias. „Dynamica", No. 2, 1976.

automotive optimization (for example: languages DYNAMO, DYSMAP[3]). Only such packages like COSMIC and COSMOS and Vensim[4] make possible connecting simulation and optimization. Although some papers have appeared in the area of SD[5], there still are not so many works dealing with this problem. The authors of this paper have some experience with the so called embedding simulation in optimisation and vice versa, doing many experiments on models of the family DYNBALANCE[6]. Recently, the main point of our

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[3] Kasperska E., Mateja-Losa E. Słota D.: Comparison of simulation and optimization possibilities for languages: Dynamo and Cosmic and Cosmos – on a base of the chosen model. Computational Science ICCS 2006 part I. Aleksandrov V.N., van Albada G.D., Sloat P.M.A., Dongarra J. (eds.). LNCS. 3991. Springer, Berlin 2006.

[4] Ventana S.E.: Vensim user's Guide version 5. Ventana Simulation Environment, 2012.

[5] Coyle R.G.: System Dynamics Modelling. A Practical Approach. Chapman & Hall, London 1996; Coyle R.G.: Simulation by repeated optimization. „Journal of The Operational Research Society", No. 50, 1999.

[6] Kasperska E.: Modelling embedded in learning the acceleration of learning by the use of the hybrid models on the base of System Dynamics paradigm. Systemy Wspomagania Organizacji, SWO, 2005; Porębska-Miąc T., Sroka H. (eds.). University of Economics. Katowice 2005; Kasperska E.: Metodologia budowy i wykorzystania modeli ewolucyjnych w aspekcie uczenia się (w) organizacji społeczno-gospodarczego. Politechnika Śląska, Gliwice 2009; Kasperska E., Kasperski A., Mateja-Losa E.: Sensitivity analysis and optimization on some models of archetypes using Vensim – theoretical issue. Studia Ekonomiczne, Zeszyty Naukowe, No. 153. Uniwersytet Ekonomiczny, Katowice 2013; Kasperska E., Kasperski A., Mateja-Losa E.: Sensitivity analysis and optimization on some models of archetypes using Vensim – experimental issue. Studia Ekonomiczne, Zeszyty Naukowe, No. 153. Uniwersytet Ekonomiczny, Katowice 2013; Kasperska E., Mateja-Losa E.: Simulation embedded in optimization – a key for the effective learning process in (about) complex, dynamical systems. ICCS 2005. LNCS 3516, Springer Verlag, Heidelberg, Berlin 2005; Kasperska E., Mateja-Losa E.: Extended sensitivity analysis of parameters and structure in system dynamics models – some case study. Proceedings of the 24th International Conference of the System Dynamics Society. Nijmegen, Netherlands. Grossler A. (eds.) et al. The System Dynamics Society, New York 2006; Kasperska E., Mateja-Losa E., Marjasz R.: Sensitivity analysis and optimization for some Supply Chain Management problems in the firm – using System Dynamics and Vensim. „Journal of Entrepreneurship, Management and Innovation. A Quarterly Journal of Nowy Sacz School of Business", Vol. 9(2), National-Louis University 2013; Kasperska E., Mateja-Losa E. Słota D.: Some extension of System Dynamics method – theoretical aspects. Deville M., Owens R. (eds.). Proc. 16th IMACS World Congress. IMACS, 2000; Kasperska E., Mateja-Losa E. Słota D.: Some dynamics balance of production via optimization and simulation within system dynamics method. Hines J.H., Diker V.G., Langer R.S., Rowe J.I., (eds.). Proc. 19th International Conference of the System Dynamics Society. SDS, 2001; Kasperska E., Mateja-Losa E. Słota D.: Optimal dynamical balance of raw materials – some concept of embedding optimization in simulation on system dynamics models and vice versa. Davidsen P.I., Mollona E.., Diker V.G., Langer R.S., Rowe J.I. (eds.), Proc. 20th International Conference of the System Dynamics Society. SDS, 2003; Kasperska E., Mateja-Losa E., Słota D.: Comparison of simulation and optimization possibilities for languages: Dynamo and Cosmic and Cosmos – on a base of the chosen model. Computational Science ICCS 2006 part I. Aleksandrov V.N., van Albada G.D., Sloat P.M.A., Dongarra J. (eds.). LNCS.3991. Springer, Berlin 2006; Kasperska E., Mateja-Losa E., Słota D.: Modelling and simulation of the organizational changes using system dynamics method – some case study. Cybernetics and systems 2006, Proceedings of the Eighteenth European Meeting on Cybernetics and Systems Research, Vienna, Austria, 18-21 April 2006. Vol. 2. Trappl R. (ed.). Austrian Society for Cybernetics Studies, Vienna 2006; Kasperska E., Słota D.: Two different methods of embedding the optimization in simulation on model dyncalance (2-2). Davidsen P.I., Mollona E., Diker V.G., Langer R.S., Rowe J.I. (eds.). Proc. 21st International Conference of the System Dynamics Society. SDS, 2003; Kasperska E., Słota D.: Modelling of the evolution in the structures, by the use of hybrid models on the base of system dynamics. Proceedings of the 2005 Conference of System Dynamics and Management Science. Sustainable development of Asia Pacific, Shanghai, China, November 4 to 6. Wang Q. (eds.) et al. School of Economics and Management. Tongji University, Development Institute, Tongji University, Shanghai 2005; Kasperska E., Słota D.: Optimization embedded in simulation on models type system dynamics – some case study. ICCS 2005. LNCS 3514, Springer Verlag, Berlin, Heidelberg 2005; Kasperska E., Słota D.: Parallel dual problem of optimization embedded in some model type system dynamics. Proceedings of the 24th International Conference of the System Dynamics Society. Nijmegen, Netherlands. Grossler A. (eds.) et al. The System Dynamics Society, New York 2006.

interest is in stability and sensitivity analysis searching, using the language Vensim. The results are quite new and can have methodological consequences for studying evolution in structures (for example structures of production-sale systems with multiobjective decision-making).

2. Production – Sale Decision Making with multiobjective criteria

The elementary feedbacks in the Production – Sale model are presented on figure 1 and figure 2. How to interpret these figures? Causal-loop diagram symbols have specific meaning. For example, an arrow is used to show causation. The item at the tail of the arrow cause a change in the item at the head of the arrow. The "+" sign near the arrowhead indicate that the item at the tail of the arrow and the item at the head of the arrow change in the same direction. If the tail increases, the head increase. If the tail decreases, the head decrease. The "-" sign near the arrowhead indicate that the item at the tail of the arrow and the item at the head of the arrow change in the opposite direction. If the tail increases, the head decrease. If the tail decreases, the head increase. The plus symbol, found in the middle of a closed loop (an arrow looping around the plus sign), indicates that the loop continues going in the same direction, causing either systematic growth or decline, behaviour that is unstable and moving away from an equilibrium point. This is called a positive feedback loop. The minus symbol, found in the middle of a closed loop (an arrow looping around the minus sign), indicates that the loop changes direction, causing the system to fluctuate or to move toward equilibrium. This is called a negative feedback loop.

Both causation, on figures 1 and 2, consider the main relations in system, important in the processes:

- Maximization of profit from sale,
- Minimization of cost of production.

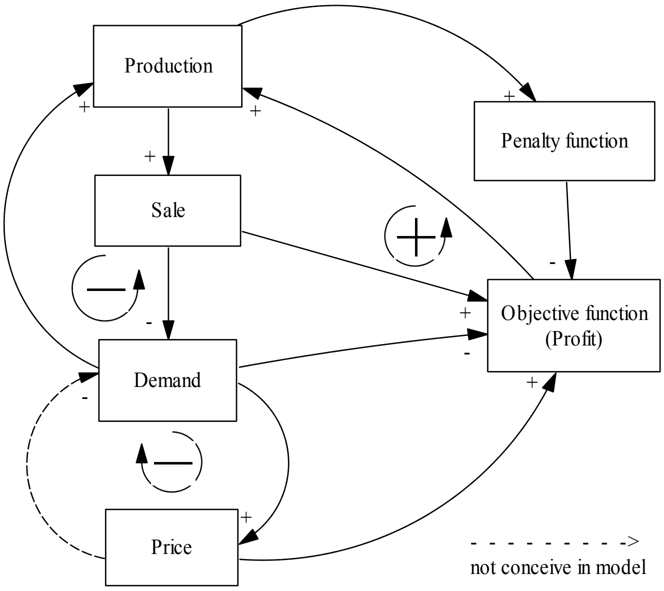

Fig. 1. Elementary feedbacks in Production – Sale model (maximization of profit)
Rys. 1. Elementarne sprzężenia zwrotne w modelu Produkcja-Sprzedaż (maksymalizacja zysku)
Source: Own idea.

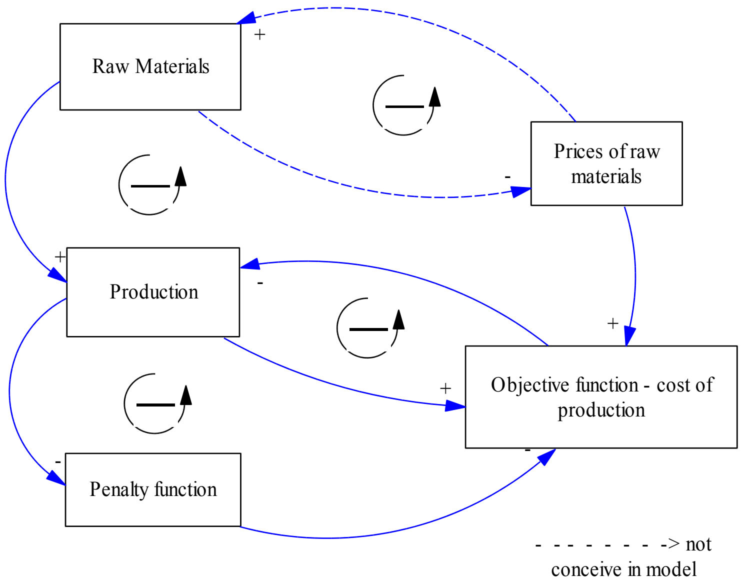

Fig. 2. Elementary feedbacks in Production – Sale model (minimization of cost of production)
Rys. 2. Elementarne sprzężenia zwrotne w modelu Produkcja-Sprzedaż (minimalizacja kosztów produkcji)
Source: Own idea.

Maximization of profit requires modelling an objective function, like the inner element of the structure, connected with such elements like:

- Price of product (modelled as the mixture of functions (two options):
  - Random sample function,
  - Combination of 3 elements: the first depending on state of inventory of a product, the second depending on demand for the product, and the third is the minimum of the first and second.
- Rate of sale, depending on the state of inventory and rate of demand (the demand for a product has a sinusoidal form with a two-year faze and a given amplitude),
- Penalty function, which takes into consideration such element like: cost of inventorying.

So the equation of the objective function is:

[illegible]

where:
PROFSL – sum profit from sale
COFPR – sum cost of production
LINCOS – sum cost of inventorying
w – weight factor for penalty

Similarly, for minimization of the cost of production, we have an equation for the objective function:

[illegible]

where:
SCRM – sum cost of raw materials
SCPR – sum cost of production (technology and people)
LINCOS – sum cost of inventorying
LOPR – sum loss of profit from sale
w1 – weight factor for cost of inventorying
w2 – weight factor for loss of profit from sale

The full structure of Production-Sale model is rather complicated[7]. Let's summarise the main assumptions of the structure:

- The production is from three raw materials (*source1, source2, source3*),
- The transformation of raw materials into product is modeled by a delay of order 3,

[7] See: Kasperska E.: Metodologia budowy i wykorzystania modeli ewolucyjnych w aspekcie uczenia się (w) organizacji społeczno-gospodarczego. Politechnika Śląska, Gliwice 2009.

- The demand for the product has a sinusoidal form with a two-year faze and a given amplitude,
- Price of the product is the mixture of functions (2 options):
  - Random sample function,
  - Combination of three alternative elements: the first depending on the state of inventory of the product, the second depending on demand for product, and the third is the minimum value of the first and the second.
- Cost of production is presented by an fob function: measuring the cost of raw materials, technology, people, a penalty factor. The cost of inventorying and cost of lost profit is modelled when the state of inventory is too small to satisfy demand,
- The profit from sale is summarizing, based on the actual price of the product.

The mathematical model in Vensim convention is presented in the Appendix. Now our point of interest is analysis of the "sensitivity" type, and taking into consideration the choice of elements of the objective functions (both described above), especially the weight factors. The sensitivity analysis can be the starting point to the optimization.

Moreover, in the context of multicriterial objective functions (or functions with penalty factors), sensitivity analysis allows to search for solutions which take into consideration different priorities of the decision makers, in an effective way, using Vensim[8] possibilities. Such experiments will be presented in the next section of the paper.

3. Results of Simulation-Optimization type experiements on the Production-Sale Decision-Making model

The SD models usually contains many parameters. It is interesting to examine the effect on their variation on simulation output. We select some parameters and assign maximum and minimum values along with a random distribution over which to vary them to see their impact on model behaviour.

Vensim has a method of setting up such sensitivity simulation. Monte Carlo multivariate sensitivity works by sampling a set of numbers from within bounded domains. To perform one multivariate test, the distribution for each parameter specified is sampled, and the resulting values used in a simulation. When the number of simulation is set, for example, at 200, this process will be repeated 200 times.

[8] Ventana S.E.: Vensim user's Guide version 5. Ventana Simulation Environment, 2012.

In order to do sensitivity simulation you need to define what kind of probability distribution values for each parameter will be drawn from. The simplest distribution is the Random Uniform Distribution, in which any number between the minimum and maximum values is equally likely to occur. The Random Uniform Distribution is suitable for most sensitivity testing and is selected by default. Another commonly-used distribution is the Normal Distribution (or Bell Curve) in which values near the mean is more likely to occur that values far from the mean. Results of sensitivity testing can be displayed in different formats. Time graphs display behaviour of a variable over a period of time. The variables spread of values, at any period in time, are displayed either in terms of confidence bounds, or as separate values which combine to form individual simulation traces.

The experiments which we made consider the investigation of weighting factors for objective functions *(OF1, OF2)*, in the aspect of theirs sensitivities.

Experiment A

In experiment A the maximum and minimum values are chosen to bound parameter *w*. We use the so called univariate type of investigation, that means "change one at time". The results of the simulation experiment is presented of figure 3 in form of confidence bounds for variable *OF1*. Next we perform the second experiment with parameters: *w*, *tchn1, tchn2, tchn3*, called multivariante type, that means "change all together". Now parameters change their values simultaneously (from the maximum and minimum appropriately). The analysis of both confidence bounds allow us to state that it is proper to perform an optimization experiment with such group of parameters like: *tchn1, tchn2, tchn3, w*.

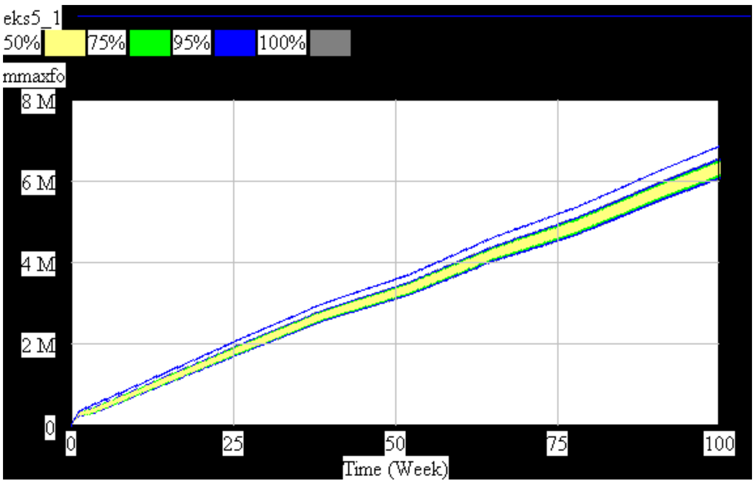

Fig. 3. Confidence bounds for variable *OF1* with parameter *w* from interval [10, 25]
Rys. 3. Zakresy ufności dla zmiennej *OF1* przy parametrze *w* z przedziału [10, 25]
Source: Own results.

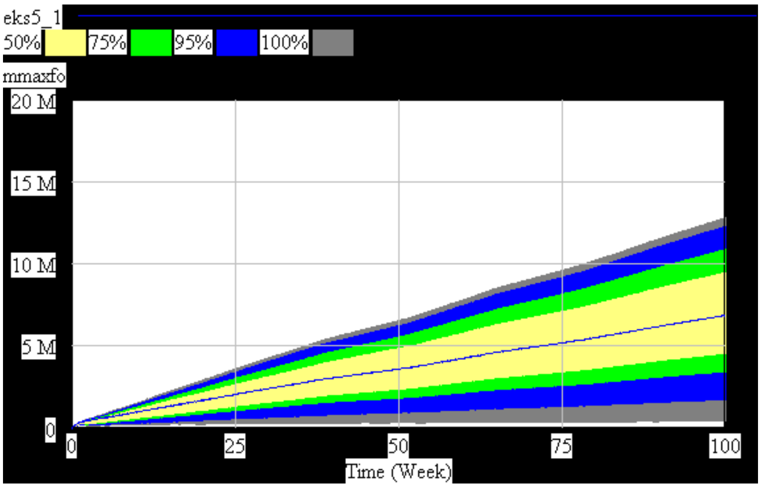

Fig. 4. Confidence bounds for variable *OF1*, with parameter *w* from interval [10, 25] and *tchn1, tchn2, tchn3* from [0, 40]
Rys. 4. Zakresy ufności dla zmiennej *OF1* przy parametrze *w* z przedziału [10, 25] i *tchn1, tchn2, tchn3* z przedziału [0, 40]
Source: Own results.

The aim of such an optimization is finding the optimal structure of production, from three technologies (they have different productivity and unit cost of production (raw materials and labour)). In consequence this relates to dynamics of factors of the objective function *(OF1)*, and in the end-on value of optimal profit.

In table 1 the results of the process of the optimization are presented.

Table 1

The results of optimization type maximization

Parameter	Final value	Initial value	Lower limit	Upper limit
w	10	10	10	25
tchn1	19.3202	20	0	40
tchn2	40	10	0	40
tchn3	40	20	0	40
Initial value of *OF1*: 6.56743e+0.006 Final value of *OF1*: 1.37364e+0.007 Final value of *PROFSL*: 20.96M Final value of *COFPR*: 6.599M Final value of *LINCOS*: 64.948				

Source: Own results.

Experiment B

In experiment B the maximum and minimum values are chosen to bound parameters: *w1, w2*. We use the so called multivariate type, that means "change all together". Now, the parameters *w1* and *w2* change their values simultaneously (from the maximum and minimum appropriately). The results of such simulation experiment are presented on figure 5 in the form of confidence bounds for variable *OF2*. Next we perform the second experiment with parameters *w, tchn1, tchn2, tchn3* called multivariate, as previously.

The influence of parameters *w1* and *w2* for the objective function *OF2* (which is the objective function for minimization of the cost of production), indicates that it is appropriate to optimize the objective function *(OF2)* with such group of parameters: *tchn1, tchn2, tchn3, w1, w2*. As in experiment A, the aim of such an optimization is finding the optimal structure of production.

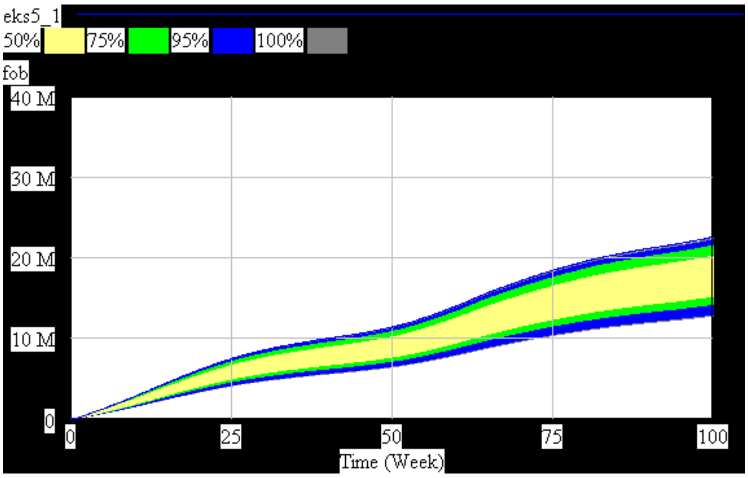

Fig. 5. Confidence bounds for variable *OF2, with* parameters: *w1* from interval [10, 25] and *w2* from interval [0.5, 1]

Rys. 5. Zakresy ufności dla zmiennej *OF2* przy parametrze *w1* z przedziału [10, 25] i *w2* z przedziału [0.5, 1]

Source: Own results.

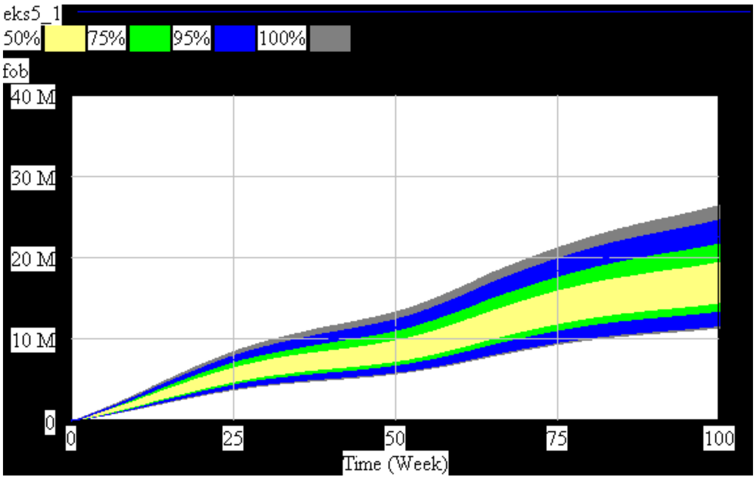

Fig. 6. Confidence bounds for variable *OF2*, with parameter *w1* from interval [10, 25] and *w2* from [0.5, 1] and *tchn1, tchn2, tchn3* from [0, 40]
Rys. 6. Zakresy ufności dla zmiennej *O* przy parametrze *w1*z przedziału [10, 25] i *w2* z przedziału [0.5, 1], *tchn1, tchn2, tchn3* z przedziału [0, 40]
Source: Own results.

The results of the process of optimization are shown in table 2.

Table 2

The results of optimization type minimization

Parameter	Final value	Initial value	Lower limit	Upper limit
w1	10	25	10	25
w2	0.5	1	0.5	1
tchn1	0.091081	20	0	40
tchn2	0	10	0	40
tchn3	40	20	0	40
Initial value of *OF2*: 2.25811e+0.007 Final value of *OF2*: 1.00851e+0.007 Final value of *SCRM*: 40.910 Final value of *SCPR*: 1.204M Final value of *LINCOS*: 34.800 Final value of *LOPR*: 16.98M				

Source: Own results.

It would seem very interesting to perform experiments C and D, in which all the weighting parameters will be optimized together in a type of optimization:

- Maximization for experiment C,
- Minimization for experiment D.

The results are presented in tables 3 and 4.

Table 3

The results of maximization using all weighting parameters

Parameter	Final value	Initial value	Lower limit	Upper limit
w	10	1	10	25
w1	25	25	10	25
w2	1	1	0.5	1
tchn1	19.3114	20	0	40
tchn2	40	10	0	40
tchn3	40	20	0	40
Initial value of *OF1*: 6.56743e+0.006 Final value of *OF1*: 1.37384e+0.007 Final value of *PROFSL*: 20.16M Final value of *COFPR*: 6.598M Final value of *LINCOS*: 64.789				

Source: Own results.

Table 4

The results of minimization using all weighting parameters

Parameter	Final value	Initial value	Lower limit	Upper limit
w	10	1	10	25
w1	10	25	10	25
w2	0.5	1	0.5	1
tchn1	0	20	0	40
tchn2	0.471126	10	0	40
tchn3	40	20	0	40
Initial value of *OF2*: 2.25811e+0.007 Final value of *OF2*: 1.00831e+0.007 Final value of *SCRM*: 42.355 Final value of *SCPR*: 1.247M Final value of *LINCOS*: 34.465 Final value of *LOPR*: 16.98M				

Source: Own results.

After such experiments – of the type simulation with optimization – it could be very interesting to go further and to perform experiments for searching for the stability of solutions. Possibilities of experiments are unlimited, and we will continue with a discussion on the future direction of investigation in the final conclusion.

4. Theoretical and practical conclusions from experiments of the type simulation-optimization on the SD model type

First, we will state theoretical conclusions:

– Simulations-optimization experiments, on models of the System Dynamics type, allow to find sensitive parameters and in consequence perform searches for optimal solutions for multicriterial problems (objective functions are modelled like inner elements of a model, with all feedback in structure),

- Searching for optimal solutions can take in to consideration different preferences of decision makers (different forms of objective function, with possibilities of weighting parameters for their factors),
- Further investigation of models of the type SD are possible in the area of searching for the stability of solutions on the basis of sensitivity analysis. The most interesting will be finding the stability of optimal structure in terms of the evaluation of a model. The method and tool gives us such supporting elements of investigation type simulation-optimization,
- Process of learning, achieved during: analysis, modelling, and simulation is not only of type: "what if?", but has normative elements (optimization), and because of this expand the possibilities of human being working with computers and models. Such investigations as described in our paper are comprised in main streams of developing methodological aspect of Decision Support Systems[9],
- Connecting simulation and optymization in System Dynamics models, as described in this paper, is not the only suggestion in the literature of the field. Authors of the paper plan to make use of genetic algorithms to finding optimal solutions in System Dynamics models. This tool should allow the finding of global optimal solutions, not only local. This connecting requites specific methods and this is a future direction of investigation for the authors of this paper.

Furthermore, we will state some practical conclusions:

- The language Vensim should be popular in the environment of System Dynamics modellers, because it is an effective tool for experiments of the type: simulation-optimization: its sensitivity and optimization setups allows almost automatic searching of confidence bounds or the optimal value of objective functions,
- Doing simulation with complex, large-scale models requires searching many variations of structures, many parameters (especially sensitive parameters), including random elements. All of these are possibilities with Vensim.

The authors of this paper are strong supporters of simulation-optimization using Vensim.

[9] Sroka H.: Systemy wspomagania decyzji kierowniczych. Prace Naukowe. Akademia Ekonomiczna, Katowice 1986; Stanek S.: Metodologia budowy komputerowych systemów wspomagania organizacji. Prace Naukowe. Akademia Ekonomiczna, Katowice 1999.

5. Appendix

Mathematical model of Production-Sale in Vensim

```
ard= INTEG ((rd-ard)/tau,p0)
cofprk=scpr+scrm
cost1=10
cost2=15
d1=1
d2=0
d3=0
desir=1400
dod=rd-rsl
DOL=-20
fob=scrm+scpr+penalty
fpri1=fprice*10*przelicznik1
fprice=SAMPLE IF TRUE(( MODULO(Time, 13 )<0.05) , SAMP, SAMP)
frd=ard+(desir-lin)/tasmo
g1=1
g2=2
g3=3
GORA=20
invcost=IF THEN ELSE(desir>olin, cost1 , cost2)
irm1=IF THEN ELSE(mtchn1>source1, source1,mtchn1)
irm2=IF THEN ELSE(mtchn2>source2, source2 , mtchn2)
irm3=IF THEN ELSE(mtchn3>source3, source3 , mtchn3)
key=0
lin= INTEG (rpr-rsl,t2)
lin0=0
lincos= INTEG (invcost*olin, t6)
linmax=1900
lmt= INTEG (+rrm-rpr,t1)
lopr= INTEG (rlopr,t3)
maxfob=profsl-maxpen
maxpen=lincos*w
maxv=rprof-invcost*olin*w-rcpr-rcrm
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```
minv=rcrm+rcpr+invcost*olin*w1+rlopr*w2
mmaxfo=maxfob-scpr-scrm
mtchn1=sw1*tchn1
mtchn2=sw2*tchn2
mtchn3=sw3*tchn3
olin=DELAY FIXED(lin, 2 , 300)
olin0=300
olis1=40
olis2=60
olis3=60
olisprice=400
p0=300
p1=100
penal1=lincos*w1
penal2=lopr*w2
penalty=penal1+penal2
perd=52
perlin=2
pric=1000
price=(1-key)*fpri1+key*tprice
price1= WITH LOOKUP (lin*przl, ([(0,100)-(1900,1500)],(0,1500),(100,1000),
(400,800),(700,600),(1000,500),(1300,300),(1600,200),(1900,100) ))
price2= WITH LOOKUP (rd*prz2, ([(200,500)-(400,1000)],(200,500),(300,850),
(400,1000) ))
price3=MIN(price1, price2 )
profsl= INTEG (rprof,t7)
prz1=1
prz2=1
przel=1
przelicznik1=1
rcpr=(rm1*ucpr1)*g1+(rm2*ucpr2)*g2+(rm3*ucpr3)*g3
rcrm=ucr1*rm1+ucr2*rm2+ucr3*rm3
rd=p0+p1*SIN(6.283*Time/perd)
rdmax=400
rdmin=200
rlopr=dod*price
```

```
rm1=IF THEN ELSE(frd>0, irm1 , 0 )
rm2=IF THEN ELSE(frd>0, irm2 , 0)
rm3=IF THEN ELSE(frd>0, irm3 , 0 )
rpr=DELAY3(rrm, tpr )
rprof=rsl*price
rrm=g1*rm1+g2*rm2+g3*rm3
rsl=IF THEN ELSE(lin<rd*TIME STEP, 0,rd)
S1=DELAY FIXED(SCHODEK+RANDOM UNIFORM(DOL, GORA , 1 ), 13 , 100)
S12=IF THEN ELSE(Time>=26:AND:Time<39, S2 , S22 )
S2= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL, GORA , 2 ), 26 , 0)
S22=IF THEN ELSE(Time>=39:AND:Time<52, S3 , S32 )
S3= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL, GORA , 3 ),39, 0)
S32=IF THEN ELSE(Time>=52:AND:Time<65, S4 , S42 )
S4= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL, GORA , 4 ), 52 , 0)
S42=IF THEN ELSE(Time>=65:AND:Time<78, S5 , S52 )
S5= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL,GORA , 5 ), 65, 0)
S52=IF THEN ELSE(Time>=78:AND:Time<91, S6, S62)
S6= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL, GORA , 6 ), 78 ,0)
S62=IF THEN ELSE(Time>=91:AND:Time<104, S7, 0 )
S7= DELAY FIXED (SCHODEK+RANDOM UNIFORM(DOL, GORA , 7 ), 91, 0)
SAMP=IF THEN ELSE(Time>=0:AND:Time<26, S1 , S12 )*przel
SCHODEK=100
scpr= INTEG (rcpr,t5)
scrm= INTEG (rcrm,t4)
source1=SAMPLE IF TRUE((MODULO(Time, 13 )<0.05) ,SAMP, SAMP)
source2=SAMPLE IF TRUE((MODULO(Time, 13 )<0.05) , SAMP, SAMP)
source3=SAMPLE IF TRUE((MODULO(Time, 13 )<0.05) , SAMP, SAMP)
supp1=100
supp2=100
supp3=100
sw1=1
sw2=1
sw3=1
t1=200
t2=300
t3=0
```

t4=0
t5=0
t6=0
t7=0
tan1=2
tasmo=12
tau=2
tchn1=20
tchn2=10
tchn3=20
TIME STEP=0.1
The time step for the simulation.
tpr=2
tprice=d1*price1+d2*price2+d3*price3
ucpr1=500
ucpr2=500
ucpr3=100
ucr1=100
ucr2=50
ucr3=10
w=1
w1=25
w2=1

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