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WORLD MODEL SIMULATION – THE EXAMPLE OF MACRO FORECASTING FOR HUMANITY DEVELOPMENT

Summary: In the early seventies The Club of Rome started a project called "The Predicament of Mankind". Based on the work of members of this club the modeling, analysis and simulation of humanity development were initiated. Furthermore, the macro models containing natural resources, population, capital investment, pollution and agriculture issues were built. One of those models – the World Model – presents a complex dynamics of all five cited issues. To address such questions as how well the humanity will progress in the future, the authors thoroughly examined this model. We performed sensitivity analysis for selected parameters such as Birth Rate and made an attempt to optimize other parameters for example the Quality of Life. The results of this research are presented together with open issues for further investigations.

Keywords: simulation, system dynamics, calibration, Vensim.

Introduction

Modeling and simulation of complex, non linear, dynamical and multilevel systems have a long history, especially in the area of the famous System Dynamics method [Coyle, 1996; Coyle, 1999; Garcia, 2006; Ruth, Hannon, 2012; Kasperska, 2009; Kasperska, Kasperski, Mateja-Losa 2014; Kasperska, Słota, 2004; Krupa, 2009; Marjasz, 2014; Radosiński, 2001; Sterman, 2000; Sterman, 2002], which 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. We can apply this approach to problems arising in social, managerial, economic or ecological systems. The main purpose of System Dynamics is to try to discover the structures that condition the observed behavior of the system over time. System Dynamics try to pose dynamic hypotheses that endogenously describe the observed behavior of system.

Research development directions and some respective examples:

- Methodological
  - archetypes
  - optimization
  - evolution
  - fuzzy sets
  - genetic algorithms
  - games
- Practical
  - supply chain
  - ecology
  - energy
  - military models

In the early seventies The Club of Rome started a project called "The Predicament of Mankind". Based on the work of members of this club the modeling, analysis and simulation of humanity development were initiated. Furthermore, the macro models containing natural resources, population, capital investment, pollution and agriculture issues were built. One of those models – the World Model – presents a complex dynamics of all five cited issues. The problems with management of ecosystems and global mechanisms is in the center of interest for observers of contemporary changes in the surrounding world. The methods of analysis and modeling of changes should be interdisciplinary, connecting such disciplines like ecology, economy, mathematics and informatics. Achievement of sustained development or opposing the effects of natural disasters and climate changing in nature, requires from the decision makers the ability of prognostic looking into the future. The effects of the human activities are long-term in time and space and sometimes they are unintuitive. In the complex systems, there are many feedbacks, thus the dynamic behavior is a result of co-operation of positive and negative loops. Like we said earlier, the System Dynamics method is the appropriate tool for modeling and simulation. Many authors [Dacko, 2010; Fiddman, 2002; Meadows, 2004; Ruth, Hannon, 2012] have undertaken this issue, but in the literature of this field we have lack of the papers connecting the simulation with the optimization [Kasperska, Mateja-Losa, 2005; Kasperska, Kasperski, Mateja-Losa, 2013; Kasperska, Mateja-Losa, Marjasz 2013; Ruth, Kasperska, Słota, 2005]. Such connection gives new opportunities for the analysis of decision making problems, and because of this we have undertaken this issue in our paper.

Presentation of the model and the object of study

The first version of World Model was introduced in the work [Forrester, 1971]. We present our version of the model made in Vensim software (see Fig. 1). It consists of five levels representing the following parameters: Population, Natural resources, Capital investment, Pollution and Capital investment in agriculture fraction. A proper subsystem is focused around each of these levels. The behavior of the World Model is the result of interaction between these subsystems. The aim of this research is to discover what impact do the changes in model parameters (or a combination of several parameters) have on the behavior of the whole system, and by such means to address such questions as how well the humanity will progress in the future.

By looking at this model, we can see the complexity in many approaches, such as the numerous factors influence on death rate for example. Therefore only the list of parameters and variables for abbreviation explanation is included. Mathematical equations are based on the Forrester book [Forrester, 1971], where they were thoroughly described.

List of the parameters and variables of World Model:
BR – birth rate
BRCM – birth rate from crowding multiplier
BRFM – birth rate from food multiplier
BRMM – birth rate from material multiplier
BRN – normal birth rate
BRN1 – normal birth rate (for research purpose)
BRPM – birth rate from pollution multiplier
CFIFR – capital fraction indicated by food ratio
CI – capital investment
CIAF – capital investment in agriculture fraction
CIAFN – normal capital investment in agriculture fraction
CIAFT – capital investment in agriculture fraction adjustment time
CID – capital investment discard
CIDN – normal capital investment discard
CIG – capital investment generation
CIGN – normal capital investment generation
CIGN1 – normal capital investment generation (for research purpose)
CIM – capital investment multiplier
CIQR – capital investment from quality ratio
CIR – capital investment ratio
CIRA – capital investment ratio in agriculture
CR – crowding ratio
DR – death rate
DRCM – death rate from crowding multiplier
DRFM – death rate from food multiplier

DRMM – death rate from material multiplier
DRN – normal death rate
DRN1 – normal death rate (for research purpose)
DRPM – death rate from pollution multiplier
ECIR – effective capital investment ratio
ECIRN – normal effective capital investment ratio
FC – food coefficient
FC1 – food coefficient (for research purpose)
FCM – food from crowding multiplier
FN – normal food
FPCI – food potential from capital investment
FPM – food from pollution multiplier
FR – food ratio
MSL – material standard of living
NR – natural resources
NREM – natural resources extraction multiplier
NRFR – natural resources fraction remaining
NRI – initial natural resources
NRMM – natural resources material multiplier
NRUN – natural resources normal usage
NRUN1 – natural resources normal usage (for research purpose)
NRUR – natural resources usage rate
P – population
POL – pollution
POLA – pollution absorption
POLAT – pollution absorption time
POLCM – pollution from capital multiplier
POLG – pollution generation
POLN – normal pollution
POLR – pollution ratio
POLS – standard pollution
QL – quality of life
QLC – quality of life from crowding
QLF – quality of life from food
QLM – quality of life from material
QLP – quality of life from pollution
QLS – standard quality of life
SWT1 – switching parameter 1 (for research purpose)
SWT2 – switching parameter 2 (for research purpose)
SWT3 – switching parameter 3 (for research purpose)
SWT4 – switching parameter 4 (for research purpose)
SWT7 – switching parameter 5 (for research purpose)

Every parameter with a number at the end of its abbreviation was used either to adjust the values of model variables or for research purpose. Let us proceed to the next section, where the results of our experiments are presented.

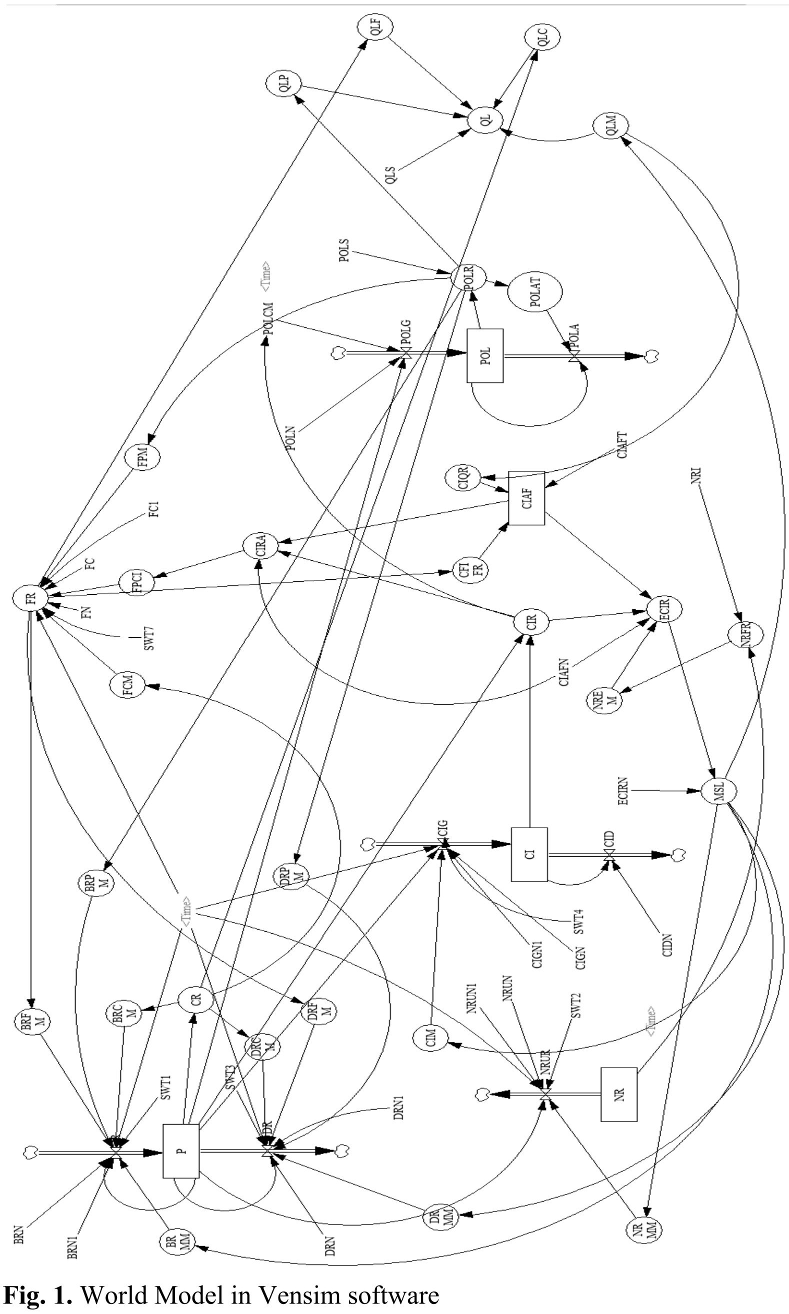

Fig. 1. World Model in Vensim software

Source: Own research.

Sensitivity analysis and optimization experiments performed on World Model using simulation in Vensim

More than 40 years passed since the first presentation of World Model. Therefore our first step was to take into account the changes that have taken place during that time, for instance greater population growth rate (modeled on the basis of data taken from [www2] and [www3]). We performed appropriate base simulations showing the adjustments made in this models Population variable (see Fig. 2). The BaseRunForrester is introducing the behavior of population as it was presented in [Forrester, 1971], as we can see a lot has changed past the forty years. The graph of both simulations starts to differ already past the Forrester book publication year 1971.

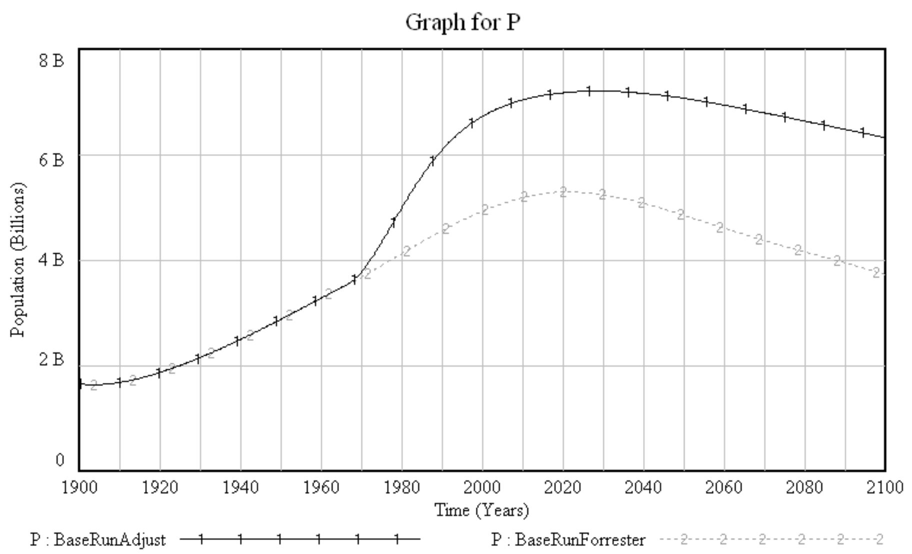

Fig. 2. Simulations of Population variable in Vensim software

Source: Own research.

The above simulation results are a part of the performed sensitivity analysis for Birth Rate and Population parameters (see Fig. 3 and Fig. 4), they also demonstrate that this slightly improved version of World Model is adapted to present–day circumstances.

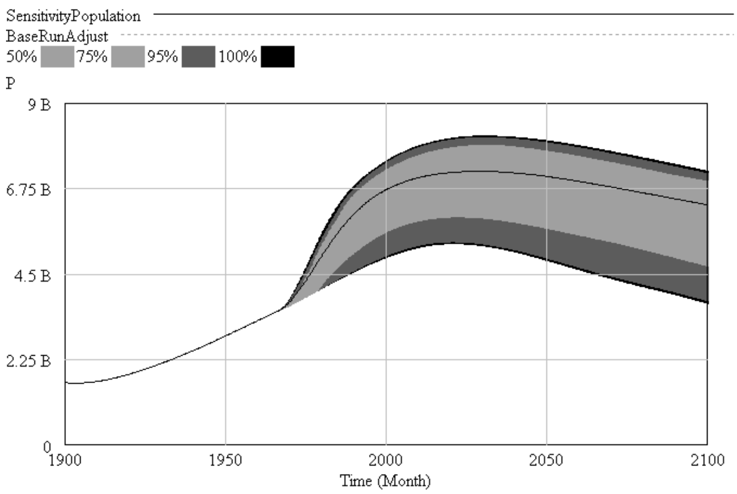

Fig. 3. Confidence bounds for Population variable

Source: Own research.

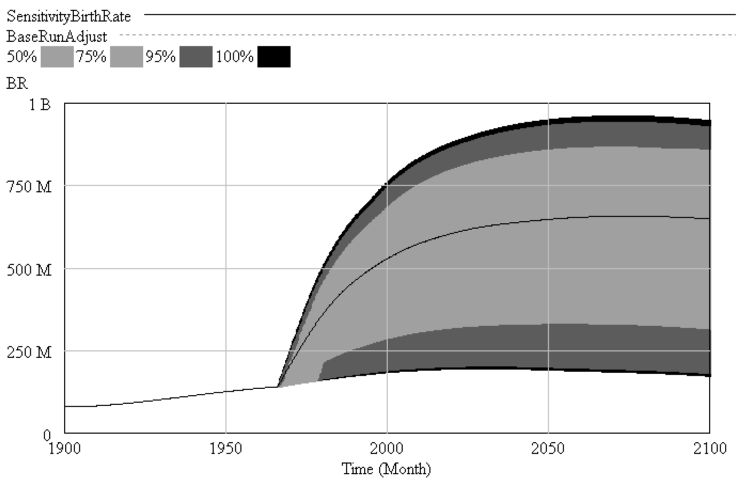

Fig. 4. Confidence bounds for Population variable

Source: Own research.

The next step is an attempt to optimize the variables most crucial from a human point of view – namely the Quality of Life and Food Ratio. For comparison purpose the BaseRunAdjust will be our point of reference to MODRun representing the optimization process. As an outcome of our research below we present a few graphs that show the best optimization results of our study.

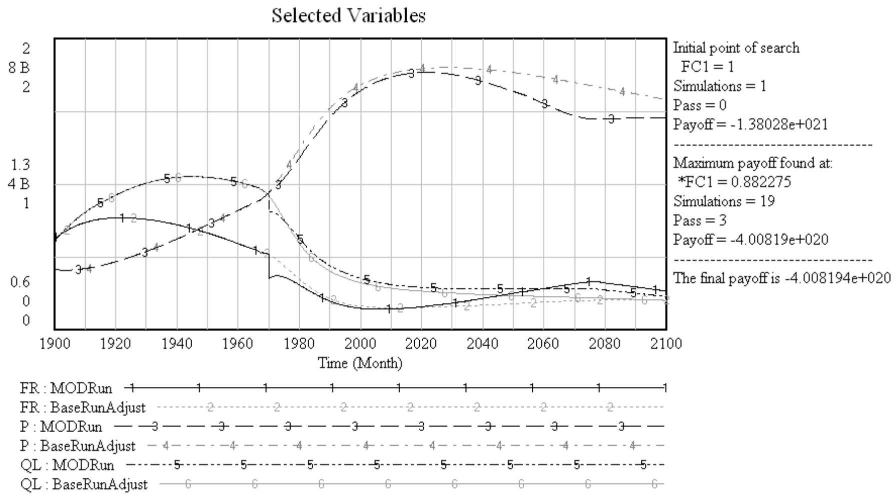

Fig. 5. Optimization result for FC1 parameter with CIGN1 set to 0,062 value

Source: Own research.

The first graph (see Fig. 5) represents the situation, in which food coefficient after 1970 year (FC1) is changed to lower optimum value. The normal capital investment generation after 1970 year (CIGN1) is set to 0,062 optimum value obtained in trial and error method. Observing the graph we can see that sudden drop in food availability (FR) in 1970 year is followed by higher availability after 2030 year in comparison to base simulation. This contrast with small increase of quality of life (QL) caused by the drop of world population value (P). Our experiment reveals high correlation between all three selected variables. In further optimization experiments we will try to reduce the impact of population drop on FR and QL variables.

Second graph (see Fig. 6) presents the outcome of optimization focused on food coefficient after 1970 year (FC1) and normal capital investment in agriculture fraction (CIAFN) parameters with CIGN1 also set to 0,062 value. The observed long term improvement in food availability (FR) and world population value (P) does not transfer to higher quality of life (QL). This indicates the need for additional focus on QL variable and more parameters must be taken into account.

Last graph (see Fig. 7) presents the outcome of optimization focused on several parameters: food coefficient after 1970 year (FC1), normal capital investment discard (CIDN), normal capital investment in agriculture fraction (CIAFN), normal death rate after 1970 year (DRN1), normal effective capital investment ratio (ECIRN), natural resources normal usage after 1970 year (NRUN1), with CIGN1 also set to 0,062 value. Some of optimal parameter values are the same as in initial simulation, others differ, meaning that every new approach in optimization process gives unique results, that cannot be obtained by separately found optimum values for each parameter. The graph for this experiment indicates that improvement in quality of life (QL) was obtained at the expense of lower food availability (FR).

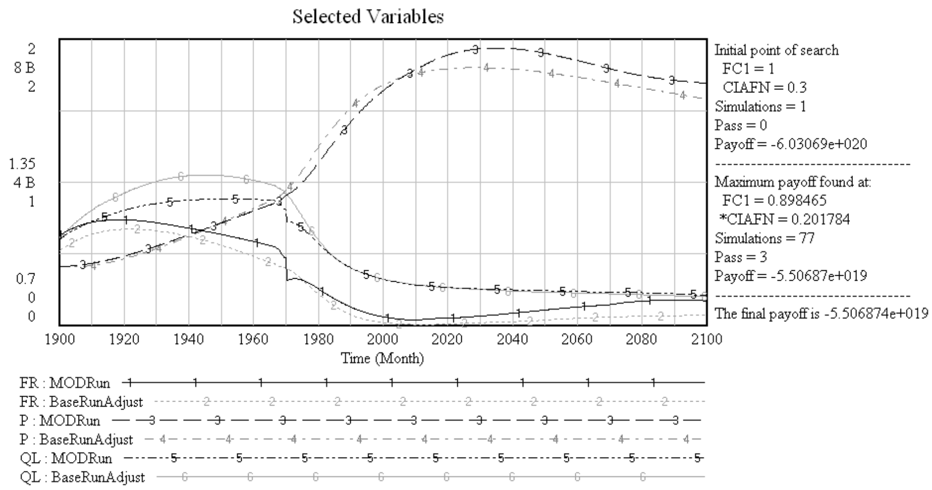

Fig. 6. Optimization result for FC1 and CIAFN parameters with CIGN1 set to 0,062 value

Source: Own research.

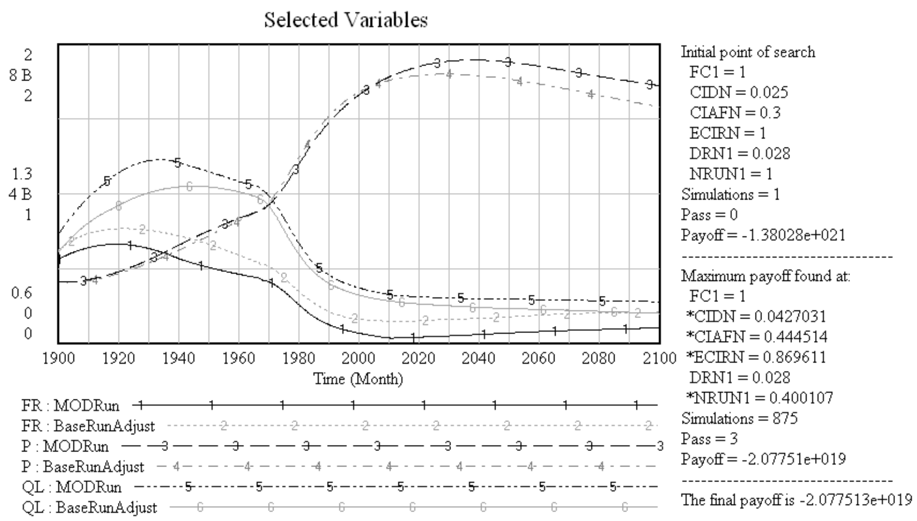

Fig. 7. Optimization result for multiple parameters with CIGN1 set to 0,062 value

Source: Own research.

Conclusions, ideas and open questions for further investigations

The aim of this paper was to present some new results of authors investigation in the area of macro forecasting simulation on updated World Model. Each of the three presented experiments describes a different approach in optimization process and indicates different problems. The applied simulation language of Vensim software helped in finding some optimum values of related initial parameters. The investigation undertaken by the authors led to the following conclusions:

- different approaches in the optimization process give unique results, that cannot be obtained by separately found optimum values for each parameter;
- Food Ratio, Population and Quality of Life variables are strongly connected, thus improvement of one variable results in decrease of another;
- high Crowding Ratio is a critical variable that decreases the Quality of Life, leaving no practical chance of QL improvement without lowering CR;

Further development of World Model can improve its vulnerability in some issues, which leaves opportunity for further investigations in the future. For example taking into account modern changes in governing natural resource, pollution, capital investment, or agriculture. Such modifications can completely change the way of perception in the model and make it more updated, which leads to the following open questions that need further research to be done:

- o What is the golden mean between the Crowding Ratio and Quality of Life variables?
- o How can we adjust World Model to better fit the modern relationships between all parameters and values?
- o What other features of everyday life and economic standards can be incorporated into the model?

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MODEL ŚWIATA – PRZYKŁAD PROGNOZY MAKRO ROZWOJU LUDZKOŚCI

Streszczenie: Na początku lat siedemdziesiątych XX w. Klub Rzymski rozpoczął projekt „The Predicament of Mankind". Opierając się na pracy członków tego klubu rozpoczęto modelowanie, analizę i symulację rozwoju ludzkości. Ponadto zbudowano modele makro zawierające parametry, takie jak: naturalne zasoby, ludność, inwestycje kapitałowe, zanieczyszczenie środowiska i problemy rolnictwa. Jeden z tych modeli – Model Świata – prezentuje złożoną dynamikę wszystkich pięciu cytowanych problemów. Aby móc odpowiedzieć na pytania o to, jak dobrze ludzkość będzie się rozwijać w przyszłości, autorzy dokładnie zbadali ten model. Przeprowadzono analizę wrażliwości dla wybranych parametrów, takich jak przyrost naturalny, i podjęto próbę optymalizacji innych parametrów, na przykład jakości życia. Wyniki tych badań są przedstawione razem z otwartymi kwestiami wymagającymi dalszych badań.

Słowa kluczowe: symulacja, dynamika systemowa, kalibracja, Vensim.