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Contents

From the Editors

Systems thinking and theory is a field of science in which we look at the whole as determined by the relationships and causal links of its variables. It shifts human experience from the dominant reductionist approach to a different way of viewing the problems that surround us. It gave rise to more specific system based methods; one of them being the System Dynamics, developed in the late 1950s by J. Forrester. It uses simulation models of complex systems, including economic ones, and explores their dynamic behaviour through mental experimentation. Placing systems science in the field of problem solving and decision making helped develop a new discipline of studies (still in statu nascendi) – Dynamic Decision Making. Dynamic Decision Making teaches us how to make right decisions in an uncertain and rapidly changing environment.

The articles collected in this issue of JEMI are directly associated with systems thinking, System Dynamics methods and the discipline of Dynamic Decision Making.

The first article presents a preliminary System Dynamics model TAMIAHUA1 developed to analyze sustainability of a natural reserve in Mexico: the Tamiahua Wetlands. Research conducted on the model suggests that fishing activities in Tamiahua Wetlands, alongside increasing levels of pollution resulting from human activities, can significantly reduce the diversity of species in the ecosystem of Tamiahua, which could threaten its sustainable development.

In the second article, the authors focus on the experimental optimization and sensitivity analysis of the classical Forrester's simulation model Customer – Producer – Employment. They present the results of simulation and optimization of logistic problems included in that model .

The third article deals with the validation of simulation models. In its first part the authors give an overview of the problem, focusing especially on the techniques of validating system dynamics models. Then, they present an example of the validation of a system dynamics model of the manufacturing resource allocation.

The fourth article is related to the discipline of Dynamics Decision Making. The authors ask if animacy facilitates decision-making in dynamic situations. To answer this question, they compare behavior in dynamic situations occurring in four types of context: Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-Social. Participants were randomly allocated to one of these contexts, and in each version they were required to learn to manipulate variables in order to bring the dynamic system to a desirable state, and maintain it at that level. The authors conclude that context induces general beliefs about casual relationships in dynamic environments that generalize across animate as well as inanimate contexts.

The fifth article presents the steps of modeling the material management system in a manufacturing company in accordance with the System Dynamics method. The variables of the mental model connected with materials were first defined as well as causal relationships among them. Causal diagrams were transformed into a simulation model that was verified. The study endpoints included the simulation of the model with empirical data and sensibility analysis "what ... if …" was performed.

We would like to thank all the authors for very interesting articles and their contribution to this JEMI edition. We also thank the reviewers for their valuable and insightful comments. We hope that the texts included in this issue will arouse readers' and scientists' curiosity.

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Guest Editor, University of Rzeszów

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Exploring Alternatives for Sustainable Development in the Tamiahua Wetlands

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Abstract

This article presents a preliminary System Dynamics model developed to analyze the sustainability of a natural reserve in Mexico: the Tamiahua Wetlands. Wetlands are often referred to as nature's kidneys because they filter contaminants from water. In spite of their importance, wetlands are endangered areas around the world. In order to build the model we take into account the Fishbanks model developed by Meadows (2004) as a starting point. Then, the model considers variables related to changes in total and economically active populations, and contaminants in water. The preliminary model presented in this study implies that fishing activity in the Tamiahua Wetlands, together with contaminants from human activity, have the potential to damage the diversity of species in the ecosystem, endangering its sustainability. Continued work on the model is intended to explore appropriate ways of preserving Tamiahua, providing inhabitants with economic activities that promote the sustainability of the region.

Keywords: *sustainable development, Wetlands, Mexico, Tamiahua.*

Introduction

This article introduces a preliminary System Dynamics model to analyze sustainability of a natural reserve located in the Northern bound of the State of Veracruz in Mexico: the Tamiahua Wetlands. The model presented in this study is the result of initial conversations among researchers interested in regional development and the preservation of the Tamiahua protected area, and builds upon such System Dynamics models as Fishbanks (Meadows, 2004). One of the authors of this initial study has been involved in extensive field research in Tamiahua, collecting information about water quality. During his fieldwork, he has observed a growth in the fishing industry followed by

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a decline on the activity of fishing cooperatives. The reduction in fishing appears to be the result of a combination of such factors as increased fishing activity, contamination and deterioration of the diversity of species in the wetlands region.

The document is organized in five more parts. The second section consists of a literature review on the nature and characteristics of wetlands, and the use of System Dynamics as a tool to study sustainability of fishing. The third section describes the methods used in the study. The next two parts: Analysis and Results and Discussion, describe the model structure and some interesting behaviors of the model TAMIAHUA1, respectively. Finally, the last section offers some final remarks and suggestions for further work.

Literature review

Wetlands are often referred to as nature's kidneys because they readily filter contaminants from water, there are also famous for their intrinsic beauty and importance as habitat for rare and endangered species as well as their role in carrying out basic ecological functions such as primary productivity, decomposition, nutrient cycling and regulation of fluxes between land and water bodies. These ecosystems can also function to remove and store nutrients and toxic pollutants in runoff from surrounding areas.

Particularly, coastal wetlands play an important role in protecting coastal water quality. They are critical ecosystems that help to regulate and maintain the hydrology by storing and releasing floodwaters. Wetlands are hard to define mainly because they are transition zones. Their hydrology is usually the most important factor determining its character. These regions are considered one of nature's most efficient filters and usually are important nurseries for fish, crabs, shellfish, and an extensive variety of animals.

Despite their importance in the ecosystems, wetlands are endangered zones all around the world. Only in the USA, an annual loss of approximately 1.05 million hectares of wetlands is estimated (Josephson, 1992). Apart from agricultural conversion, wetlands are continuously jeopardized as result of overfishing, burgeoning development, sediment contamination and nutrient pollution, all this is the result of growing population and increasing unplanned development in coastal counties. Such situation in many cases promotes excessive exploitation of fisheries and an increasing number of threatened, endangered and extinct indigenous species.

System Dynamics has been used in exploring the environmental management and sustainability in applications that tackle problems of forestry in Indonesia, irrigated lands in Spain, renewable resource management in Norway, wildlife management in the USA and blue-green algae bloom in the coastal waters of Australia (Cavana and Ford, 2004). What these applications have revealed is that modeling dynamically these complex problems with many factors can enlighten the implementation of possible policies to alleviate the problem. System Dynamics has proven to be a useful tool when complex systems need to be re-oriented towards greater sustainability through policies that are quite different from those currently implemented and which should focus on the true driving factors of the system (Martínez Fernández and Esteve Selma, 2004). Our study subscribes to these assumptions and aims.

Particularly, System Dynamics has been used successfully to analyze and study fishing systems in a variety of ways (Morecroft, 2007; Otto and Struben, 2004; Ruth, 1995). Most of these previous efforts were focused on analyzing the problem known as the "Tragedy of the Commons" and policies to control overexploitation of fishing areas. The model presented in this article builds on previous work in System Dynamics and studies the impact of contaminants and of fishing activities on the diversity of species in Tamiahua Wetlands.

Method

It is clear, from the analysis of the research site, that to achieve a sustainable and holistic understanding of the complexity faced by the Tamiahua Wetlands and its stakeholders, we need to go beyond simply predicting the fishing activity. Economic and social variables interact dynamically with environmental and institutional variables.

To explore the effect of fishing on the interaction of other variables, a System Dynamics model was constructed. System Dynamics, originally known as Industrial Dynamics, is a creation of Jay Forrester in the 1960s at the Massachusetts Institute of Technology (Forrester, 1961). System Dynamics is essentially a methodology which uses the theory of information feedback and control in order to evaluate organizations and problems. The basic idea underpinning this approach is that any complex situation can be described in terms of stocks and flows; flows being main actions increasing or decreasing the stocks. System Dynamics assumes that things are interconnected in complex closed patterns of causality, and that the world is made up of flows, stocks and feedback loops. Other assumptions include that information flows are intrinsically different from physical flows, and that non-linearities and time-delays embedded in the system's structure are important to understand the system behavior (Sterman, 2000). The main focus of the methodology is to capture the structure of complex problems, representing it in terms of stocks, flows and feedback loops, which constitutes a dynamic hypothesis to explain problematic behaviors. The model structure and behavior are then compared with known relationships and behaviors in the system in several iterations.

System Dynamics has been used in a variety of contexts, as a problem evaluation on the premises that the structure of a system, that is the way the systems are connected, generates its behavior, aiming to predict the behavior of the system (Richardson and Pugh, 1989, Stave, 2003, Sterman, 2000). While statistical forecasting models rely on equations developed *ex post*, i.e. following observations, System Dynamics aims first to determine the systems structure consisting of positive and negative relationships between variables, feedback loops, systems archetypes, and delays (Sterman, 2000; Wolstenholme, 1982, 2003) followed by *ex ante* projection where future system states are replicated from the System Dynamics model (Winz and Brierley, 2007).

As already mentioned in this article, the modeling effort is based upon the knowledge and experience of two experts, one on regional development, and the other on water and environment. Although obtaining quantitative data to build the model has proven to be difficult, knowledge from field work on the region has been used to ensure a better understanding of behavior over time and structural hypotheses. The model is still in a preliminary stage, but initial model structure and some key parameters seem reasonable to expert judgment.

Analysis

The Tamiahua Wetlands

The Tamiahua Lagoon is located in the northern part of the state of Veracruz, Mexico. It is a coastal lagoon and covers an area of 217,500 acres, of 52.2 miles length, 9.6 miles width, and the depth of 2.2-3.3 yards. It has two water mouths, one in the north and another in the south, and is located in between two large rivers, Panuco in the north and Tuxpam in the south (see Figure 1).

There are some valuable natural resources in the area which comprise an important mangrove swamp towards the south of the lagoon and coral reef formations to the east, on the Gulf of Mexico coast.

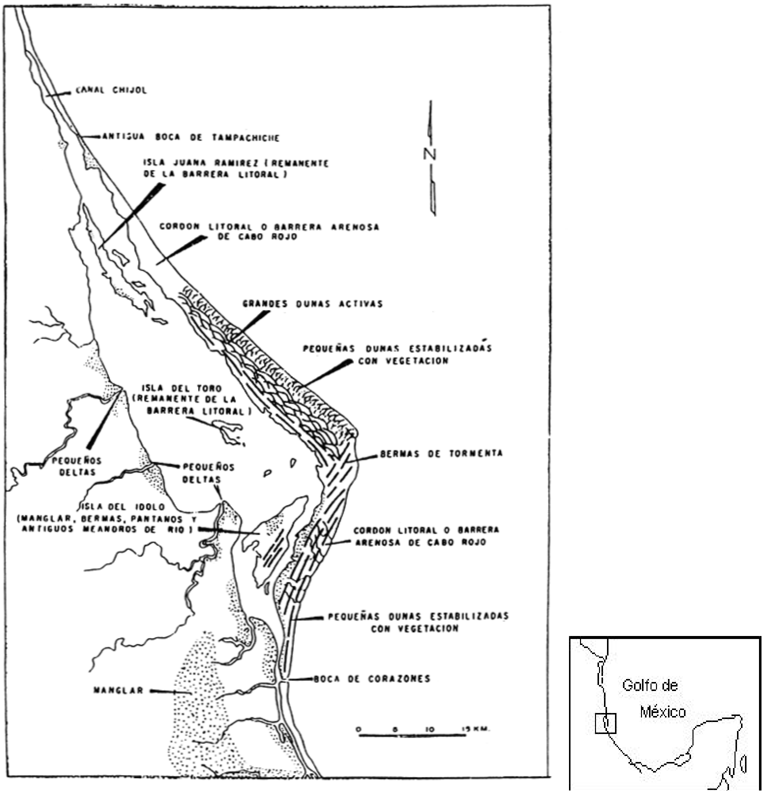


Figure 1. The Tamiahua wetlands localization

Source: Revista internacional de contaminación ambiental – Bioacumulación (2013).

The biodiversity of the place is rich, the area being inhabited by mollusk, crustacean, polychaeta, waterfowl, and a place for turtles laying eggs. Due to its ecology, botany, zoology, limnology, and hydrology richness, the Tamiahua was designated as a protected wetland included in the Ramsar Treaty of November 27th, 2005. The Ramsar Convention provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

However, in the last ten years, a pollution problem has been affecting fishing activities in the lagoon. Industrial and residential pollutants are brought to the lagoon through 5 main rivers. The main types of pollutants are: hydrocarbon, agro-chemicals, fertilizers, metals and all sort of organic and solid waste (Albert, Bandala, Torres-Nacho, and Villanueva, 2006).

Socio-economic conditions

Surrounding the Tamiahua Lagoon there are 5 municipalities with a total population of 205,000 inhabitants. The economically active population (EAP) amounts to 40 percent of total population (INEGI, 2005, 2010). The main economic activity in this region is concentrated in the primary sector, mainly agriculture, as 75 per cent of the EAP is located in this sector. Only 2.5 percent operate in the manufacturing sector, and the rest of the EAP work in the service sector (INEGI, 2005, 2010). The net rate of population growth in the region is estimated at 1.8 percent annually.

The fishing activity is carried out by approximately 4,000 people (Cooperativa Pesquera, Tamiahua, 2012). They are grouped in 340 business units known as fishing cooperatives, with an average size of 12 people. Out of 4,000 people, 60 percent, that is 2,400, are proprietors of the business units, and the remaining 1,600 fishermen work as employees. It is estimated that the total fleet is composed of 680 fishing boats, which means an average of 2 boats per company.

According to recent data, annual fish catchment is about 12,750 tons. This amounts to an average catchment per boat of 18.75 tons per year, or 37.5 tons per company. The estimated price per ton in the intermediary market is US$1,500.

The market price of a boat is US$10,500, and it has a usable life of 20 years. The operating cost for each boat is estimated to run at US$10,000 per year, including wages.

Cooperatives in Mexico, as the fishing ones in Tamiahua, normally receive financial support by the Federal Government. In particular, the Ministry for Agricultural and Fishing Resources decides on fishing permits and funding for cooperatives after an economic feasibility study.

Model description

The model TAMIAHUA1 consists of four main sectors and was built using Vensim PLE Version 5.8. The first two sectors are similar to the ones used on the Fishbanks model (Meadows, 2004), and include the fish population and the fleet size. The third sector includes population dynamics in the region, and the last sector considers the contamination level in the water of the wetlands.

Figure 2 shows the basic structure of fish population and fishing. The red parts in the model are those that are unique to the model presented in this study. The stock of diversity of the species was important to include, given the key role that this diversity plays on the cleaning function of wetlands and its impact on the growth of fish population. As shown in the figure, fishing practices in Tamiahua have been recognized to have an impact on the diversity of the species. Moreover, water contaminants and the diversity of the species have also had an impact on the population of fish in the lagoon.

Figures 3 and 4 represent the growth of the fishing fleet. Figure 3 includes the representation of the attractiveness of the fishing industry compared to other activities in the Tamiahua region. Profit is the difference between income and costs associated to fishing, and the profitability of other economic activities was estimated using the minimum wage in Mexico. As shown in Figure 4, the funding to increase fleet size does not come in this region from profits in the fishing industry, but from subsidies provided by the State government. As described by one of the experts involved in the modeling process, fishing cooperatives' need to increase the fleet or replace the existing boats exerts pressure on State government to provide more public funds to buy new boats.

Figure 5 shows the way in which the attractiveness of the fishing industry attracts Tamiahua region inhabitants to join (or leave) fishing cooperatives.

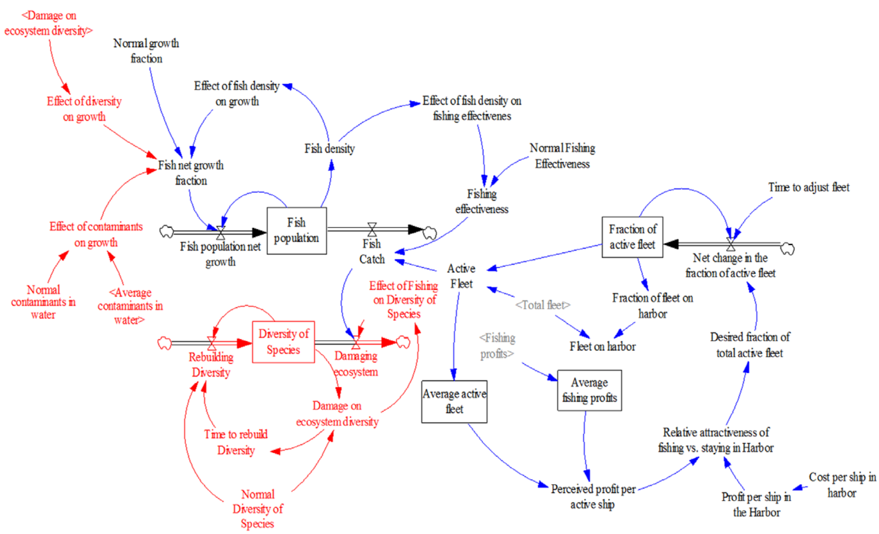


Figure 2. Fish population and fishing activities

Source: Authors' research on the basis of Meadows (2004).

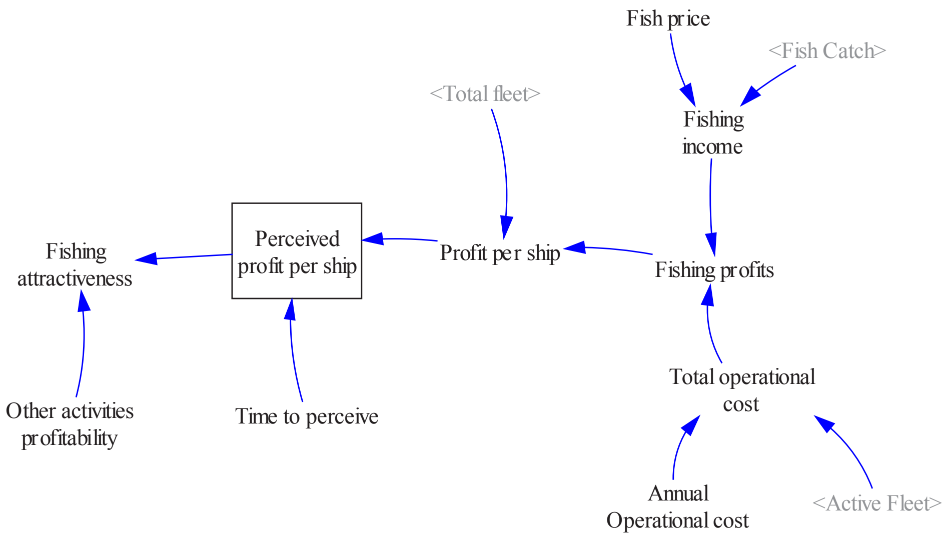


Figure 3. Fishing attractiveness

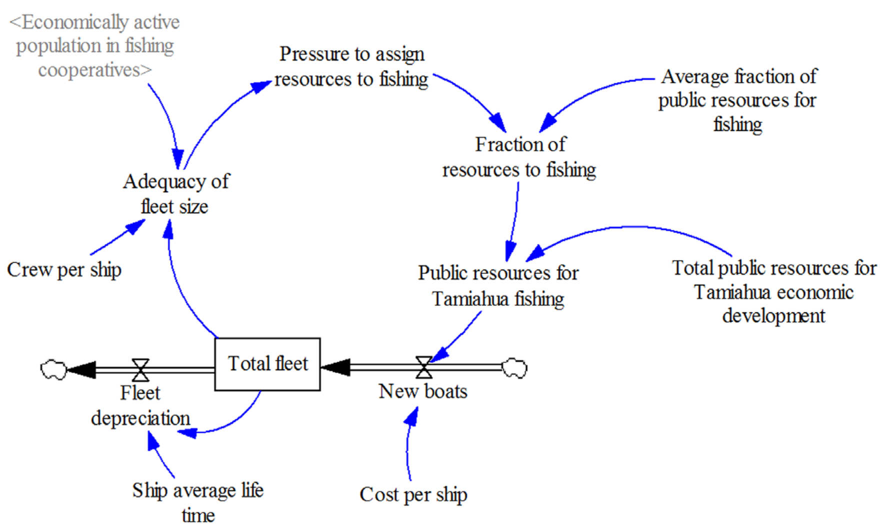


Figure 4. Fleet growth

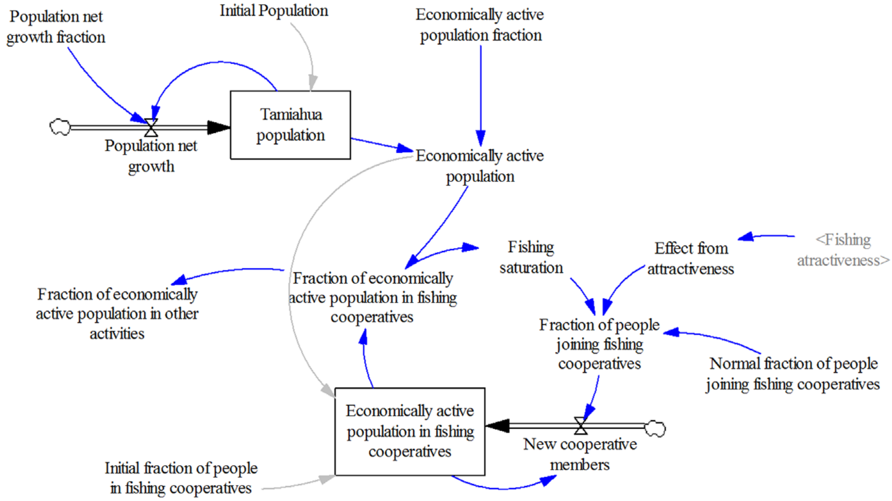


Figure 5. The Tamiahua population undertaking fishing activities

Finally, Figure 6 presents a theory of how contaminants come into the lagoon, and how the lagoon absorbs a fraction of these contaminants before the water reaches the sea. The Tamiahua lagoon has experienced a considerable increase on its pollution levels resulting from the release of chemicals produced in oil-related, industrial and agricultural activities in the zone. During the last fifty years, the system has received oil spills from crude exploitation facilities and oil pipelines. Besides, most of the municipalities settled in the surroundings of the lagoon lack sanitation systems producing domestic wastewater and leachates from solid waste sites are released without any treatment to the lagoon (Albert et al., 2006). As shown in figure 6, contaminants coming from industrial effluents upstream in the rivers and from sewers and human activity may threaten the diversity of the species and have an impact on the absorption capacity of the Tamiahua Lagoon.

Appendix A shows the parameters values and equations that were used for the model.

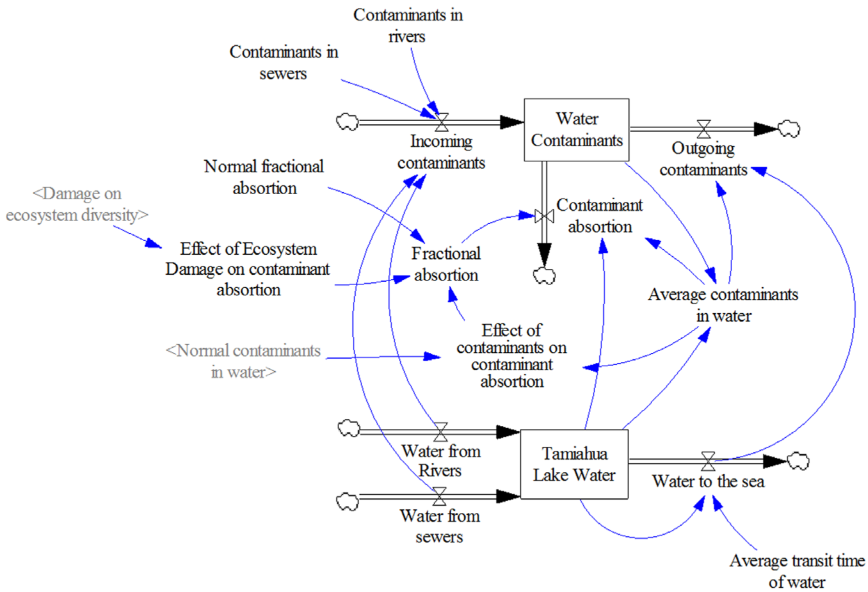


Figure 6. Contaminants in water

Results and discussion

Figures 7, 8 and 9 show some of the behaviors of the model in a base scenario. Figure 7 shows the way in which fishing activity slowly erodes the diversity of the species, eventually impairing the ability of the fish population to reproduce in a healthy way. Figure 8 shows the dynamic behavior of the fleet size, the active fleet and the fleet in harbor. As shown in the figure, the impact on the fish population promoted by contamination and the decrease on the diversity of the species is not yet enough in this model to have an impact on the fishing activities. Given that the actual fleet size is similar to the simulated fleet size, this base scenario suggests that the observed decrease on fishing activity in Tamiahua responds to the contamination of the wetlands or to the impact of the fishing techniques on the diversity of the species.

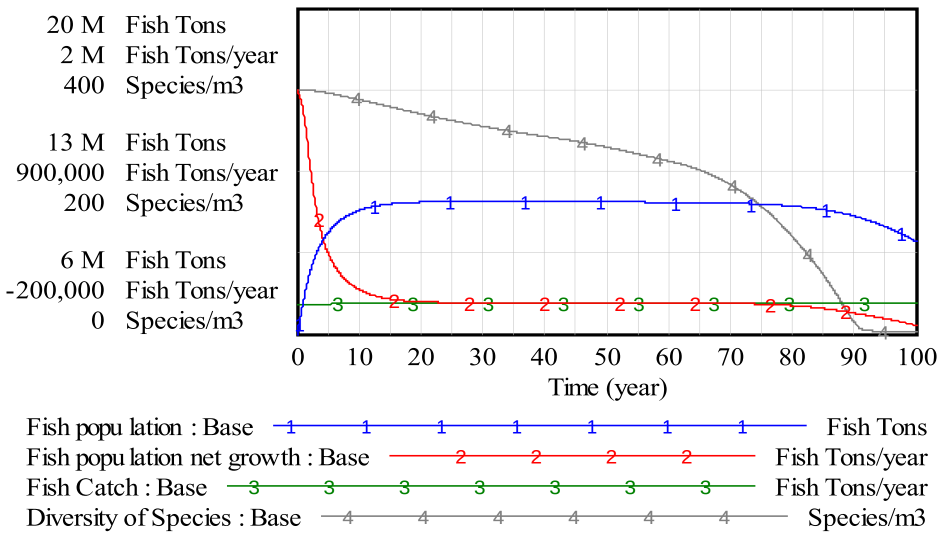


Figure 7. Fish population

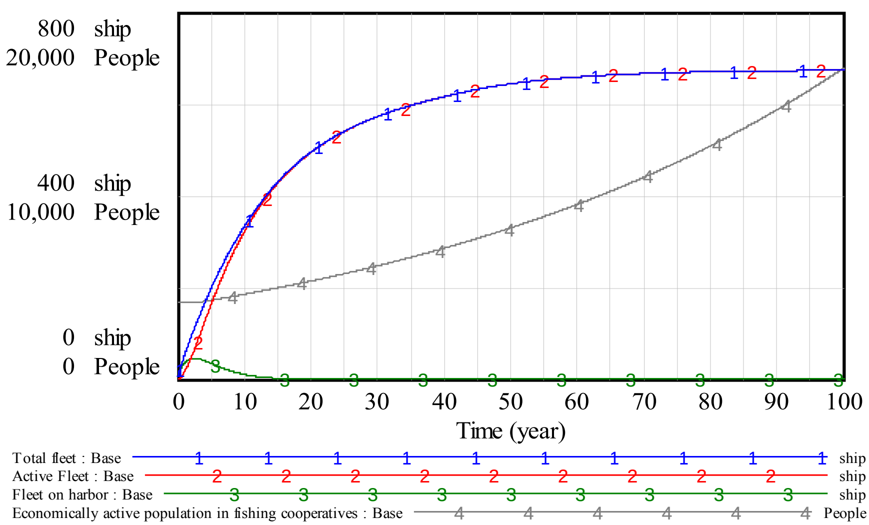
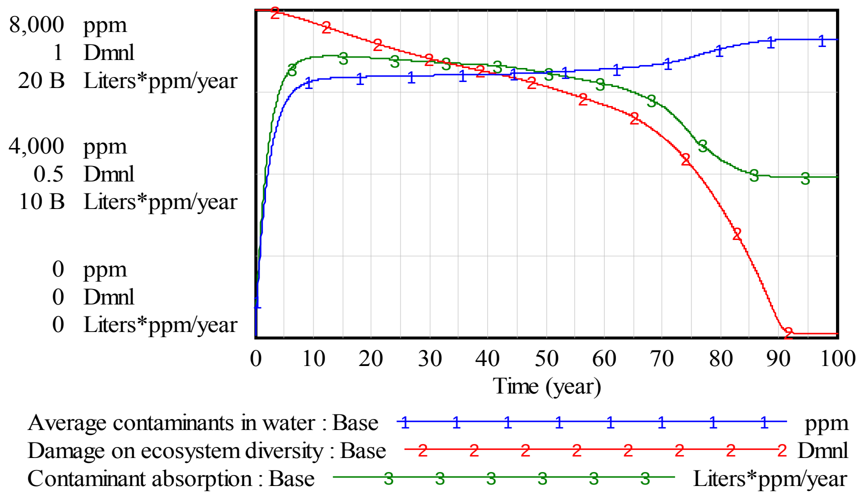


Figure 8. Fleet size and population

Figure 9 shows some key behaviors of the ecosystem. During the last years of the simulation, it is possible to observe an important damage in the diversity of the species, which leads to an increase in contaminants in the lake, attributed mostly to the reduction in the capacity of the lagoon to absorb contaminants.



Notes:
Pppm: Parts per million.
Dmnl: Dimensionless, as it refers to Diversity of Species/Normal Diversity of Species.

Figure 9. Contaminants and ecosystem diversity

The initial explorations with the model involved 5 parameter changes producing also 5 basic scenarios. In the first scenario, we increased the damage on the ecosystem produced by the fishing activity. The second scenario consists of an increase in incoming contaminants to the lagoon. The third and fourth scenarios involve changes in the attractiveness of alternative economic activities, making fishing more or less attractive. The last scenario explores the impacts of increased resources from government to the fishing industry.

As shown in Figures 10 to 13, attractiveness of alternative economic activities have a very limited impact on model behavior. The main reason is that the main source of economic resources to increase the fleet size is government funds. An increase in government funds, on the other hand, does have an impact on the sustainability of the ecosystem because it allows for the fleet size growth, accelerating damage to the ecosystem, and collapse of the fishing industry. Increasing contaminants from rivers and changes in fishing practices for ones with higher environment impacts have an important impact on fish population. Increased contaminants have a more continuous impact, and increased impact from fishing practices contributes to a faster decline in fish population.

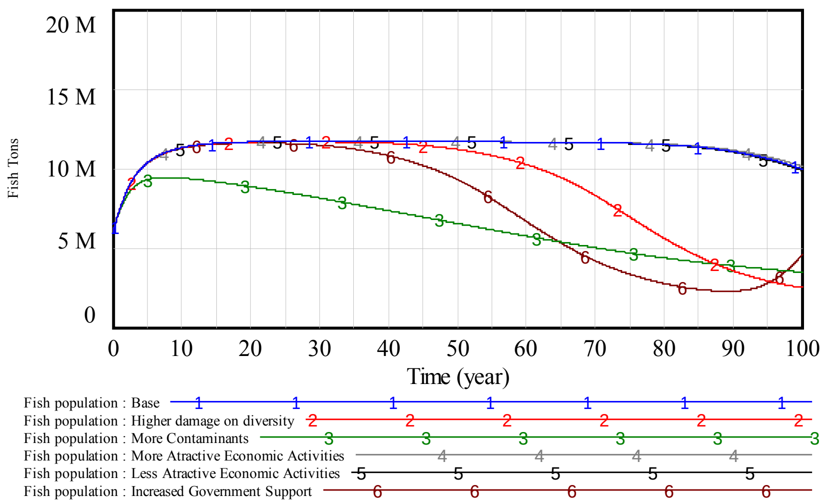


Figure 10. Comparative graph for fish population

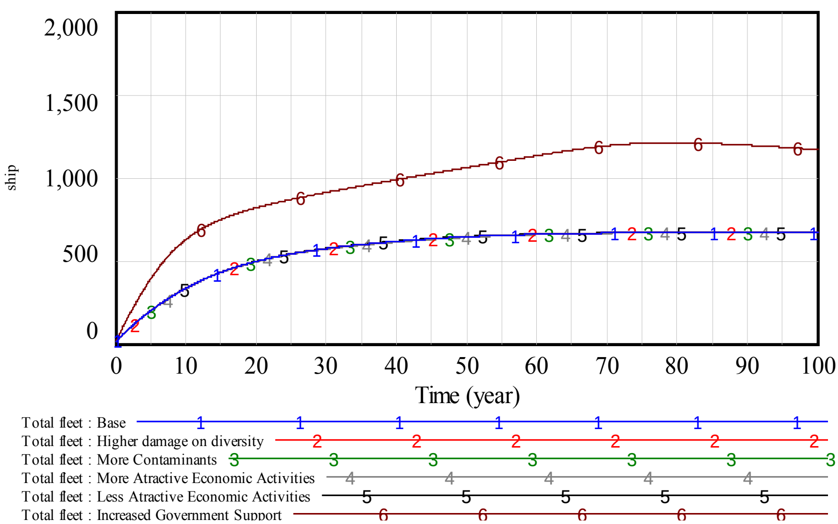


Figure 11. Comparative graph for total fleet

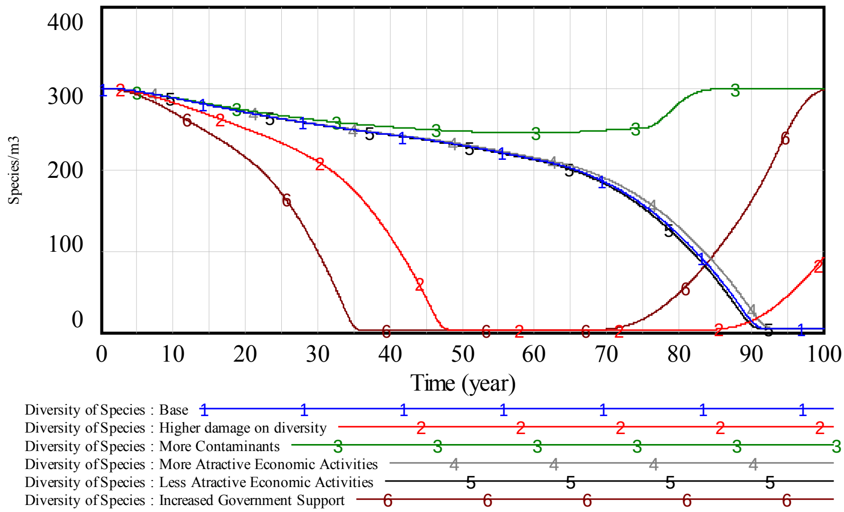


Figure 12. Comparative graph for diversity of species

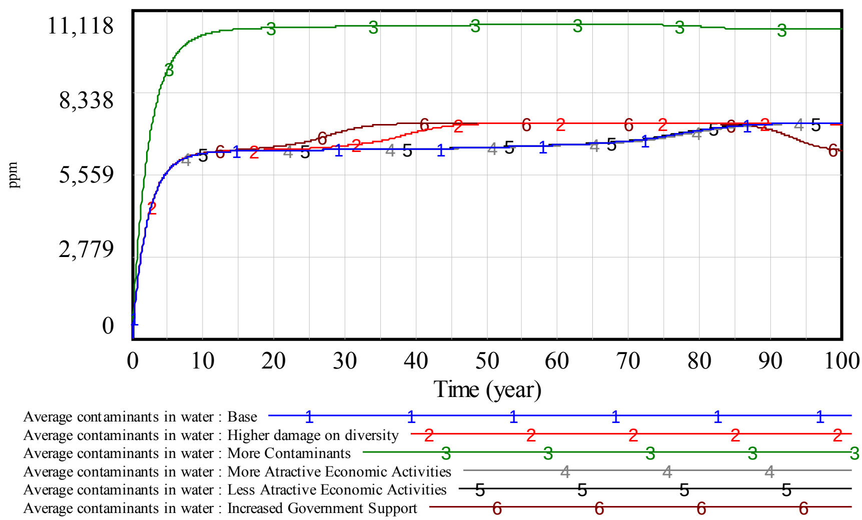


Figure 13. Comparative graph for contaminants in water

Conclusion

In this short article, we presented a preliminary model to study the sustainability of the Tamiahua Lagoon considering the fishing activity and the impact this activity makes on the diversity of species in the lagoon. Additionally, the model includes the impact of contamination of the wetlands. Preliminary experiments suggest that fishing practices and contamination have the potential to create a significant imbalance in the system, apparently in a more important way that the actual fishing intensity.

Fishing activity is considerably limited by the availability of government funds. In this way, government decisions on funding the fishing activity affect the stability of the system.

Although the model presented in this study has a reasonable structure, it still needs to be refined in terms of parameter values, mostly those associated to the ecosystem. We will continue our experiments with the model to create a series of policy recommendations to the State Government of Veracruz in Mexico.

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Abstrakt (in Polish)

Artykuł prezentuje wstępny symulacyjny model TAMIAHUA1, opracowany w celu dokonania analiz związanych z utrzymaniem naturalnego rezerwatu przyrody w Meksyku – mokradeł Tamiahua Wetlands. Mokradła są często określane jako „nerki natury", ponieważ stanowią naturalny filtr oczyszczający zanieczyszczenia wodne. Pomimo ich znaczenia, są one obszarami zagrożonymi. Punktem wyjścia do opracowania modelu przedstawionego w artykule był model przedstawiony przez Meadows (2004). Model ten rozbudowano między innymi o zmienne obrazujące ekonomiczną aktywność ludności oraz wielkość zanieczyszczeń w wodzie. Badania na modelu sugerują, że działalność połowowa na obszarach Tamiahua Wetlands wraz z rosnącym poziomem zanieczyszczeń wynikających z działalności człowieka mogą znacząco wpłynąć na zmniejszenie różnorodności gatunków w ekosystemie Tamiahua, co może zagrozić jego zrównoważonemu rozwojowi. Dodatkowe badania według pięciu scenariuszy dostarczają wniosków, które mogą prowadzić do podjęcia takich decyzji, które mogłyby wpłynąć na zrównoważone zarządzanie rozwojem tamtejszego regionu.

Słowa kluczowe: *zrównoważony rozwój, mokradła, Meksyk, Tamiahua.*

Appendix A. Parameters and model equations

(001) Active Fleet = Total fleet * Fraction of active fleet
Units: ship
Number of ships fishing in the Wetlands

(002) Adequacy of fleet size = (Economically active population in fishing cooperatives / Crew per ship) / Total fleet
Units: Dmnl
A ratio describing how well the current fleet employ people in Tamiahua. A ratio greater than reveals unemployed people

(003) Annual Operational cost = 245000
Units: pesos/(year*ship)
Cost of operating an active ship per year

(004) Average active fleet = SMOOTH (Active Fleet, Time to register average)
Units: ship
Average number of ships fishing in Tamiahua

(005) Average contaminants in water = Water Contaminants / Tamiahua Lake Water
Units: ppm
Water contaminants measured in parts per million

(006) Average fishing profits = SMOOTH (Fishing profits, Time to register average)
Units: pesos/year
Average profits from fishing per year

(007) Average fraction of public resources for fishing = 0.1
Units: Dmnl
The average represents the importance to subsidize fishing by local government.

(008) Average transit time of water = 3
Units: year
This is the time that takes for water coming from rivers to reach the sea in its transit through the Wetlands

(009) Contaminant absorption = Average contaminants in water * Tamiahua Lake Water * Fractional absorption
Units: Liters*ppm/year

This rate represents the cleaning process that happens in the Wetlands
(010) Contaminants in rivers = 5000
Units: ppm
These are contaminants coming from rivers, regularly they are fertilizers that accumulate in the river because of agricultural activities
(011) Contaminants in sewers = 12000
Units: ppm
These are contaminants coming from sewers, regularly these contaminants are city residuals that accumulate in the river because of urban activities, both residential and industrial
(012) Cost per ship = 250000
Units: pesos/ship
The cost of a ship in pesos
(013) Cost per ship in harbor = 50
Units: pesos/(year*ship)
The cost of having a ship in harbor per year
(014) Crew per ship = 6
Units: People/ship
The number of people needed to man a ship
(015) Damage constant = 0.0015
Units: Species/(Fish Tons*m3) [0,1,0.001]
A constant representing the damage on the diversity in species because of fishing.
The diversity is important for the cleaning process that happens in the Wetlands
(016) Damage on ecosystem diversity = Diversity of Species / Normal Diversity of Species
Units: Dmnl
This is the current status of the Wetlands relative to the normal count of species.
(017) Damaging ecosystem = Fish Catch * Effect of Fishing on Diversity of Species
Units: Species/(year*m3)
This outflow represents erosion in the ecosystem as a result of fishing practices
(018) Desired fraction of total active fleet = DFTFC f ("Relative attractiveness of fishing vs. staying in Harbor")
Units: Dmnl
This fraction determines the number of ships fishing as a result of the profitability of fishing
(019) DFTFC f ([(-2,0)-(2,1)],(-2,1),(-1.6,0.98),(-1.2,0.9),(-0.8,0.8),(-0.4,0.66),(0,0.5),(0.4,0.34), (0.8,0.2),(1.2,0.1),(1.6,0.02),(2,0))
Units: Dmnl
This is the function of the fraction of ships fishing. The more profitable the fishing is, the more ships do it.
(020) Diversity of Species = INTEG(Rebuilding Diversity - Damaging ecosystem, Normal Diversity of Species)
Units: Species/m3
A level representing current bio-diversity in Tamiahua wetlands.
(021) ECCA f ([(0,0.5)-(2,1.5)],(0,1.2),(0.2,1.19737),(0.4,1.18421),(0.6,1.15789),(0.8,1.09649), (1,1),(1.2,0.864035),(1.4,0.710526),(1.6,0.600877),(1.8,0.530702),(2,0.5))
Units: Dmnl
This function describes the ability of the Wetlands to clean themselves under different concentrations of contaminants.
(022) ECFNG f ([(0,-1)-(2,1)],(0,1),(0.2,0.903509),(0.4,0.719298),(0.6,0.5),(0.8,0.27193), (1,0),(1.2,-0.192982),(1.4,-0.307018),(1.6,-0.385965),(1.8,-0.45614),(2,-0.5))
Units: Dmnl
This function describes the impacts of water contamination on the ability of the fish population to reproduce
(023) Economically active population = Economically active population fraction* Tamiahua population
Units: People

People in working age available to work outside home
(024) Economically active population fraction = 0.3
Units: Dmnl
Fraction of people in working age available to work outside home
(025) Economically active population in fishing cooperatives = INTEG(New cooperative members, Initial fraction of people in fishing cooperatives * Economically active population)
Units: People
People working in coop fisheries
(026) EDCFG f ([(0,-4)-(2,2)],(0,0.8),(0.2,1.07895),(0.4,1.26316),(0.6,1.21053),(0.8,0.921053),(1,0.394737),(1.19878,-0.0526316),(1.38226,-0.473684),(1.57187,-1.02632),(1.78593,-1.5),(2,-2.13158))
Units: Dmnl
This function represents the ability of the fish population to reproduce, given a certain fish density
(027) EDG f ([(0,-1)-(1,1)],(0,-0.5),(0.1,-0.464912),(0.2,-0.403509),(0.3,-0.289474),(0.4,-0.149123),(0.5,0),(0.6,0.22807),(0.7,0.491228),(0.8,0.754386),(0.9,0.903509),(1,1))
Units: Dmnl
This function describes the impacts of bio-diversity on the ability of the fish population to reproduce
(028) EEDCA f ([(0,0)-(1,1)],(0,0.5),(0.1,0.504386),(0.2,0.508772),(0.3,0.530702),(0.4,0.570175),(0.5,0.635965),(0.6,0.763158),(0.7,0.855263),(0.8,0.938596),(0.9,0.973684),(1,1))
Units: Dmnl
This function describes the impacts of bio-diversity on the ability of the Wetlands to clean themselves
(029) EFA f ([(0,-1)-(2,1.2)],(0,-0.5),(0.2,-0.150877),(0.4,0.157895),(0.6,0.466667),(0.8,0.727193),(1,1),(1.2,1.13246),(1.4,1.1807),(1.6,1.1807),(1.8,1.1807),(2,1.2))
Units: Dmnl
This function describes the impacts of fishing attractiveness on the number of people that wants to work on this industry
(030) EFDS f ([(0,0)-(1,1.2)],(0,0),(0.025,0.6),(0.05,0.8),(0.075,0.95),(0.1,0.99),(0.2,1),(0.3,1),(0.4,1),(0.5,1),(0.6,1),(0.7,1),(0.8,1),(0.9,1),(1,1))
Units: Dmnl
This function describes the effect of fishing practices on bio-diversity
(031) Effect from attractiveness = EFA f (Fishing attractiveness)
Units: Dmnl
The fishing attractiveness function
(032) Effect of contaminants on contaminant absorption = ECCA f (Average contaminants in water / Normal contaminants in water)
Units: Dmnl
The effect of contaminants on contaminant absorption
(033) Effect of contaminants on growth = ECFNG f (Average contaminants in water / Normal contaminants in water)
Units: Dmnl
The impact of contamination on the fish population ability to regenerate
(034) Effect of diversity on growth = EDG f (Damage on ecosystem diversity)
Units: Dmnl
The effect of bio-diversity on the fish population ability to reproduce
(035) Effect of Ecosystem Damage on contaminant absorption = EEDCA f (Damage on ecosystem diversity)
Units: Dmnl
The impact of bio-diversity on the ability of the Wetlands of cleaning themselves
(036) Effect of fish density on fishing effectiveness = SEDC f (Fish density)
Units: Dmnl

The impact of fish density on fishing
(037) Effect of fish density on growth = EDCFG f (Fish density)
Units: Dmnl
The impact of fish density on fish population net growth
(038) Effect of Fishing on Diversity of Species = Damage constant * EFDS f (Damage on ecosystem diversity)
Units: Species/(Fish Tons*m3)
The impact of fishing on the wetlands bio-diversity
(039) FINAL TIME = 100
Units: year
The final time for the simulation.
(040) Fish Catch = Active Fleet * Fishing effectiveness
Units: Fish Tons/year
This rate describes the yearly catch
(041) Fish density = Fish population / Tamiahua lake carrying capacity
Units: Dmnl
A ratio describing how much fish are in the Wetlands compared to the total capacity
(042) Fish net growth fraction = Effect of fish density on growth * Effect of contaminants on growth* Effect of diversity on growth * Normal growth fraction
Units: 1/year
This is the yearly growth fraction considering all factors that have an impact on it
(043) Fish population = INTEG(Fish population net growth - Fish Catch, 6e+006)
Units: Fish Tons
Fish population in the Tamiahua wetlands
(044) Fish population net growth = Fish population * Fish net growth fraction
Units: Fish Tons/year
The Fish population net growth rate
(045) Fish price = 15000
Units: pesos/Fish Tons
Price per fish ton
(046) Fishing attractiveness = Perceived profit per ship / Other activities profitability
Units: Dmnl
A ratio comparing fishing profitability to the profitability of other economic activities
(047) Fishing effectiveness = Normal Fishing Effectiveness * Effect of fish density on fishing effectiveness
Units: Fish Tons/(year*ship)
The effectiveness of every ship in catching fish, as a function of fish density
(048) Fishing income = Fish Catch * Fish price
Units: pesos/year
Total income from fishing
(049) Fishing profits = Fishing income - Total operational cost
Units: pesos/year
Net profit from fishing
(050) Fishing saturation = FS f (Fraction of economically active population in fishing cooperatives)
Units: Dmnl
The current limits of job supply in the fishing industry
(051) Fleet depreciation = Total fleet / Ship average life time
Units: ship/year
Fleet depreciates linearly on a given average life time
(052) Fleet on harbor = Total fleet * Fraction of fleet on harbor
Units: ship
Number of ships that are left on the harbor instead of going fishing
(053) Fraction of active fleet = INTEG(Net change in the fraction of active fleet, 0.05)
Units: Dmnl

The fraction of ships that are actually fishing
(054) Fraction of economically active population in fishing cooperatives = Economically active population in fishing cooperatives / Economically active population
Units: Dmnl
The fraction of people working in fishing cooperatives
(055) Fraction of economically active population in other activities = 1 - Fraction of economically active population in fishing cooperatives
Units: Dmnl
The fraction of people working in other industries different from fishing
(056) Fraction of fleet on harbor = 1 - Fraction of active fleet
Units: Dmnl
This is the fraction of the fleet that cooperatives decide to keep on the harbor
(057) Fraction of people joining fishing cooperatives = Effect from attractiveness * Fishing saturation * Normal fraction of people joining fishing cooperatives
Units: 1/year
The fraction of people joining the fishing industry because of the attractiveness of the industry, as well as the demand for crew members
(058) Fraction of resources to fishing = Average fraction of public resources for fishing * Pressure to assign resources to fishing
Units: Dmnl
The actual amount of public money to invest in fishing cooperatives
(059) Fractional absorption = Effect of contaminants on contaminant absorption * Effect of Ecosystem Damage on contaminant absorption * Normal fractional absorption
Units: 1/year
The fraction of contaminants that the Wetlands can manage per year
(060) FS f ([(0,0)-(1,1.3)],(0,1.2),(0.1,1.2),(0.2,1.2),(0.3,1.19167),(0.4,1.15746),(0.5,1.11184),(0.6,1.04912),(0.7,0.992105),(0.8,0.87807),(0.9,0.615789),(1,0))
Units: Dmnl
The function of job supply saturation in the fishing industry
(061) Incoming contaminants = Contaminants in rivers * Water from Rivers + Contaminants in sewers * Water from sewers
Units: Liters*ppm/year
Total contaminants incoming into the Wetlands
(062) Initial fraction of people in fishing cooperatives = 0.07
Units: Dmnl
Model assumption about the initial value of the fraction of people working in the fishing industry
(063) Initial Population = 200000
Units: People
Model assumption about initial values of the population in the region
(064) INITIAL TIME = 0
Units: year
The initial time for the simulation.
(065) Net change in the fraction of active fleet = (Desired fraction of total active fleet - Fraction of active fleet) / Time to adjust fleet
Units: 1/year
The rate adjusting the fraction of fleet fishing per year
(066) New boats = Public resources for the Tamiahua fishing / Cost per ship
Units: ship/year
Ship construction rate, assuming that all ship construction is subsidized by government
(067) New cooperative members = Fraction of people joining fishing cooperatives * Economically active population in fishing cooperatives
Units: People/year
The rate of new workers joining the fishing industry

(068) Normal contaminants in water = 10000
Units: ppm
Reference value for contaminants in the Wetlands
(069) Normal Diversity of Species = 300
Units: Species/m3
Reference value for diversity in the Wetlands
(070) Normal Fishing Effectiveness = 20
Units: Fish Tons/(year*ship)
Average fishing capacity per boat
(071) Normal fraction of people joining fishing cooperatives = 0.01
Units: 1/year
Average growth of workforce in the fishing industry
(072) Normal fractional absorption = 0.1
Units: 1/year
Average absorption of contaminants
(073) Normal growth fraction = 0.2
Units: 1/year
Average fertility of the fish population per year
(074) Other activities profitability = 20000
Units: pesos/(year*ship)
Average profit in other industries competing with the fishing industry
(075) Outgoing contaminants = Water to the sea * Average contaminants in water
Units: Liters*ppm/year
Contaminants that leave the Wetlands into the sea
(076) PARF f ([(0,0)-(2,2)],(0,0),(0.2,0.105263),(0.4,0.298246),(0.6,0.517544),(0.8,0.77193),(1,1),(1.2,1.2193),(1.4,1.37719),(1.6,1.4386),(1.8,1.45614),(2,1.5))
Units: Dmnl
The function describing the effect of the adequacy of the fleet size into the pressure to build more ships by government
(077) Perceived profit per active ship = Average fishing profits / Average active fleet
Units: pesos/(year*ship)
The perception of profit of ships fishing that will have an impact on the fraction of active boats
(078) Perceived profit per ship = SMOOTH (Profit per ship, Time to perceive)
Units: pesos/(year*ship)
Perception of ship profitability. Which will have an impact on working in the fishing industry
(079) Population net growth = Population net growth fraction * Tamiahua population
Units: People/year
Net rate of population growth
(080) Population net growth fraction = 0.015
Units: 1/year
Average population growth
(081) Pressure to assign resources to fishing = PARF f (Adequacy of fleet size)
Units: Dmnl
A function of the adequacy of job supply in the fishing industry
(082) Profit per ship = Fishing profits / Total fleet
Units: pesos/(year*ship)
(083) Profit per ship in the Harbor = 0 - Cost per ship in harbor
Units: pesos/(year*ship)
A reference value to decide on sending ships to fish
(084) Public resources for Tamiahua fishing = Fraction of resources to fishing * Total public resources for Tamiahua economic development
Units: pesos/year
Amount of public money used to increase the fleet

(085) Rebuilding Diversity = (Normal Diversity of Species - Diversity of Species) / Time to rebuild Diversity
Units: Species/(year*m3)
Regeneration of the Wetlands ecosystem

(086) "Relative attractiveness of fishing vs. staying in Harbor" = Perceived profit per active ship / Profit per ship in the Harbor
Units: Dmnl
A ration comparing active boats profit to costs of staying idle

(087) SAVEPER = TIME STEP
Units: year
The frequency with which output is stored.

(088) SEDC f ([(0,0)-(2,1.5)],(0,0),(0.149847,0.447368),(0.388379,0.754386),(0.599388,0.912281),(0.798165,0.960526),(1,1),(1.19878,1.03947),(1.41896,1.08553),(1.59633,1.16447),(1.8,1.2),(2,1.2))
Units: Dmnl
The relationship between fish density and ship effectiveness

(089) Ship average life time = 15
Units: year
Working life of a boat

(090) Tamiahua lake carrying capacity = 1e+007
Units: Fish Tons
Estimated max fish population

(091) Tamiahua Lake Water = INTEG (Water from Rivers + Water from sewers - Water to the sea, 2.4e+007)
Units: Liters
Total water in the wetlands

(092) Tamiahua population = INTEG(Population net growth, Initial Population)
Units: People
Total population

(093) TIME STEP = 0.0625
Units: year
The time step for the simulation.

(094) Time to adjust fleet = 3
Units: year
Average time to make changes on the fraction of active fleet

(095) Time to perceive = 2
Units: year
Average time to perceive fishing industry profitability

(096) Time to rebuild Diversity = WITH LOOKUP(Damage on ecosystem diversity, ([(0,0)-(1,50)],(0,50),(0.1,34.6491),(0.2,25.4386),(0.3,18.6404),(0.4,14.693),(0.5,10.7456),(0.6,7.45614),(0.7,4.82456),(0.8,3.28947),(0.9,2.19298),(1,1)))
Units: year
A function describing the effect of ecosystem damage on the ability of the wetlands to regenerate

(097) Time to register average = 1
Units: year
Average reporting time in the fishing industry

(098) Total fleet = INTEG(New boats - Fleet depreciation, 10)
Units: ship

(099) Total operational cost = Annual Operational cost * Active Fleet
Units: pesos/year
Total cost of active fleet

(100) Total public resources for Tamiahua economic development = 7.5e+007
Units: pesos/year

Public resources available

(101) Water Contaminants = INTEG(Incoming contaminants - Contaminant absorption - Outgoing contaminants, 1e+009)
Units: Liters*ppm
Total contaminants on the wetlands

(102) Water from Rivers = 4e+006
Units: Liters/year
Water incoming from rivers

(103) Water from sewers = 4e+006
Units: Liters/year
Water incoming from sewers

(104) Water to the sea = Tamiahua Lake Water / Average transit time of water
Units: Liters/year
Water flowing to the sea

Sensitivity Analysis and Optimization for Selected Supply Chain Management Issues in the Company – Using System Dynamics and Vensim

Elżbieta Kasperska*, Elwira Mateja-Losa**, Rafał Marjasz***

Abstract

The aim of our paper is to present the new results of research work on optimization and simulation for some logistic problems in the company. The System Dynamics (SD) method and the Vensim simulation language are applied in order to solve specific managerial problems described by Forrester in the model of supply chain. The historical model of Customer-Producer-Employment System by Forrester (Forrester, 1961) has not been examined with the sensitivity analysis, from the "automatic" testing perspective. Optimization experiments have not been conducted, either. It is surprising, since the model is old and widely known. The opportunities offered by the Vensim language allow us to perform such analysis. The visualization called "confidence bounds" is used, to show the behaviour of chosen variables over a period of time. The Monte-Carlo method is applied for sampling a set of numbers from within bounded domains (distribution for each searching parameters is specified). The authors of this paper conducted numerous experiments in this scope. This paper presents their results and offers some conclusions formulated at the end.
Keywords: *System Dynamics, sensitivity analysis, optimization, Vensim.*

Introduction and literature review

The problem of sensitivity analysis and optimization performed on complex, nonlinear, dynamical and multilevels systems is very interesting from the methodological point of view, especially in the area of System Dynamics (SD). System Dynamics (Coyle, 1977, 1994, 1996, 1998, 1999; Forrester, 1961, 1969, 1971, 1972, 1975; Kasperska, 1995, 2002, 2003, 2005; Radosiński, 2001; Sterman, 2002; Wąsik, 1997, 1983) was developed in the late 1950's and early 1960's at the Massachusetts Institute of Technology's Sloan School

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of Management by Jay W. Forrester. The 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 behaviour of the system over time. System Dynamics tries to pose “dynamic” hypotheses that endogenously describe the observed behaviour of system.

In the area of System Dynamics method, there have not been much theory or practice related to combining simulation and optimization. Although the first trials were sufficiently long ago (Keloharju, 1977, 1980, 1983; Winch, 1976), the fact is that incorporation or embedding simulation to optimization (and vice versa) has not been as popular as it should be in our view. Probably one of the main reasons was the lack of effective tools. Popular software packages originally used in SD modelling and simulation, did not offer possibilities of automatic optimization (for example: languages DYNAMO, DYSMAP (Kasperska and Mateja-Losa, Słota, 2006). Only such packages as COSMIC and COSMOS and Vensim (Ventana, 2007) make it possible to connect simulation and optimization. Hence some papers published in the field of SD (e.g. Coyle, 1996, 1998), though the work on this subject is still scarce. The authors of this paper have some experience with the so-called embedding simulation in optimization and vice versa, having conducted numerous experiments on DYNBALANCE family of models (Kasperska, 2005, 2009; Kasperska and Mateja-Losa, 2005, 2006; Kasperska, Mateja-Losa and Słota, 2000, 2001, 2003, 2006; Kasperska and Słota 2003, 2005, 2006).

The SD models usually contain several parameters. It is interesting to examine the effect of 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 the 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 specified parameter is sampled, and the resulting values are used in a simulation. When the number of simulations is set, for example, at 200, this process will be repeated 200 times.

In order to perform sensitivity simulation, the user needs to define what kind of probability distribution values for each parameter will be drawn. 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 the value near the mean is more likely to occur than the values far away from the mean. The 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 values which combine to form individual simulation traces.

Research method

The object of the experiments is the model named "Customer – Production – Employment", described in the literature by Forrester (1961) and Łukaszewicz (1975). The authors of this article used the description of the model, abbreviations for parameters and variables after Łukaszewicz. Our intention is not to present the model, which is well-known, but to draw the reader's attention to the sensitivity and optimization experiments. In our paper we suggest the process of "automatic" sensitivity analysis and optimization by Vensim.

Analysis and study

Presentation of the object of the experiments and the assumptions of the simulation

Figure 1 presents the structure of the model "Customer – Production – Employment" in Vensim convention.

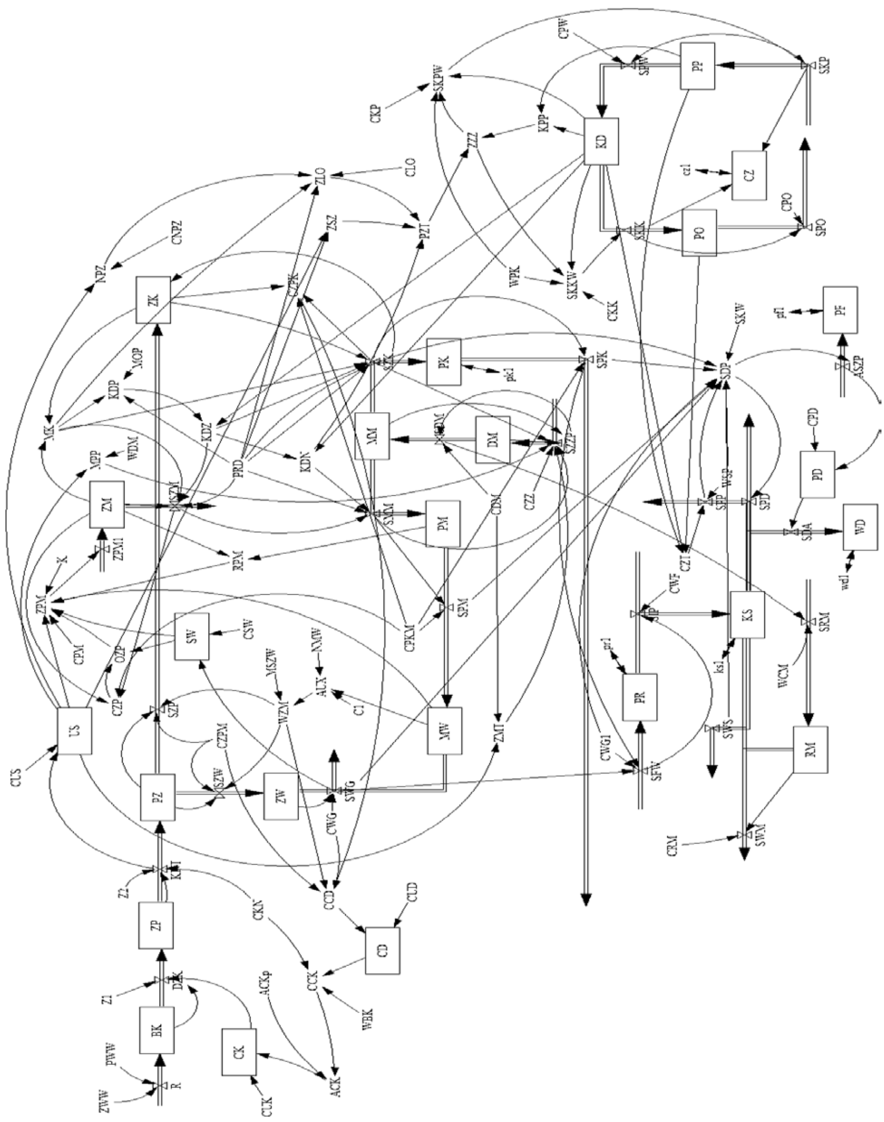

Figure 1. Model "customer-production-employment system"

Source: Authors' research, on the basis of Łukaszewicz (1975).

Table 1 presents the assumptions of the simulation of the above model.

Table 1. Assumptions of the simulation

Name of levels	Initial value of level	Name of parameters	Initial value of parameter
	Order Filling, Inventory Reordering		
PZ	1000	K	4
ZW	700	CUS	15
MW	4000	CSW	2
US	1000	CWG	1
SW	700	CZPM	1
		CPM	6
	Manufacturing		
ZM	2800	PRD	2.66
ZK	1200	CPKM	6
PM	4200	MOP	1
PK	1800		
	Material Ordering		
MM	6000	WDM	6
DM	3000	CDM	3
	Labor		
KD	375	CPO	4
PP	0	CKK	10
PO	0	CPW	3
CZ	0	WPK	0
CNPZ	4	CLO	20
	Customer Ordering		
BK	30000	CKN	3
ZP	3000	CUD	4
CK	30	CZPM	1
CD	4.7	CPKM	6
		CWG	1
	Cash, Profit and Dividends		
KS	10000	WSP	80
PR	50000	CWG1	100
RM	6000	WCM	20
PD	20000	CRM	3
PF	0	SKW	50

Source: based on Forrester (1961) and Łukaszewicz (1975).

Results of the experiments on sensitivity analysis and optimization for some logistics problems in the company

There are numerous logistics problems in the "Customer – Production – Employment" model. We would like to draw the reader's attention to some of them.

Problem number 1 – Too long time of delivery from Producer to Customer. To conduct this experiment we selected the parameters: "CUD" (Time to Adjust Quoted Delivery at Factory), "CZPM" (Delay in Clerical Processing at Factory), "CWG" (Delay in Shipping at Factory), and observed the confidence bounds for variable "CD" (Delay in Quoted Delivery at Factory). The results are presented in Figure 2.

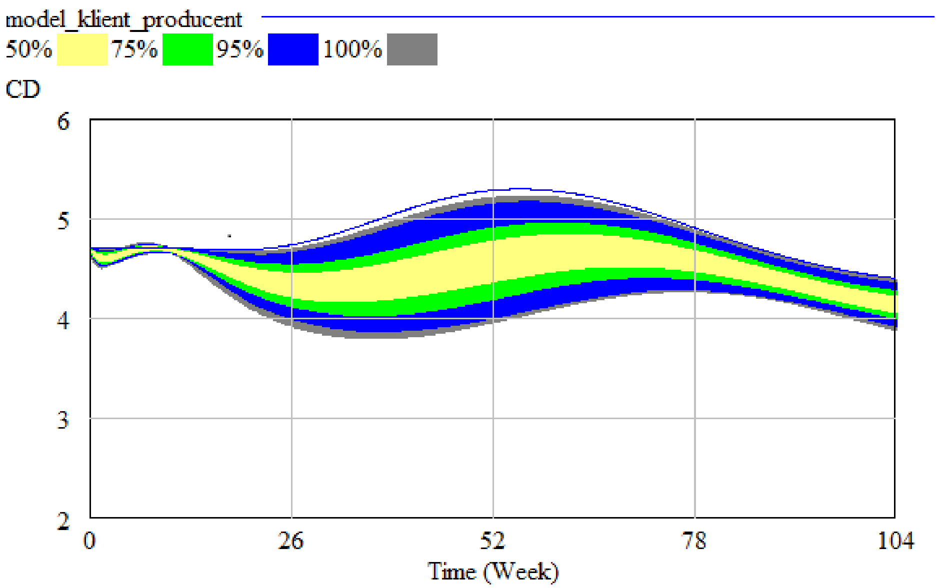

Figure 2. Confidence bounds for variable "CD" for variation of parameters: "CUD" ϵ (3,5), "CZPM" ϵ (0.5,1), "CWG" ϵ (0.5,1)

Our aim was to shorten the "CD" time". So we planned the optimization experiment consisting in minimization and used the optimization setup by Vensim, which is shown on windows on Figures 3 and 4.

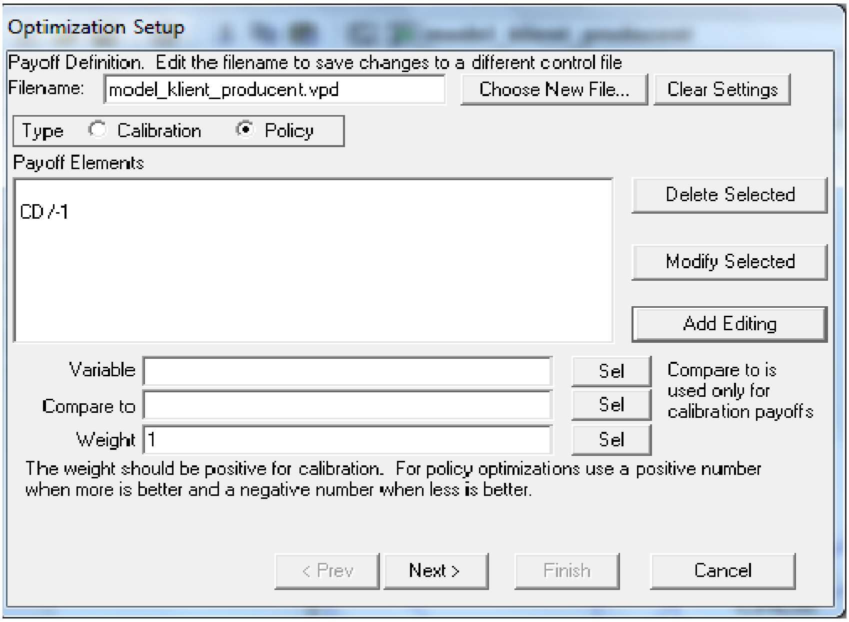

Figure 3. Optimization setup by Vensim

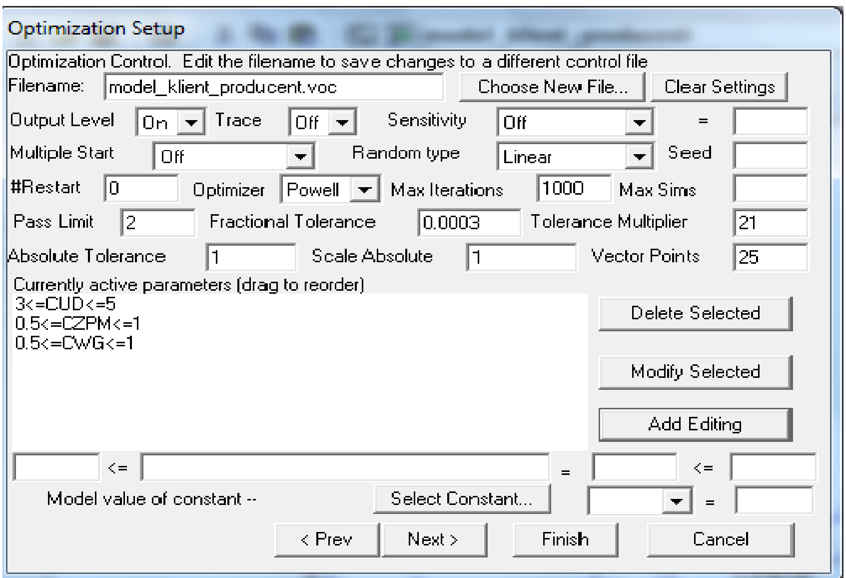

Figure 4. Optimization setup by Vensim

The results of the experiment are presented in Table 2.

The second problem is: Too large fluctuations of labour level in the company.

To conduct this experiment we selected the parameter "CLO" (Time for Backlog Adjustment at Factory), and observed the confidence bounds for variables: "KD" (Production Workers at Factory), "CZ" (Total Labour Change at Factory). The results are shown in Figures 5 and 6.

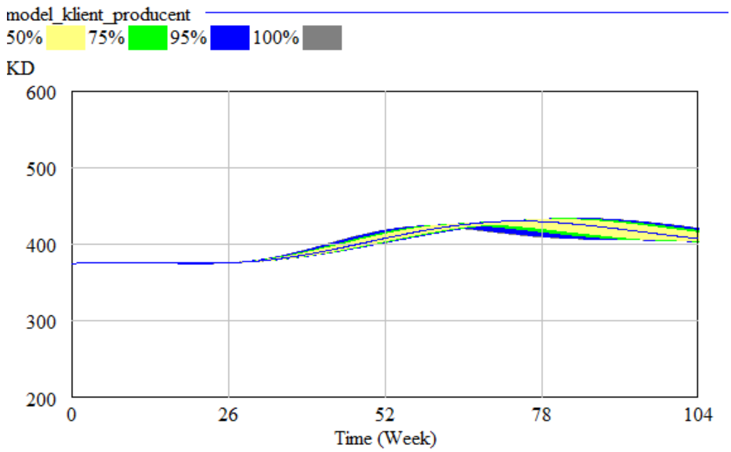

Figure 5. Confidence bounds for variable "KD", for variation of parameter "CLO" ϵ (10,30)

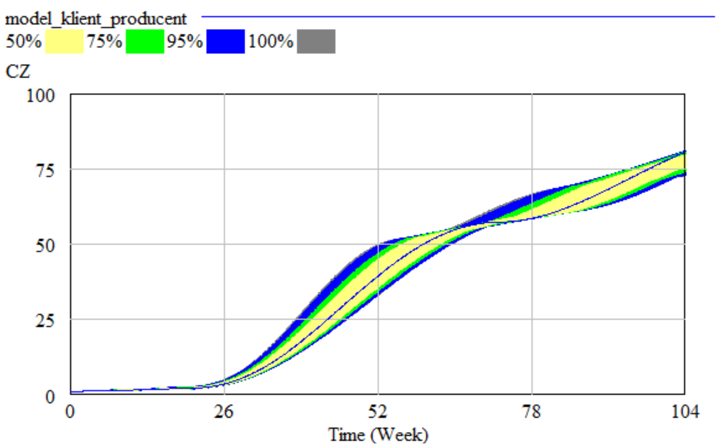

Figure 6. Confidence bounds for variable "CZ", for variation of parameter "CLO" ϵ (10,30)

Our aim was to shorten the "CZ". As above we planned the optimization experiment, consisting in minimizing the value of that variable. The results of the experiment are presented in Table 2.

The third problem is: Too large fluctuation of "KS" level (Cash Balance at Factory).

To conduct this experiment we selected the parameter "CWG1" (Finished-Goods Price at Factory), "SKW" (Standard Inventory Cost per Item at Factory), "WSP" (Wage Rate at Factory), "PRD" (Productivity of Labour at Factory). The observed confidence bounds for net profit are demonstrated in Figure 7.

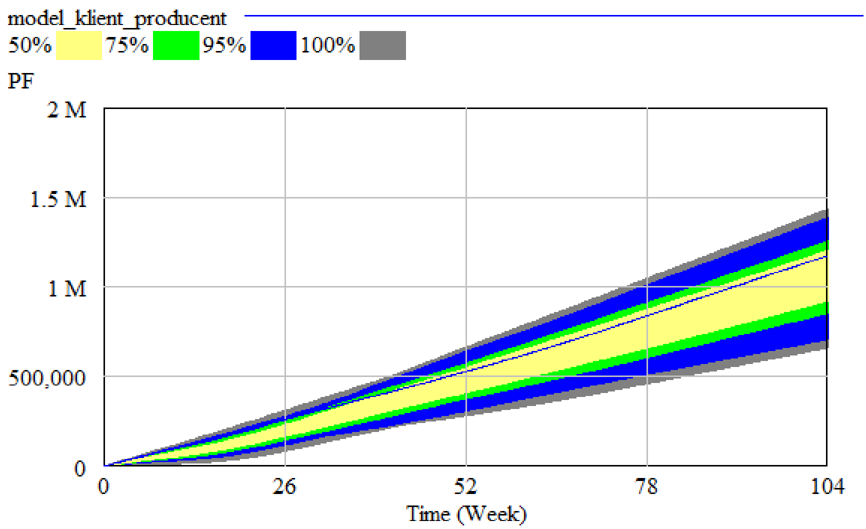

Figure 7. Confidence bounds for variable "PF", for variation of parameters: "CWG1"ϵ (90,100), "SKW" ϵ(45,50), "WSP" ϵ(70,80), "PRD" ϵ(2,2.66)

Our aim was to maximize "PF" (Net Profit Rate at Factory). We conducted the optimization by Vensim (see: windows in figures 8 and 9). The results are presented in Table 2.

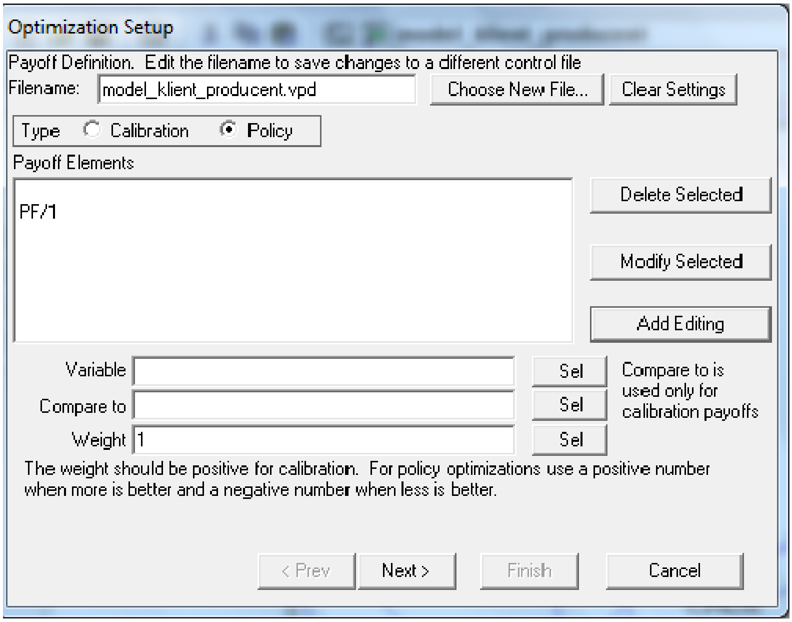

Figure 8. Optimization setup by Vensim

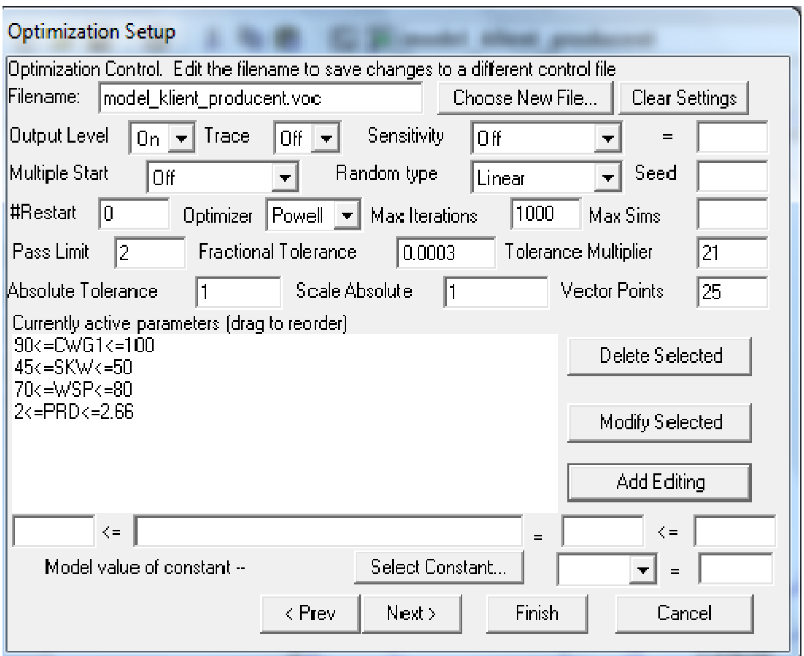

Figure 9. Optimization setup by Vensim

Table 2. Results of optimization experiments for logistic problem

Problem (no.)	Type of optimization (MIN, MAX)	Scope of parameters	Optimized values of parameters	Objective function Initial value Final value
1.	MIN	CUD ϵ (3,5)	CUD=3	CD=4.89912 CD=4.2645
		CZPM ϵ (0.5,1)	CZPM=0.545774	
		CWG ϵ (0.5,1)	CWG=0.595165	
2.	MIN	CLO ϵ(10,30)	CLO=30	CZ=3845.9 CZ=3285.4
3.	MAX	CWG1 ϵ (90,100)	CWG1=100	PF=1.286e+006 PF=1.417e+006
		SKW ϵ (45,50)	SKW=45	
		WSP ϵ (70,80)	WSP=80	
		PRD ϵ (2,2.66)	PRD=2	

The possibilities of such experimentations are practically unlimited, however, the scope of our paper does not allow to extend the analysis.

Discussion of results

The comparison of the initial and final values of objective functions in Table 2 allows us to ascertain that the choice of parameters and their scope was quite good, since the value of objective function has improved in all considered cases. The interesting fact is that the choice had "local" meaning (in the sense that parameters were from the sectors that were similar to objective functions).

Łukaszewicz (1975) ascertains that in large scale models there are few sensitive parameters and a lot of insensitive parameters. It is vital to detect those sensitive parameters and thus improve the behavior of the system. Naturally the 'trial-and-error' process is time and labor-consuming. This sensitive analysis by Vensim allows us to estimate the sensitiveness of selected variable for the choice of given parameters in an easier way and prepare the basis for optimization process.

It should be stressed that the obtained results are in line with specific assumption about the characteristics of the model entrance. Łukaszewicz in his paper (Łukaszewicz, 1975) recommended that the analysis of the model behavior should be under a wide spectrum of entrances, not only the classic "step" functions (like in our case) but the sinusoidal or linear ones (for example: trapezium). In books of Forrester (1961) and Łukaszewicz (1975) there are many examples of the analysis using the "trial and error" method. As a result of such analysis, the model behavior has been improved. In our paper we suggest the process of "automatic" sensitivity analysis and optimization by

Vensim. Obviously, this simulation language was not known by Forrester or Łukaszewicz, and their results of simulation were time and labor-consuming, and impressive in their times.

Conclusion

Firstly, we would like to draw a number of theoretical conclusions:

- as Jackson (2006) said: "creative holism is necessary in the modern world. Managers are facing ever increasing complexity, change and diversity, and the solutions they have at their disposal to cope with these issue are inadequate". Thus we can say that the possibilities presented by SD are adequate for solving logistics problems in the firm.
- simulation – optimization experiments, on System Dynamics models allows to find sensitivity parameters and consequently conduct the search for optimal solution for multi-criteria problems (objective functions are modelled like inner elements of the model, with feedback in its structure),
- searching for optimal solutions can take into consideration different preferences of decision makers (different form of objective function, with possibilities of weighting parameters for their factors).
- Secondly, we would like to offer some practical conclusions:
- logistics problems in the firm can be investigated using sensitivity analysis and optimization by Vensim,
- the Vensim language should become popular in the environment of System Dynamics modellers, because it is an effective tool for such experiments as: simulation – optimization: its sensitivity and optimization setups allow almost automatic search for confidence bounds or optimal value of objective functions,
- doing simulation with complex, large scale models, requires seeking many versions of structures, many parameters (especially sensitive parameters), including random elements. All of this is offered by Vensim. Moreover, a new version of this language (see: Vensim 2013) allows its users to create interactive games. This constitutes a new direction of future investigations for the authors.

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Abstrakt (in Polish)

Celem artykułu jest prezentacja wyników badań symulacyjnych i optymalizacyjnych przeprowadzonych przez autorów, a dotyczących wybranych problemów logistycznych występujących w firmach. Autorzy artykułu zastosowali metodę Dynamiki Systemowej (SD) i język symulacyjny Vensim w celu rozwiązania określonych problemów opisanych w modelu Klient – Producent – Zatrudnienie autorstwa J. Forrestera. Historyczny już model Klient – Producent – Zatrudnienie Forrestera nigdy nie był badany w zakresie analizy wrażliwości – w sensie "automatycznej" analizy. Nie poddawano go również eksperymentom optymalizacyjnym. Jest to zaskakujące, gdyż model ten jest stary i powszechnie znany. Możliwości języka symulacyjnego Vensim pozwalają na przeprowadzenie takiej analizy. Autorzy wykorzystali wizualizację zwaną „confidence bounds" dla ukazania zachowania niektórych zmiennych występujących w modelu, w funkcji czasu. Język symulacyjny Vensim wykorzystuje metodę Monte-Carlo w próbkowaniu wybranych zmiennych występujących w modelu przy zadanym z góry zakresie zmienności (przy czym losowanie dokonywane jest zgodnie z rozkładem, który musi być znany). Autorzy pracy wykonali wiele eksperymentów w tym zakresie. Wyniki ich pracy są zaprezentowane w artykule. Na końcu sformułowano wnioski z przeprowadzonych badań.

Słowa kluczowe: *Dynamika Systemowa, analiza wrażliwości, optymalizacja, Vensim.*

Validation of System Dynamics Models – a Case Study

Justyna Lemke*, Małgorzata Łatuszyńska**

Abstract

The purpose of this article is the analysis of the system dynamics model validation illustrated by the example of a model of the manufacturing resource allocation. In the first part of the article the authors present an overview of the definitions of validation and verification that can be found in the reference literature. Also, they emphasize the role which validation and verification play in the modeling process. Furthermore, they discuss the techniques of system dynamics model validation with particular focus on tests of the model structure, behavior and policy implications. The second part of the article contains an example of the validation process of a system dynamics model simulating manufacturing resource allocation in an electronic company. The purpose of the model is to assess the long-term effect of assigning workers to individual tasks on such production process parameters as efficiency or effective work time. The authors focus their particular attention on that part of the model which deals with a storehouse, one of the company production units. They conduct tests of its structure and behavior. When validating the structure the authors make use of the information obtained in a series of interviews with the company staff. They also refer to the generally accepted knowledge found in the reference literature. The results generated by the model in the course of the behavior tests are compared with the real data. The authors evaluate both the logic of the system behavior and the level of accuracy of the output data in reference to the real system.

Keywords: *validation of simulation models, system dynamics*

Introduction

Nowadays simulation is commonly used in many areas of business management. It is applied to forecasting as well as to understanding mechanisms within companies. Simulation models can be particularly helpful for minimizing wrong decision-making. It must be noted, however, that the model that is to satisfy the user's requirements has to meet quality standards regarding both the software and the accuracy of its representation of reality. This is why among many stages of creating a simulation we can find its verification and validation (Maciąg, Pietroń & Kukla, 2013, p. 161). It is an

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essential, but controversial (Barlas, 1996, p. 183) and still unsolved (Martis, 2006, p. 39) aspect of modeling methodology. The quality of a study conducted by means of a simulation model largely depends on its validation.

The purpose of this article is the analysis of the system dynamics model validation illustrated by the example of a model of the manufacturing resource allocation.

Literature review

One of the difficulties hindering the process of verification and validation lies in the understanding of both terms. Some authors claim that there is no need to differentiate between the two – for instance Pidd sees verification and validation as synonymous (Pidd, 1998, p. 33). But, as shown in Table 1, most authors recognize verification as different from validation.

Table 1. Verification and validation by selected authors

Verification	*Validation*	*Source*
Testing if the symbolic (formal) model has been properly transformed into its operational form (e.g. a computer program).	Proving that in the experimental environment the accuracy of the operational model (usually a computer one) is satisfying and in keeping with its intended use.	(Maciąg, Pietroń & Kukla, 2013, p. 162)
Testing if the computer program of the computerized model and its implementations are correct.	Proving that within its application domain the computerized model has a satisfying level of accuracy which is in keeping with its intended use.	(Sargent, p. 166)
Testing a seemingly correct model by its authors in order to find and fix modeling errors.	An overview and assessment of the model operation performed by its authors and by experts in the field in order to find out if the model with a satisfying level of accuracy represents the real system.	(Carson, 2002, p. 52)
The process of ascertaining if the implementation of the model (the computer program) represents precisely the concept authors' description and specification.	The process of deciding on the assessment method as well as the very assessment of the level to which the model (its data) represents the real world from the perspective of its intended use.	(Davis, 1992, pp 4-6)

Verification is regarded as a necessary, yet insufficient stage of model assessment, while validation is considered – in its narrower sense – to be one of the assessment stages, or – in a broader approach – the very assessment itself (Balcerak, 2003, pp 27-28).

Despite the differences, the above quoted definitions have something in common. Verification is typically conducted by the author of a model and refers to a computer program. In other words, it is the process of checking if the program is free from formal, 'technical' faults, while validation is a more complex issue – it results in determination if and how well the model represents the reality.

Consequently, if a computer program is to be working properly and a model should represent the reality, a question must be asked when it should be tested in the course of modeling. The time to perform the tests is another question to be answered by a modeler. Various authors suggest, following Sargent's paradigm (Sargent, Verification and Validation of Simulation Models, 2010), that verification and validation should be run parallel during the modeling process and that validation should refer to data as well as to two models: the computer model and the conceptual one (see Figure 1).

The purpose of the conceptual model validation is to answer the question whether the model includes the appropriate number of details to meet the simulation objective, while the purpose of the data validation is to find out if the data used in the model is accurate enough. In case of a computer model, its validation, called the operational validation, answers the question whether the model adequately represents the real system. Robinson (Robinson, 1997, p. 54) recommends testing individual parts of the model (*White-box Validation*) and the model as a whole (*Black-box Validation*).

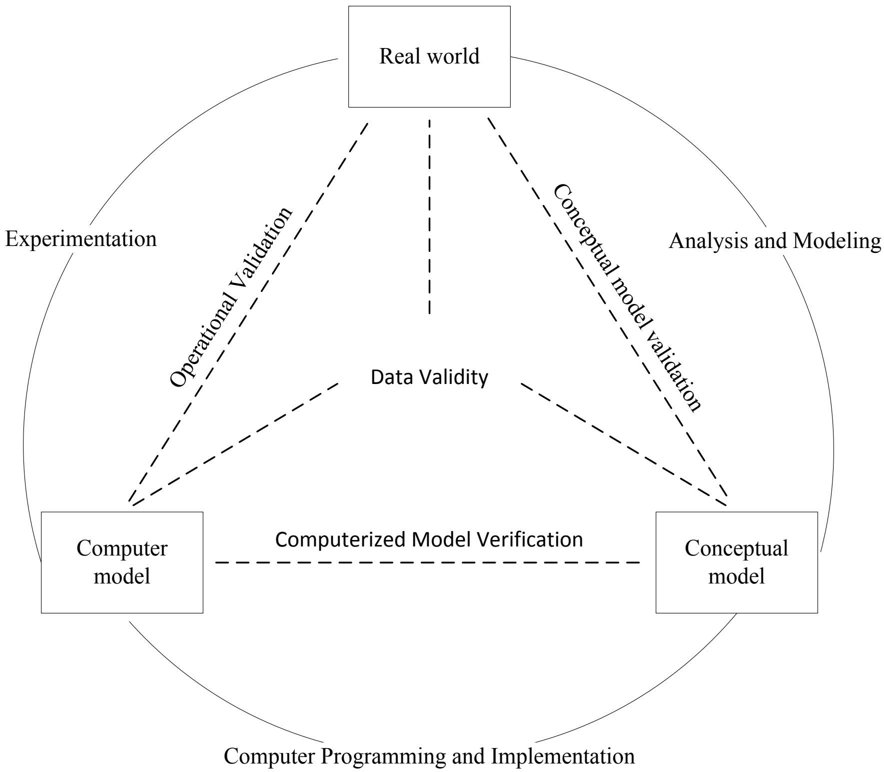

Figure 1. Verification and validation of a simulation model in the process of modeling

Source: own study on the basis of (Sargent, 2010, pp 169).

Another problem to be faced by those who are assessing the model is the reality representation. The question is what this means. According to Khazanch (Martis, 2006, p. 43), a conceptual model can be considered validated, hence adequately representing the real world, if it is:

- plausible,
- feasible,
- effective,
- pragmatic,
- empirical,
- predictive,
- inter-subjectively certifiable
- inter-methodologically certifiable.

It is essential to choose the validation methods that are adequate for the model purpose. Depending on the reference point for the data generated by the system or on the modeling objective, various authors recommend testing the descriptive, predictive or structural validity (see: (Balcerak, 2003, p. 37); (Davis, 1992, pp 7-8)). It is worth noting that it is not necessary to test all the three conditions. Therefore, if, for instance, the purpose of the model is to find out why productivity in a company has been falling, there is no need to check if the data supplied by the model is going to correspond to the values that the company will generate in the future.

Model testers have at their disposal various techniques that help answer the above questions. Balci (Balci, 1986, p. 6) divided these techniques into two basic groups: the statistical and the subjective ones. The former include the variance analysis and the linear regression, while the latter comprise the comparison with other models, degeneration tests, event validation, historical data validation or the Schellenberg criteria. The lists and descriptions of these methods can be found in: (Martis, 2006; Balci, 1986; Jaszkiewicz, 1997, pp 193-199; Davis, 1992, pp 18-25). Further in the article its authors present those techniques that are recommended in the literature as useful for the validation of system dynamics models.

Research methods

As mentioned above, the choice of methods depends primarily on the purpose of the model. Therefore, when recommending tests for models built in the System Dynamics (SD) convention, we should first of all define their characteristics.

System Dynamics is a method of continuous simulation developed by J. W. Forrester and his associates at Massachusetts Institute of Technology during the late 1950s and early 1960s. Information about its assumptions and application can be found in numerous publications, such as (Campuzano and Mula, 2011, pp 37-48; Łatuszyńska, 2008, pp 32-77; Maciąg, Pietroń and Kukla, 2013, pp 182-212; Ranganath, 2008; Tarajkowski, 2008, pp 33-163). As far as the choice of validation methods is concerned the most important thing, apart from the continuity of the modeled systems, is that the modeler's principal aim is the examination of their dynamic properties. At the same time, it should be noted that the above mentioned dynamics results from the system structure and from periodic regulatory procedures (Maciąg, Pietroń i Kukla, 2013, p. 184).

In view of the above mentioned properties of the system dynamics models, Sterman (Sterman, 1984, p. 52; Sterman, 2000, pp 858-889) suggests validating a model in the context of its structure, behavior and the implications of the user's policy. Tests recommended for each of the groups and the related problems are presented in Table 2.

Table 2: Validation tests of system dynamics models

Test	*Problem*
	Tests of Model Structure
Structure Verification	Is the model structure consistent with the present state-of-the- art?
Parameter Verification	Are the parameters consistent with the present state-of-the-art?
Extreme Conditions	Does every equation make sense even if the inputs reach extreme values?
Boundary Structure Adequacy	Does the model contain the most important issues addressing a given problem?
Dimensional Consistency	Is every equation dimensionally consistent without the necessity to use parameters that are non-existent in the real world?
	Test of Model Behavior
Behaviour Reproduction	Does the model endogenously generate the symptoms of the problem, the behavior of modes, phases, frequencies and other characteristics of the real system behavior?
Behaviour Anomaly	Do the anomalies occur when the model assumptions have been removed?
Family Member	Does the model represent the behavior of various instances of the same class objects when their input parameters have been entered?
Surprise Behaviour	Is the model able to identify 'new' behavior that has not been known in the real system?
Extreme Policy	Does the model behave properly when extreme input values have been entered or when an extreme policy has been implemented?
Boundary Behaviour Adequacy	Is the model behavior sensitive to the addition or the change of the structure which represents reliable alternative theories?
Behaviour Sensitivity	Is the model sensitive to reliable changes of parameters?
Statisitical Character	Do the model outputs have the same statistical characteristics as the real system outputs?
	Tests of Policy Implications
System Improvement	Has the real system been improved as a result of the application of the simulation model?
Behaviour Prediction	Does the model describe correctly the results of the new policy?
Boundary Policy Adequacy	Are the policy recommendations sensitive to the addition or the change of structure which represents possible alternative theories?
Policy Sensitivity	Are the policy recommendations sensitive to reliable changes of parameters?

Source: own study on the basis of Sterman, Appropriate Summary Statistics for Evaluating the Historical Fir of System Dynamics Models, 1984, p. 52.

It should be underlined that the choice of a test does not determine the technique by means of which it must be performed. Plenty of suggestions can be found in the works by Barlas (Barlas, 1996) or Sterman (Sterman, 2000). The authors of this article present some of these techniques on the example of the manufacturing resource allocation.

Analysis and study

The model, whose validation is to be found below, was built for an electronic company that deals mainly with manufacturing low-voltage condensers. The model purpose was to assess the long-term effect of the workforce allocation to individual production cells on production process parameters as the volume of the work-in-progress products and the productivity. On the basis of the data provided by the company the authors identified 19 production cells. Due to their sporadic workload some of the cells were not taken into account. The cells were grouped according to their tasks. As a result, a network of 9 overlapping cells was obtained (Table 3).

Table 3. A network of production cells in the company

From \ To	G_BL	G_IMP	G_MON	G_PIER	G_WTOR	G_KJ	G_MG	G_NP	G_ZAL
G_BL	X	X	X	X		X		X	
G_IMP		X	X			X	X	X	
G_MON	X	X	X	X	X	X	X	X	
G_PIER	X		X	X	X				
G_WTOR	X		X	X	X				
G_KJ		X	X			X	X	X	X
G_MG	X		X	X	X		X	X	X
G_NP			X			X	X	X	X
G_ZAL			X			X	X	X	

Having surveyed the staff, the researchers realized that the company did not have a consistent methodology of task distribution. Each foreman was in charge of a group of workers and allocated tasks on their own authority. The absence of clearly defined mechanisms of controlling the transfer of semi-fabricated products from one work station to another turned out to be the key challenge in the process of the model creation. What is more, the company never registered the number of staff working in a cell. That information was eventually obtained through the analysis of operations performed by individual workers and the allocation of the operations to individual production cells. This is why in the process of modeling the researchers sought the solutions that would represent as precisely as possible the number of workers employed in each cell as well as the number of semi-fabricated products leaving each cell.

Figure 2 shows a part of the model representing the operation of the MG cell (inventory). This part was validated, which conforms to the aforementioned methodology of validating individual parts of the model. Because their purpose was not to determine the number of workers assigned to a task, but to assess the applied policy, the researches set a one-month simulation time step. The analysis covered full 21 months. The number of workers was calculated by dividing the inventory working time by the working time of a single worker in a cell. In order to count the number of semi-fabricated and finished products leaving the inventory the researchers multiplied the number of batches in a given period of time by the average number of items in a batch in that period.

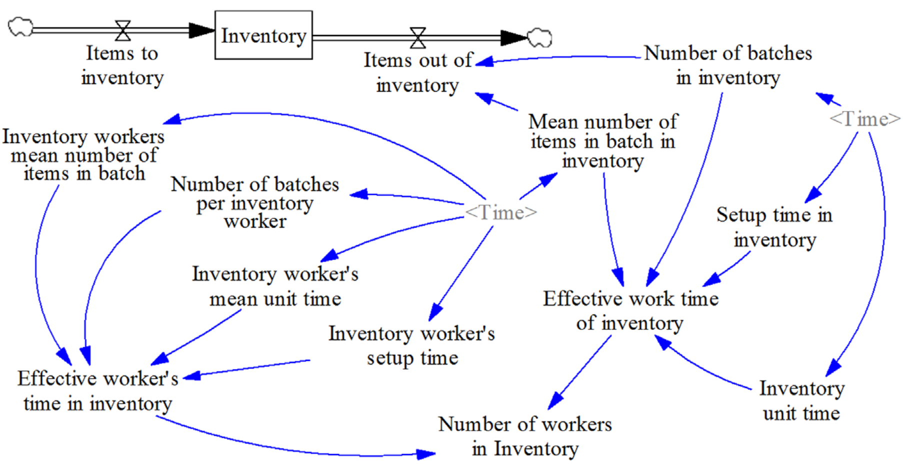

Figure 2. A part of the model – a production cell: inventory

The model was tested by means of the structure and behavior tests. Since the model has not been implemented yet, the test of policy implications cannot be performed.

When validating the structure the authors first of all used the data obtained in the course of survey among the company staff. They also based their validation on generally accepted knowledge from the reference literature.

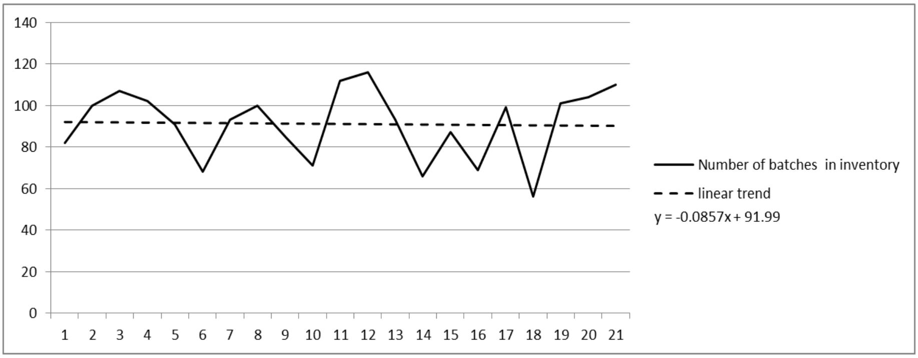

Figure 3. Characteristics of the flow of batches through the inventory (the variable: number of batches)

It should be noted that the structure validation tests are some of the most difficult ones to formalize and perform (Barlas, 1996, p. 190). The information which is indispensable at this stage of validation cannot be presented just as a set of figures. The tools used by the authors of this paper to evaluate the structure accuracy fit the requirements of Barlas' standards.

The following input parameters of the system were tested: the number of batches in the inventory (*the number of batches in inventory*) and the unit time of assignments performed in the inventory (*Unit time inventory*). Following the preliminary assessment of the charts (see examples in Figures 3 and 4) and the calculations run for different types of trends, the researchers, basing on linear trends, decided to determine the values necessary to set the effective working time for each production cell and the working time of one production cell worker. The trend equations are shown in Table 4.

Table 4. Values of the trends and the mean squared error for the parameters of the MG production cell

Variable	*Trend*
Single worker's working time parameters	
Inventory worker's mean number of items in batch	Y=-0.4092t+49.699
Inventory worker's mean unit time	Y=1e-05t+0.0015
Number of batches per inventory worker	Y=-0.0493t+16.142
Inventory worker's setup time	Y=-0.0062t+0.3119
Parameters of production cell effective working time	
Mean number of items in batch in inventory	Y=-2.4413t+103.76

Variable	*Trend*
Inventory unit time	Y=1e-05t+0.0078
Number of batches in inventory	Y=-0.0857t+91.99
Setup time in inventory	Y=-0.002t+0.0909

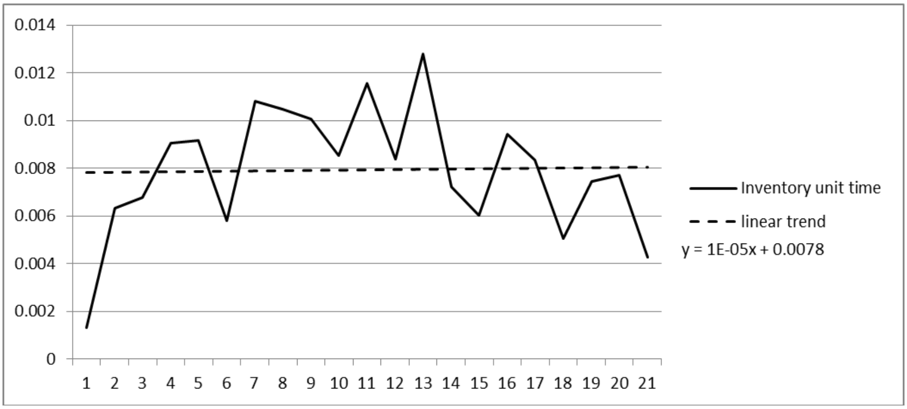

Figure 4. Characteristics of the unit time of assignments in the inventory (the variable: Inventory unit time)

Although some fluctuations do appear in the real system, they are not of seasonal nature. Additionally, the model is supposed to clarify the relations between the number of workers in individual production cell and the parameters of the production process rather that to forecast the value of individual parameters. Therefore, in a view to the lengthy period covered by the analysis, the above fluctuations can be considered hardly significant.

In the second group of tests proposed by Barlas, i.e. the valuation of the model behavior, the authors examined, among others, the system behavior logic.

In the above discussed example they checked if the single cell worker's working time did not exceed the value of the effective working time of the production cell itself. The chart (Figure 5), generated by the VENSIM program, shows that in this context the model can be considered reliable.

At the same time the parameter values generated by the model were compared with those generated by the real system. In order to perform the valuation the authors decided to use the Theil statistics proposed in the reference literature (Kasperska, 2005, p.137).

Table 5 shows the results of the Theil statistics for the following variables: *number of items in inventory* and *number of workers in inventory*.

Table 5. *The Theil statistics for the number of items leaving the inventory and the number of inventory workers*

Parameter	*Items out of inventory*	*No of workers in inventory*
UM	0.0027	0.0955
US	0.4447	0.8128
UC	0.5526	0.0917
U	1	1

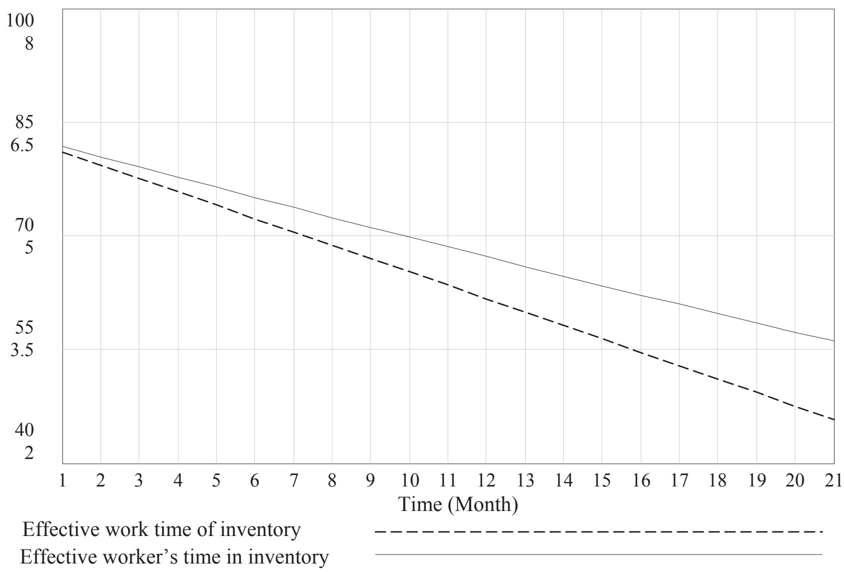

Figure 5. Comparison of the effective working time of a production cell with the effective working time of a single worker

The Theil statistics parameters were supplemented with the analysis of the charts where actual data was compared with the simulated ones (Figures 6 and 7).

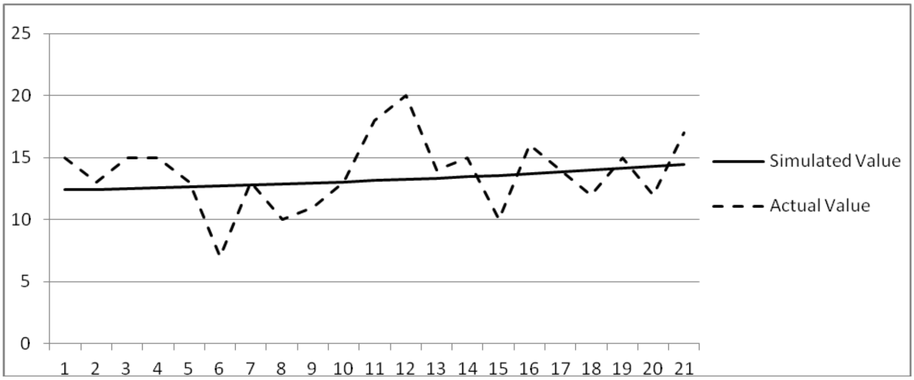

Figure 6. Comparison of the charts representing the actual and simulated data about the number of workers in a production cell (the variable: number of workers in inventory)

The characteristics of the set of the Theil statistics parameters for the variable *Number of workers in inventory* can be regarded as belonging to the (0, 1, 0) pattern. The disturbances in the real system, as indicated in the chart, are not taken into consideration in the model. Since, as it has been mentioned before, the purpose of the model is not to examine the periodic fluctuations, the error can be seen as non-systematic.

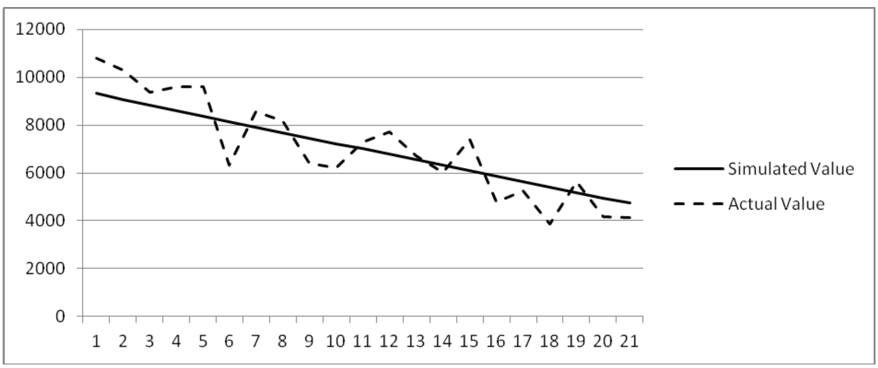

Figure 7: Comparison of the charts representing the actual and simulated data about the number of items leaving the inventory (the variable: Items out of inventory)

In case of the variable *Items out of inventory* the Theil statistics system (1, α, 1-α) as well as the chart analysis allow us to make an assumption that the real and simulated data have the same mean and trends, but they differ point by point and the deviations from the real data are the effect of a non-systematic error.

Therefore the analysis of the data and the comparison of the charts presenting the actual and simulated data lead to the conclusion that in this particular aspect the model is burdened with a non-systematic error, thus it can be regarded as reliable.

Discussion

The above example proves that the afore discussed part of the model can be regarded as workable as far as its representation of the real system is concerned. Admittedly, we can assume that if the model has turned out reliable in case of one production cell, the same computation scheme will be applicable to the others. But if we want to prove beyond any doubt that the whole model is reliable, we should expand the validation over all the remaining cells. Moreover, the elements that are linking individual cells should be tested as well. First of all, however, we should find out if the total number of workers in all the production cells does not exceed the number of workers in the company. In addition, the work-in-progress in any of the cells cannot reach negative values.

We should also make certain that the values adopted as data are obtained from the IT system currently operating in the company. In order to improve the reliability of computations it is worth considering the introduction of additional parameters - such as the time a single worker spends in a production cell - to the company records.

At the same time it seems worthwhile to prolong the period of time covered by the analysis – it could result in better leveling off the fluctuations occurring in the real system.

Conclusion

Summarizing, it is worth noting that the definitions of validation include such expressions as ‘a satisfying level of accuracy’ or ‘in keeping with the model’s intended use’, which are subjective phrases. It means that whether a model is considered reliable or not will largely depend on the judge’s impression (Sargent, 1998). What is more, neither verification nor validation is absolute, so we are not able to decide if the model has been verified or validated in 100%. Therefore, we cannot acknowledge that it is reliable unless we have run as many tests as necessary (Carson, 2002, p. 52). Although the model can be tested at different stages of its creation by various people (such as the modeler or an independent expert), the truth is that it is its user who will eventually decide how effectively the model helps them in their decision-making.

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Abstrakt (in Polish)

Celem niniejszego artykułu jest analiza procesu walidacji modeli zbudowanych w konwencji metody dynamiki systemów na przykładzie modelu alokacji zasobów produkcyjnych. W pierwszej części artykułu autorzy przedstawiają przegląd definicji walidacji i weryfikacji, które można znaleźć w literaturze przedmiotu. Ponadto podkreślają rolę, jaką odgrywa weryfikacja i walidacja w procesie modelowania. Omawiają także techniki walidacji modelu systemu, ze szczególnym uwzględnieniem testów struktury modelu, jego zachowania i implikacji decyzyjnych. Druga część artykułu zawiera przykład procesu walidacji modelu systemu alokacji zasobów produkcyjnych w firmie elektronicznej. Celem tego modelu jest ocena długoterminowego wpływu przypisania pracowników do poszczególnych zadań na takie parametry produkcyjne jak wydajność oraz efektywny czas pracy. Autorzy koncentrują swoją szczególną uwagę na części modelu dotyczącej magazynu, przeprowadzając badania jej struktury i zachowania. Podczas sprawdzania poprawności struktury autorzy korzystają z informacji uzyskanych w serii wywiadów z pracownikami firmy. Odnoszą się także do ogólnie przyjętej wiedzy, jaką można znaleźć w literaturze przedmiotu. Uzyskane wyniki badań są porównane z danymi rzeczywistymi. Autorzy oceniają zarówno logikę zachowania systemu jak i poziom dokładności danych wyjściowych w odniesieniu do systemu rzeczywistego.

Słowa kluczowe: *walidacja modeli symulacyjnych, dynamika systemów.*

Context and Animacy Play a Role in Dynamic Decision-Making

Magda Osman, Alexandros Ananiadis-Basias***

Abstract

Perception, judgment, and reasoning are all processes that are sensitive to cues to animacy (i.e. the presence of signals that indicate an object behaves as if it has intentions and internal goals). The present study investigated the following question: Does animacy facilitate decision-making in a dynamic control system? To address this, the present study used a dynamic decision-making task and compared behavior in four different contexts (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social). Participants were randomly allocated to one of these contexts, and in each version they were required to learn to manipulate variables in order to bring the dynamic system to a desirable state and maintain it at that level. The findings suggest that it is not animacy per se that facilitates decision-making behavior, but rather the presence of a context. However, animacy made an impact on the type of strategic behavior implemented when interacting with the dynamic system. We argue that context induces general beliefs about causal relationships in dynamic environments that generalize across animate as well as inanimate contexts.

Keywords: *animacy, dynamic decision making, context, causality.*

Introduction

There are a host of cognitive functions that suggest that we are highly sensitive to cues that imply animacy. As well as spatial and temporal features, one of the most reliable cues to infer animacy is whether or not an object behaves in a dynamic manner (Falmier & Young, 2008; Scholl & Tremoulet, 2000). That is to say, if the object moves in a co-ordinated way that we recognize as purposeful, then we are likely to infer that it is animate. What this means is that objects that display actions implying intentionality, and can therefore be interpreted as goal directed, are in turn highly salient to us (Goa, Newman, & Scholl, 2009). Some scientists have even suggested that the reason for this apparent bias is because we have "social brain" (Adophs, 2003; Gobbini, Koralek, Bryan, Montgomery, & Haxby, 2007) which is highly

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tuned to particular properties in the environment that display social-causal interactions. In fact, social contexts help consolidate complex information for the same reason that animacy does, and this is because these types of contexts can be interpreted as goal directed situations (Shafto, Goodman & Frank, 2011). Therefore, there are many arguments for suggesting that animacy is an important feature of objects which may even facilitate basic cognitive functions.

Perception studies suggest that we infer animacy in the movements of geometric objects (e.g. circle A moving in the same path as circle B), because the movements imply causal interactions that have a social element (e.g. circle A "*chasing*" another circle B) (Gao, Newman, & Scholl, 2009; Schlottmann, Ray, Mitchell, & Demetriou, 2006). As well as perception, studies examining memory retrieval (Fernandes, & Moscovitch, 2002; Traxler, Williams, Blozis, & Morris, 2005) and lexical decision-making (for some languages) (Gennari, Mirković, & MacDonald, 2012; Mak, Vonk, & Schriefers, 2002) show that if the stimuli are judged to be animate (i.e. living vs. non-living things) then they facilitate performance. In addition, investigations of causal reasoning have explored the facilitative effects of animacy on induction in children (Frankenhuis, House, Barrett, & Johnson, 2013) and adults (Zhou, Huang, Jin, Liang, Shui, & Shen, 2012). These studies also suggest that there is a reliable improvement in accuracy when inferences are made based on the presentation of stimuli that imply animacy.

Clearly, there is strong support for a view that the perceived animacy of objects has a facilitative effect on various cognitive processes (Scholl & Tremoulet, 2000). More specifically, a stronger inference may be that cues to animacy play an important role in our cognition because they carry valuable causal information about the relational properties between objects we observe in the world (Falmier & Young, 2008). If we can understand the causal relationship between objects, this in turn would be useful when it comes to predicting and controlling objects in the world (Osman, 2010). One area in which this issue is particularly salient is in complex dynamic control situations. Researchers that are concerned with these contexts have focused on the kinds of decision making processes that are required to interact with and control outcomes in them (i.e. Dynamic Decision Making research).

Dynamic decision making

Dynamic decision-making environments are microworlds that simulate real life situations in which a complex dynamic system can change as a direct result of an individual's actions upon it, a change can occur independently of the individual's actions (i.e. autonomously) or as a result of a combination of the two, (e.g. a pilot flying an aircraft). More to the point, dynamic decision-making (DDM) is the process by which people manipulate input variables in such a way as to reach and maintain a desirable change in an output variable. Crucially, the underlying relationship between inputs and outputs in the system that the decision-maker interacts with is dynamic (Osman, 2010). For instance, take a simple context such as changing the value on the thermostat of your radiator to maintain a warm temperature in your living room. The room may warm up more or less quickly depending on how old the heating system is, and where in the world you are (e.g., winter in Finland), as a result you might be required to regulate (i.e. control) the value on the thermostat as times goes on. Typically, in DDM tasks participants start with a context (e.g., heating the home) and are then given a goal (e.g., learn to regulate the temperature of the sitting room to 18 degrees). They are then tested on their ability to adapt their knowledge to new goals (e.g., regulate the temperature to 12 degrees).

For many, the appeal of this research domain is because of its high validity, because many real world decision-making problems are dynamic and complex (e.g., Berry & Broadbent, 1984; Mathews, Tall, Lane, & Sun, 2011; Osman, 2010; Selten, Pittnauer, & Hohnisch, 2011). The contexts used in this research field range from controlling a water purification plant (Burns & Vollemeyer, 2002), an ecosystem (Vollemeyer, Burns & Holyoak, 1997), water pump (Gonzalez, 2005), sugar factory (Berry & Broadbent, 1984), military management (Mathews et al, 2011), to a patient's health (Osman & Speekenbrink, 2012). However, to the authors' knowledge, there have been no dedicated studies that have compared decision-making behavior across different contexts, in order to uncover the types of contexts that would facilitate decision-making behavior in complex dynamic systems.

Moreover, it may in fact be the case that the animacy of the system is a key factor that facilitates DDM. If the system is perceived as animate, then people may infer that the system is goal- directed, and therefore, this may facilitate causal reasoning that in turn leads to improved DDM (Hagmayer, Meder, Osman, Mangold, & Lagnado, 2010). Furthermore, examining the impact of the animacy on decision-making has practical implications. If a complex dynamic system is perceived to be animate, and in turn it is shown to facilitate DDM, then automated control systems could be couched more obviously in ways that could invoke perceptions of animacy.

Present study

Given that there is convergence across many different areas of cognitive research in suggesting a special status for animacy in cognition, we predict that decision-making performance should be more accurate for animate compared to inanimate dynamic systems. If the effect of animacy is strong, then we might expect an advantage in decision-making performance when compared with Inanimate contexts (Social, and Non-social). Therefore in the present study, we compared DDM performance in an Animate-Social Context, with an Inanimate-Social Context, Inanimate-Non-Social Context, and a baseline No Context version of our DDM task.

Methods

Participants: Eighty-eight graduate and undergraduate students from University College London and Queen Mary University of London volunteered to participate in the experiment for reimbursement of £6 ($9.18) (Mean age 23, SD 7.5). There were four conditions: Abstract [baseline] (n =22, F = 15), Animate-Social (n = 22, F = 10), Inanimate-Social (n =22, F = 16), Inanimate-Non-social (n=22, F= 12). All participants were tested individually. For each condition, participants were randomly allocated, so that half performed tests in the test phase in the order of Control Test 1 then Control Test 2, and the remaining half performed Control Test 2 first, then Control Test 1.

Design: The study included four different contexts (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social). But with this exception, all other aspects of the task were identical in all four conditions. We chose a non-linear system to examine participants' ability to make decisions in this task. Our rational was that if non-linear tasks are difficult to perform (Lipshitz & Strauss, 1997) for the reason that the type of structure of the system is hard to learn, then facilitation via context should be easier to detect in measure of performance when compared to an abstract version of the task. The structure of the task consisted of three inputs and one output (see Equation 1).

$$y(t+1) = 1/(1+\exp(-1*(y(t) - 30 + 6*|6 - x1(t)| + 5*|4 - x2(t)| + e(t)))) \quad (1)$$

There were two inputs (x1, x2 as referred in the equation below) which had a direct effect on the output value when they were manipulated individually. The third input had no direct effect on the output (y(t)), hereafter referred to as Null input. In other words, a value selected by the participant for the third input had no direct consequence on the output value. Instead, the null input simply revealed the noise term in the equation (e (t)) below;

the value of which was selected from a normal distribution with a zero mean and a standard deviation of 4. Participants were naïve to the underlying relationship between the inputs and the output, which can be described in the following equation, in which *y* (*t+1*) is the output value on the next trial. Each input parameter ranged from 0-10. The system was designed in such a way that in order to successfully manage the state of the system to the specific target goal, the optimal manipulation of the inputs required that for Input 1 values should be selected from a range between 4 and 8, and for Input 2, values from a range between 3 and 7 should be selected.

The general instruction to participants was that they would have a chance to play a game on the computer in which they had to learn to control a system by deciding what things to change from trial to trial. They were also informed that they would later be tested on their ability to control the system after they became familiar with it. Figure 1 presents screenshots of a typical trial as experienced by a participant in the Inanimate-Social version (the picture in the top right of each screen shot differed according to what condition participants were in). The task was performed on a desktop computer, using custom software written in C# for the .NET framework. The task consisted of a total of 172 trials, divided into two phases. The learning phase involved 60 learning trials and the test phase included two control tests each 40 trials long, and two prediction tests each of which waw 16 trials long. During learning participants were required to achieve and maintain a target value consistently across all 60 trials, and in each control test participants were presented with a target value to reach and maintain throughout the course of each test.

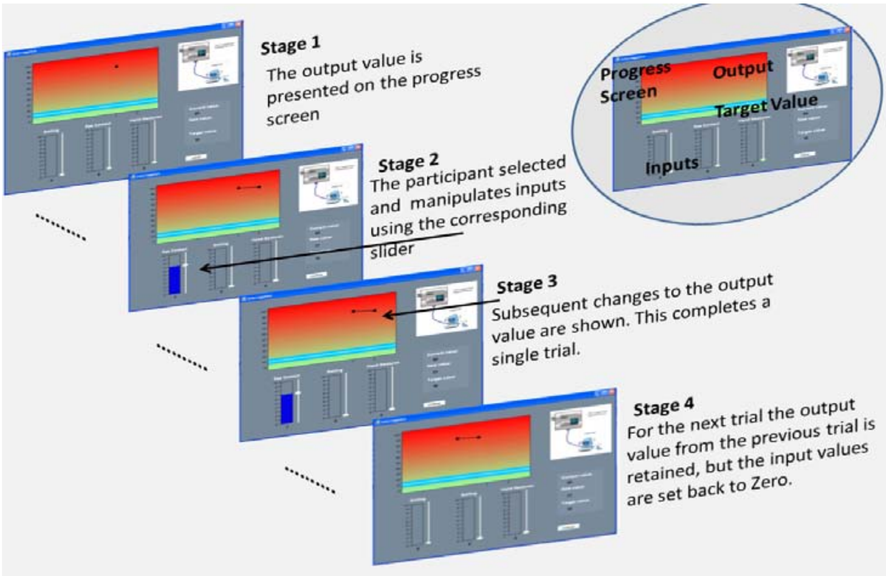

Figure 1. Sequence of actions in a single trial in the task

Materials: *Abstract (Baseline version):* The cover story for the abstract version did not contain any context. The inputs were simply labelled as A (i.e. Input 1) (0-10), B (i.e. Input 2) (0-10), and C (i.e. Input 3) (0-10), and the output was referred to as variable X (0-100). Participants were instructed to manipulate the inputs in order to control the output value to a specific level. *Animate-Social Context*: The cover story was set within a forensic context. Participants were told to imagine they were part of a forensic team, and that they had to interact with a policeman (animate) by varying three types of non-verbal behavior: Hand Gestures (i.e. Input 1) (Hand) – the amount of hand gesturing ranged from 0 (no hand gesturing) to 10 (constant hand gesturing), Eye Contact (i.e. Input 2) (Eye) – the amount of eye contact ranged from 0 (no eye contact) to 10 (constant eye contact), Smiling (i.e. Input 3) (Smile) – the amount of smiling ranged from 0 (no smiling) to 10 (constant smiling). Based on the data that the policeman received (i.e. the levels of Eye Contact, Smiling, and Hand Gestures on each trial) they would then give a rating of suspiciousness, which would be presented as a Suspicion value on the progress screen (i.e. Output value). *Inanimate-Social Context:* The cover story was identical to the Animate-Social version with one important exception. Instead of a policeman, participants were told that a lie detector machine processed the data on each trial. Thus, in this version the social context was retained since the variables that participants were manipulating (e.g., Hand gestures, Smiling, Eye-contact) are associated with social exchanges with other animate objects, but crucially participants were interacting with an inanimate object (i.e. lie detector). *Inanimate-Non-Social Context*: The cover story instructed participants to imagine they were engineers testing the effectiveness of a new oven on the market. The three inputs referred to components of the oven (Fan Speed (i.e. Input 1) – the fan speed ranged from 0 (not activated) to 10 (constantly operating), Vapor Pressure (i.e. Input 2) – the Vapour Pressure ranged from 0 (no Vapor Pressure) to 10 (constant Vapour Pressure), and Amplitude (i.e. Input 3) – the Amplitude ranged from 0 (no Amplitude) to 10 (constant Amplitude). Participants were also told that each of the three variables they could manipulate may have an effect on the temperature level of the oven. The framing of this context was designed to remove any social behaviors, and so participants were simply interacting with an inanimate object.

Procedure: *Learning Phase*: To begin, during learning participants were presented with a computer display with three inputs and one output (See Figure 1, top right panel). In all four conditions for trial 1 only the starting values of the inputs were set to 0, and the starting value of the output was pre-set to 80, while the target value for all 60 trials was 10. In all other trials the output value was not pre-set. Thus, the goal for each condition was the same, participants were required to reach and maintain the value 10 on each trial, which was depicted on a scale from 0-100 on a progress screen and also as a numerical value. At the start of the experiment it was made clear to participants that they were free to manipulate whichever combination of inputs they liked, or if they preferred, they need not necessarily manipulate any inputs on a trial. Once they were satisfied with their decision on a trial, they pressed a button to move on to the next trial (see Figure 1). The history of the output values generated across five consecutive trial periods remained on the progress screen while participants were interacting with the system. However, the trial history was a moving window of 5 trials long and so the progress screen was updated on each trial.

Test Phase: This phase was identical to the learning phase in all respect, with the following exception. Each control test was 40 trials long. In addition, in Control test 1 the starting value was 80 and participants were required to control the output value to 10 (i.e. the same as the target value during learning), and in Control test 2 the starting value was 10 and the target value was 85. Hence Control Test 2 was a test of transfer of knowledge. There were two tests of prediction, one presented after each control test. Here participants were given the values of inputs for a trial and then asked to predict the value of the output, or were given the value of the output on a trial, and were asked to predict the value of one of the inputs. For both Predictive Test 1 or

Predictive Test 2 there were 16 trials, 4 trials to predict each of the following, Input 1, Input 2, Input 3 and the output. While values for Input 3 could not be entered into analysis (because the Input was a null variable), they were still presented in the prediction tests so as not to alert participants that there was anything peculiar about this input. The presentation of the 16 trials in each prediction test was randomized for each participant. No feedback was presented as to accuracy of performance in these tests.

Scoring: *Control performance* during the learning phase and the control test phase was calculated to generate an error score; this was the absolute difference between the achieved output on a trial and the target value. Thus a lower error score indicated better control of the system. Input-Manipulation: We used Osman and Speekenbrink's (2011) simple method for identifying strategies. The *Input- Manipulation method* was based on calculating, for each participant, the proportion of trials across all 60 learning trials (or 40 trials each, per Control test) in which no input was changed (No-Manipulation), one input was changed (One-Input) two inputs were changed (Two-Inputs), and all inputs cues were changed (All-Inputs). For scoring of *predictive performance* in the Predictive tests error scores were calculated; this was based on the difference between the predicted value and the actual value. Again, a lower error value indicated better predictive accuracy.

Results

This section is organized in accordance with the two phases of the experiment: *Learning phase* in which control performance and input manipulation were examined; *Test phase* in which control performance, input manipulation and predictive performance were analysed.

Learning Phase: The following analysis compared control performance during learning of all four conditions (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social). A 6 (Block) x 4 (Condition) repeated measures ANOVA was conducted, and it revealed that familiarity with the task increased performance significantly (see Figure 2), in a main effect of block $F(5, 420) = 3.34$, $p = .006$, partial $\eta^2 = .03$. Post-hoc comparisons revealed that there were significant differences in control performance between each block ($t(87) > 2.5$, $p < .05$), suggesting that control performance was incrementally improving across blocks. Planned comparisons also revealed that the Animate-Social condition showed greater accuracy when controlling the output than the Abstract condition ($t(42) = 2.40$, $p = .02$), the Inanimate-Social condition showed a marginal significant difference in accuracy of control over the Abstract condition ($t(42) = 1.79$, $p = .08$), and Inanimate-Non-social condition also showed a significant advantage over the Abstract condition in control accuracy ($t(42) = 2.13$, $p = .03$). No other comparisons were significant. The findings suggest that learning to control a system without a context impairs performance as compared to when a context is present.

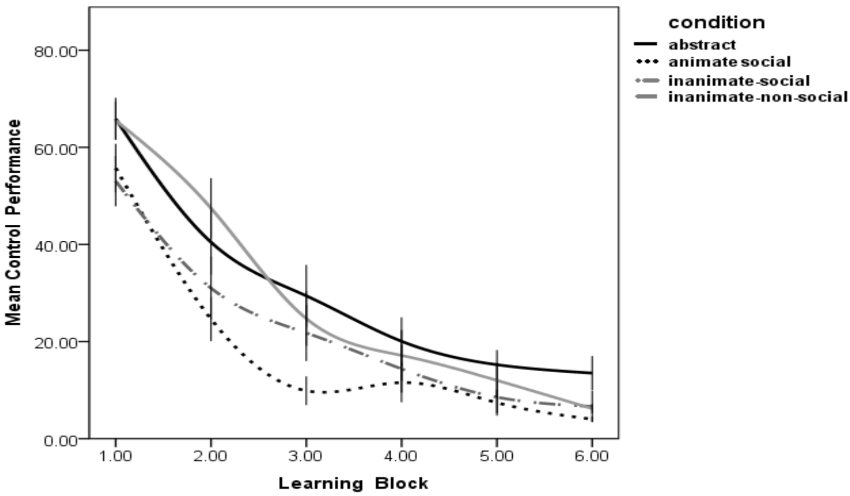

Figure 2. Control performance during learning by condition and learning block (SE +/-)

We also conducted a 4x4 ANOVA using Input-manipulation (No-Manipulation, One Input, Two Inputs, All inputs) as within-subject factors, and Condition (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social) as the between-subject factor. There was a main effect of Input-manipulation method, $F(3,252) = 256.39$, $p = 0.0006$, partial $\eta^2 = .73$, indicating that people used the four types of input manipulations to different degrees. With the exception of comparisons between No-Manipulation and One-Input, all other comparisons between types of Input manipulations were significant, with Bonferroni correction ($t(87)$, $p < 0.001$) (See Figure 3). The analysis also revealed the following interactions. There was an Input-manipulation method x Condition interaction, $F(9,252) = 2.22$, $p = 0.02$, partial $\eta^2 = 0.07$. Follow up analyses revealed that those in the Abstract condition employed the Two-Input strategy less than the Animate-Social ($p < 0.05$), and the Inanimate-Non-Social, ($p < 0.05$). No other analyses were significant.

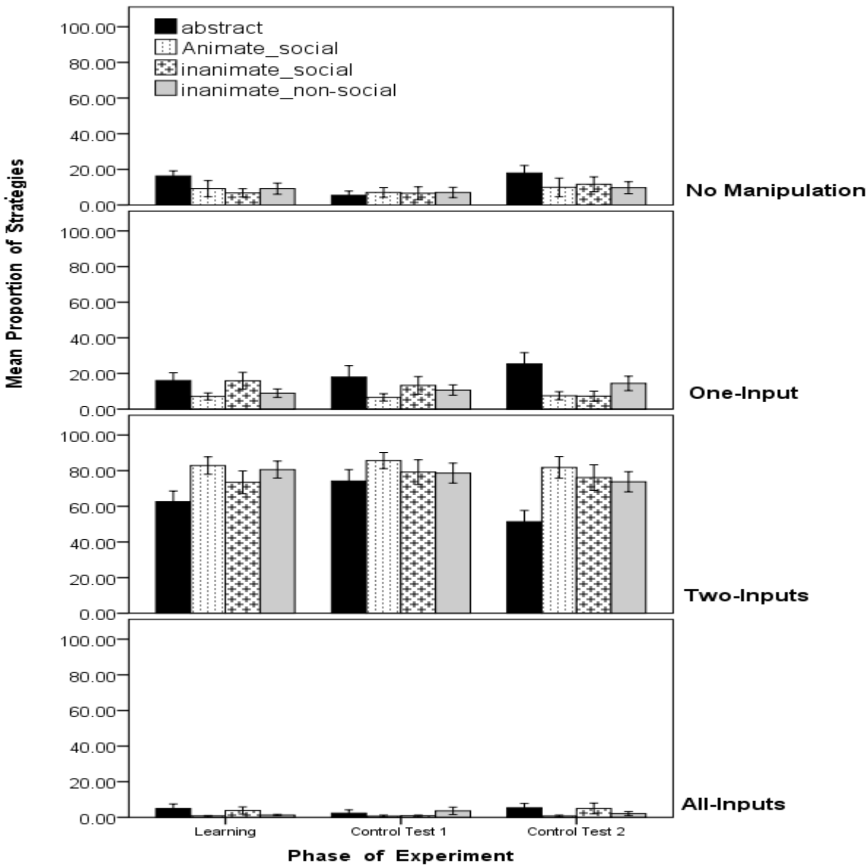

Figure 3. Mean choice of input manipulation, during learning and both Control Tests, by strategy and by Condition (SE 1 +/-)

Testing phase: A 2 (Test) x 4 (Condition) x 2 (Control Test order 1 & 2) ANOVA was conducted on test performance scores. The analysis showed there was a significant effect of condition, $F(1,84) = 5.07$, $p = .003$, partial $\eta^2 = .15$. Planned comparisons revealed that the Animate-Social condition (Mean = 13.19, SD = 8.53) was more accurate at controlling the output than the Abstract condition (Mean = 19.71, SD = 13.90) ($t(42) = 4.20$, $p = .0001$). Also, the Inanimate-Social condition (Mean = 14.03, SD = 9.38) showed a significant advantage over the Abstract condition ($t(42) = 2.92$, $p = .005$), and Inanimate-Non-social condition (Mean = 15.61, SD = 12.90) also showed a significant advantage over the Abstract condition in control accuracy ($t(42) = 2.47$, $p = .01$). No other comparisons were significant. Again, consistent with the pattern of results in learning phase, in the test phase control performance was facilitated by the presence of a context.

We conducted a 2x4x4 ANOVA using Test (Control Test 1, Control Test 2, and Input-manipulation method (No-Manipulation, One Input, Two Inputs, All Inputs) as within-subject factors, and Condition (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social) as the between-subject factor. There was no significant difference in the pattern of Input manipulations in Control Test 1 and Control Test 2, so we collapsed across tests ($F<1$). There was a main effect of Input-manipulation method, $F(3,252) = 239.10$, $p = 0.0002$, partial $\eta^2 = .74$. As with the learning phase, here too with the exception of comparisons between No-Manipulation and One-Input, all other comparisons between types of Input manipulations were significant, with Bonferroni correction ($t(87)$, $p < 0.001$) (see Figure 3). The analysis also revealed the following interactions. There was an Input-manipulation method x Condition interaction, $F(9,252) = 2.13$, $p = 0.02$, partial $\eta^2 = 0.07$. Follow up analyses revealed that those participants in the Abstract condition employed the Two-Input strategy less than the Animate-Social, ($p < 0.05$). In addition, those in the Abstract condition utilized the One-Input strategy more than the Animate-Social. No other analyses were significant.

After the main experiment participants were required to predict the value of each of the three inputs, and the output. However, our analyses concern the prediction scores for Input 1 and Input 2 and the Output value. We omitted Input 3 from the analyses because it was a null input. A 2 (Input 1, Input 2, Output) x 2 (Prediction Test 1, Prediction Test 2) x 4 (Abstract, Animate-Social, Inanimate- Social, Inanimate-Non-social) ANOVA was conducted. The analyses revealed a main effect of input (see Figure 4), suggesting that overall, accuracy in predicting the values of the two input variables and the output variable differed, $F(1,84) = 148.17$, $p = .0003$, partial $\eta^2 = .65$. No other analysis was of significance. Given that there was no difference between scores for Prediction Test 1 and Prediction Test 2, they were combined in order to perform post-tests. The analyses revealed that prediction judgments for the output value were significantly more inaccurate as compared to predictions for Input 1 $t(87) = -8.96$, $p = .0005$, and compared with Input 2 $t(87) = -8.65$, $p = .0003$. In addition, predictions were more inaccurate for Input 2 as compared to Input 1, $t(87) = -2.06$, $p = .04$. No other analysis achieved the significance level.

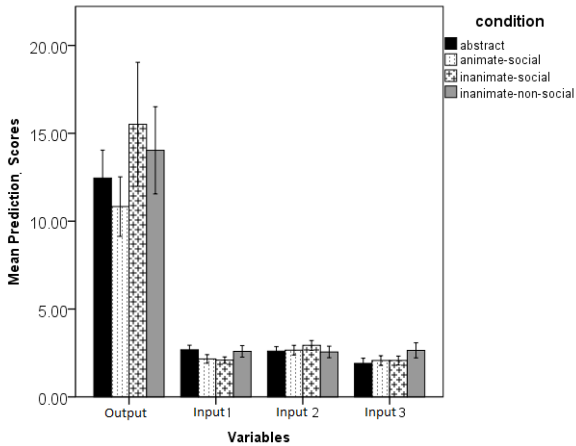

Figure 4. Prediction scores by condition and by input variable (SE +/-)

Manipulation Check: The manipulation check was used to examine if the four contexts were differentiated on the basis of animacy and social context. An additional set of 24 undergraduate and postgraduate volunteers (mean age 28.0, *SD* = 4.8) from Queen Mary University of London were presented with just the cover stories for each of the four conditions (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social). The presentation of the cover stories was randomized for each participant. At the end of reading each cover story, participants were required to rate the animacy of the object to be controlled (i.e. Animate-Social= Policeman's mental state, Inanimate-Social = Lie-detector, Inanimate-Non-social = Cooker, Abstract = Unspecified). They responded on a scale from 1 "definitely not alive" to 7 "definitely alive" (Tremoulet & Feldman, 2000). Participants also had to rate whether an interaction with the system was social, by which we meant that the cover story required that people considered their interactions to primarily involve a human agent. They responded on a scale from 1 "not at all social" to 7 "definitely social". The mean responses to both questions are presented in Figure 5. We submitted the ratings into an ANOVA with 2 (Rating of Animacy, Rating of Sociality) x 4 (Abstract, Animate-Social, Inanimate-Social, Inanimate-Non-social) ANOVA being conducted. There was a significant main effect of condition, $F(2,69) = 138.75$, $p = .0003$, partial $\eta^2 = .85$. There was no significant difference in the pattern of responses between the two types of ratings. With the exception of comparisons between Abstract and Inanimate-Non-social, all paired t-test comparisons were significantly different in ratings for Animacy as indicated in Figure 5 ($p < .001$). Similarly, for ratings for Sociality, there was no difference between Abstract and Inanimate-Non-social contexts, whereas all other comparisons were significant ($p < .005$).

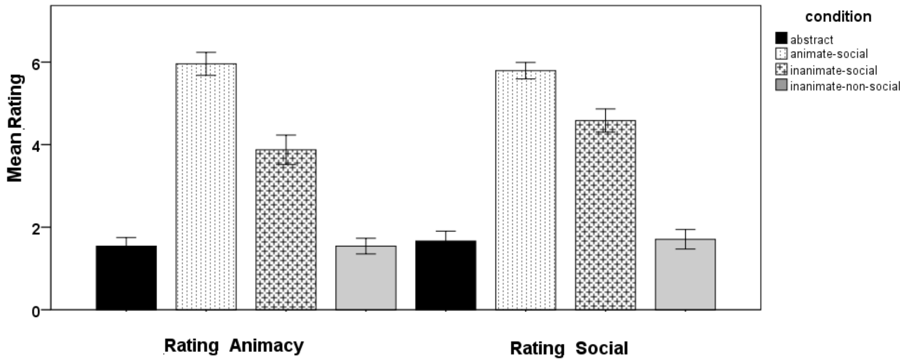

Figure 5. Mean rating of Animacy and Sociality by condition (SE +/-)

Discussion

The present study sought to investigate the faciliatory effects of animacy on dynamic decision-making. The second objective of this study was to compare decision making performance across different contexts in the same non-linear system. To this end, the study revealed a robust context effect that was preserved across both learning and test phases of the experiment.

In summary, having measured control performance we found no evidence to suggest that animacy *per se* facilitated performance, however, the findings clearly showed that in learning and in test contextualized versions of the DDM task facilitated performance. In addition, strategic behavior during learning and test indicated that those in the Abstract condition (without context) manipulated fewer combinations of inputs than those in contextualized conditions, particularly the Animate- Social condition. This suggests that animacy impacted on the type of strategy that participants implemented. However, when measuring predictive accuracy, the findings of this study suggest that this was insensitive to the context and animacy manipulations. Participants were more accurate when predicting cause to effect (i.e. input value, given an output value) then predicting effect to cause (i.e. output value, given input values). A prosaic explanation for this pattern of results may be that the range of values for the inputs was between 0-10, and so the scope for error was smaller than for estimating the output value, which could range from 0-100. In the remainder of this discussion we consider two questions.

In dynamic decision-making tasks why might animacy effect performance less than context? To begin, we are confident, based on our manipulation checks, the cover stories were distinguishable on the basis of animacy and sociality, and they led in the direction we expected. Therefore, we would expect that in the main study participants were initially sensitive to the type of context they were in, at least with respect to reading the cover story and the instructions. However, it may be the case that when it then came to interacting with the system, over time other more general factors became more salient than the animacy of the system. In other words, the presence of a context that could invoke general prior knowledge could be utilized more effectively than any specialized knowledge concerning the animacy of the objective being controlled. There is good evidence to suggest that people recruit prior experiential knowledge in order to perform complex decision making and problem solving tasks (Lane, Mathews, Sallas, Prattini, & Sun, 2008; Mathews et al, 2011).

This type of knowledge may include general causal beliefs about how components of a system interact with each other (Bechlivanidis & Lagnado, in press). In addition, it may well be the case that this type of knowledge is likely to be more effective, given that the specific causal relationships between inputs and outputs in the systems used in the present study were artificial. We constructed a system in which performance could legitimately be compared across all four contexts we devised, which was necessary for the purposes of this study. As a consequence, prior knowledge about the types of relations referred to in the animate context used in the present study was unlikely to be applicable to solving the task, as compared to a general understanding about the way in which inputs and outputs may behave in contexts that contain non-linear relationships. However, with respect to this point, the findings do suggest that there was a specific and consistent difference, both in learning and test, between the Animate-Social and the Abstract contexts. Here we speculate that people may have more prior experience of non-linear relationships in animate than inanimate contexts, and as a result people are more interactive with non-linear systems, which may explain why participants showed a consistent tendency to manipulate more inputs than when there is no context present. Putting it another way, the general reluctance to manipulate multiple inputs at a time in the abstract context may reveal that participants were more tentative and perhaps more conservative in their approach to the system.

Why does context matter in dynamic decision-making tasks? One reason may in fact be that contexts facilitate the intake of causal knowledge, and so there is a deeper issue concerning how people interact with DDM tasks which facilitate causal knowledge. Controlling a dynamic environment requires intervention-based decisions, which involves planning the choice of which input to manipulate and estimating the likely output from that intervention (Hagmayer, et al, 2010; Rottman, & Keil, 2012). The role of causal knowledge in DDM research is only a recent research issue, but gaining in momentum (Hagmayer, et al, 2010; Hagmayer & Osman, 2012; Rottman, & Keil, 2012). These theorists converge on the view that people's predictions and choice of actions in dynamic environments are founded on their causal knowledge of the relationships between inputs and outputs (Lagnado, Waldmann, Hagmayer, & Sloman, 2007; Glymour, 2003; Sloman, 2005). Therefore, the presence of a context facilitates the uptake of causal knowledge, which in the case of the present study is all the more impressive, given that participants were required to learn to control a dynamic non-linear system. However, it is also important to bear in mind that the relationship between context and the underlying causal structure of the system used in the present study was completely arbitrary. Despite the fact that great efforts were made to make the contexts themselves, any facilitation that did occur must have been based on participants associating their experience with manipulating the inputs to the available real world concept that the task provided, which the abstract condition did not offer. This association appeared to be so significantly strong that it impacted on the types of strategies that were developed to control the system. Given this implication, if participants are indeed sensitive to the context, then presumably DDM performance should suffer if the underlying causal system contradicts the context that the system is couched in. For instance, in a case where an input-output variable had a negative linear relationship, but the context implied a positive linear relationship (e.g., turning the bath tap, in order to fill the bath). Finally, a more general point that can be made here is that if context matters, then our ability to successfully control systems in the real world may be determined by how effectively we can utilize causal knowledge.

Conclusion

There are several compelling demonstrations of the facilitatory effects of cues to animacy (e.g., dynamics) on performance in a variety of cognitive processes; however this has not been explored in the context of dynamic decision-making. The present study was the first of its kind to directly compare decision-making performance in a non-linear dynamic system across a variety of contexts. The findings reveal that there was a general performance advantage when the system was couched in a context, regardless of whether or not it was animate. In addition, the pattern of strategic behavior in the system indicates that animacy encourages greater interaction than when the system is devoid of context. The present study proposes that the facilitatory effects of context in dynamic decision-making can be explained on the basis of general causal beliefs that people bring to bear to help them co-ordinate their actions in a dynamic system.

Acknowledgments

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Abstrakt (in Polish)

Postrzeganie, osąd i rozumowanie to procesy wykazujace wrażliwość na sygnały wskazujące na personifikacje ich źródła (animacy - np. gdy nieożywiony obiekt zachowuje się tak, jakby posiadał wolę i intencje). To studium poświęcone jest pytaniu, czy personifikacja (animacy) ułatwia podejmowanie decyzji w dynamicznych sytuacjach? Aby odpowiedzieć na to pytanie, porównywane jest zachowanie w dynamicznych sytuacjach zachodzące w czterech rodzajach kontekstu: Abstrakcyjnym, Społeczno-personifikacyjnym, Społeczno-niepersonifikacyjnym oraz Niespołeczno-niepersonifikacyjnym. Uczestnicy eksperymentu byli przypadkowo ulokowani w tych kontekstach i w każdym przypadku musieli uczyć sie manipulowac zmiennymi decyzyjnymi aby doprowadzić kontrolowany system do pożądanego stanu, a następnie stan ten utrzymać. Badanie wykazało, że to nie personifikacja per se ułatwia podejmowanie decyzji, ale raczej charakter kontekstu. Niemniej personifikacja odgrywa istotną rolę przy układaniu strategii kontrolowania dynamicznych systemów. Autorzy twierdzą, że to kontekst umożliwia tworzenie przekonania co do przyczynowych relacji istniejacych w dynamicznym otoczeniu, zarówno w odniesieniu do społecznego jak i niespołecznego otoczenia.

Słowa kluczowe: *dynamiczne podejmowanie decyzji, personifikacja (animacy), kontekst, związek przyczynowy.*

The Modeling Process of the Materials Management System in a Manufacturing Company Based on the System Dynamics Method

*Małgorzata Baran**

Abstract

The article presents the steps of modeling of the material management system in a manufacturing company. First, the modeling procedures indicating by Forrester, Łukaszewicz, Souček, Tarajkowski and Sterman were described and the essence of materials management in a manufacturing company was presented. Next, modeling of the materials management system was shown - step by step. Initially, the variables of the mental model connected with materials were defined, then variables in casual loop diagrams were linked. Diagrams were transformed into a simulation model that has been verified. The validation of the simulation model was conducted by using the following methods: assessing the correctness of the boundary of modeling, adequacy of the model structure and adopted values (constants) compared with available knowledge about the modelled system; test of the accuracy and consistency of the units of variables adopted in the model and test of the model behavior in extreme conditions. The study endpoints included the simulation of the model on empirical data, which were collected in the company Alpha and test of the "what ... if ...". The test showed that the small changes in control norms (constants), which control the system, could have influenced to more rational management of that system.

Keywords: *simulation modeling, system dynamics, materials in a manufacturing company.*

Introduction

Modeling should be understood as an experimental or mathematical method for investigating complex systems, phenomena and processes (technical, physical, chemical, economic, social) on the basis of constructing models. One of the methods of the modeling is a method of System Dynamics (Łukaszewicz, 1975; Coyle, 1977; Wąsik, 1983; Richardson, 1996a, 1996b; Radosiński, 2001; Śliwa, 1994; 2001, 2012; Kasperska, 2005; Senge, 2006; Łatuszyńska, 2008; Krupa, 2008; Baran, 2009, 2010a, 2010b, 2010c). The method was developed in the late 50-ies of XX century by J. Forrester (1961; 1969; 1971; 1972). It

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is used to build simulation models of complex systems, including economic systems, and to explore and investigate their dynamic behaviour. The main objective of modeling using the System Dynamics is not only a graphical representation of the structure of the system, its complexity and relations, but also look for possible solutions to the problems, which are included in it. Experiments carried out in the virtual world help design the real world (perceived), and real world experiences provide information to the virtual world. A clear and unambiguous indication of the problem (or problems) for which the system will be modelled is one of the most important aspects of modeling.

The purpose of this article is to present the steps of modeling of the material management system in a manufacturing company. The basis for the construction of the model was the model built by Sterman (2000, p.727). The model was slightly modified by the author (and management of the Alpha**) and adopted to the realities of business activity of Alpha enterprise. The simulation model uses empirical data collected in that company.

Literature review

General principles of modeling systems have been presented by Forrester in *Principles of Systems* (1971). In thirty one points he included, among others, guidelines for determining the boundaries of the system, linking variables in feedback loops, determining accumulations, flows, information variables in systems and the principles of simulation.

A pioneer in the convention modeling methods in Polish literature was Łukaszewicz (1975). He pointed out 10 steps for modeling and analysis of specific, investigated system from identification and formulation of the problem by identification the information feedback loop connecting decision rules, then construction of the structural and mathematical model, verification model and ending with implementation of the system changes, which are connected with experimental results conducted on the model.

Souček (1979) draws attention to the four basic principles of construction of models, emphasizing, that each system is made of tanks, which are combination of channels, through which items flow streams from one tank to another. The size of streams of individual elements in the system is created on the basis of decisions, that must be understood as a process of converting information about system into control signals of flowing streams in the system. For any decision included in the model, the rule that specifies how and on what information decisions will be made, should be established. During modeling, each modeller should also take into account exogenous

** Executives asked to change the name of your company.

variables of the system, which should be regarded as a relatively independent of the explored system.

Tarajkowski (2008) points to the existence of the eight essential steps of modeling systems, assigning each stage the specific tasks, which must be performed. In the first stage it is necessary to identify an object (or system issues) to be modelled. One can come here for various difficulties both methodological and cognitive. Therefore it is important to present the issues, that makes it possible to distinguish it from all others and to collect such information of the system, which will remain in alignment with the real world. The second step is to determine how modelled system behaves from the point of view of logic, and what tasks meet. The third and fourth stage focus on a graphical presentation of memory system architecture. The structure of the system initially is shown with simple graphs, identifying common feedback and their types, and next, as a cause - effect diagram including accumulation, flow, and auxiliary variables. The fifth step is a quantification of the model and determination of the characteristic behaviour, that characterizes the individual variables in the model, as well as the identification of delay. It allows for building relevant equations and making a selection of simulation program in the sixth stage. In the seventh stage of the research the correctness of the model by comparing the historical values of variables with simulation values and modification the simulation model in case of detecting different types of discrepancies are carried out. And at the end, in the eighth stage, one ought to determine the final version of the model, conduct a number of predictive tests, test various hypotheses and strategies and acceptance of the final results.

Research methods

In this article, the authoress is used the modeling procedure of systems specified by Sterman (2000, p. 86). The management of Alpha made that choice. The Systems Dynamics method isn`t widely practised in Poland and the management trusted the foreign expert. Sterman suggests the following steps, when we working with a model of the selected system:

1) Selection of the problem or issue that will be subject of process of modeling and indication for him:
    - modeling boundaries;
    - key variables, that fully present the system;
    - the time horizon, which is such a time period, which takes into account both the past behavior of the variables of the problem (based on the historical data), as well as their behavior in the future, possible to identify thanks to the subsequent simulation; the time horizon should

be long enough to be able to capture all interactions that may occur between these variables.

2) Formulation of dynamic hypotheses by considering how the given problems and phenomena in the modelled system are formed, what kind of behaviour they are characterized and building structure of model using tools, such as:
   - a list of endogenous variables (characterizing for investigated system), exogenous variables (external factors constantly affecting the system) and the variables excluded from the model;
   - general sketches of the subsystems, that build the whole system, taking into account endogenous and exogenous variables;
   - depending diagrams, that make it possible to capture the cause - effect relationships between variables and determine kinds of feedback;
   - accumulation and flow maps, which clearly indicate the accumulation variables, that are the heart of the model, variables having an effect on the accumulation (flows) and other necessary auxiliary variables (information);
   - diagrams, that focus on strategies and direction of action for the management of individual flows, taking into account the information flowing and delays, which arising from the waiting time between the decision, their implementation and consequences.
3) Construction of the simulation model (using appropriate software), in which:
   - variable will be assigned by the appropriate numerical data (value);
   - variables will be linked to the corresponding equations;
   - will set the initial values for each accumulation.
4) Testing the model, which usually consists of the following processes:
   - assessing the adequacy of the choice of the boundary model structure compared with the available knowledge of the modelled system;
   - evaluating the accuracy and consistency of assumed units of the variables in the model;
   - assessing consistency adopted parameter values with the actual values;
   - testing the model under extreme conditions;
   - estimating the ability of the model (e.g. using statistical methods) to reproduce the real behaviour of the system.
5) Design and evaluation of different strategies resulting from observing the behaviour of the variables in the model, testing possible solutions.

In realization of the subsequent steps of the modeling process, management of Alpha tried to give answers to supporting questions, which summarized in Table 1.

Table 1. Supporting questions in modeling process

Step of the modeling process	Supporting questions
1. Selection of the problem or issue that will be subject of process of modeling	• What is the problem? • What key variables directly related to the problem should be considered? • What is the time interval needed to capture the essential behavior of the variables in the model? • What behavior was characterized by the key variables in the past and how they might behave in the future?
2. Dynamic hypotheses	• What are the current theories explaining the activity of the system? • Which key variables will be accepted as endogenous and exogenous? • Assuming the boundary of modeling, which previously adopted variables should be excluded from the model? • Can one identify any specific subsystems of the whole system? • What kinds of feedback loops exist between the variables? What is the cause and what is effect? • Which of accepted variables are accumulations and flows? • Are there any auxiliary variables? • In which areas in the model, will there be a delay? What will be the delays type and nature? • Are there specific strategies for targeting the flows?
3. Construction of the simulation model	• What value will the variables in the model take? • What type of equations will be connected with chosen variables? • What are the initial values for accumulations? • How long are the delays?
4. Testing the model	• Is the behavior of the variables in the model consistent with reality and historical data? • What is the behavior of the variables under changed conditions? • How does model behave under extreme conditions?
5. The project's strategy and its assessment	• What changes in policies related to the management of the system can be improved? How to present them in the model? • Will the changes solve the problems considered in the system? • What are the consequences of the modifications? • Other questions like: „what ... if ....?

Source: Own elaboration on basis of Sterman (2000).

The modeling process is an iterative process. The initial plan dictates the frame and the scope of work in the model, but a more detailed analysis and understanding of the essence of the issues often results in the return of thinking of modeling - the results of the relevant step force to return and improve the previous steps.

Analysis and study

Materials management in a manufacturing company

Materials management in a manufacturing company is closely related to its basic activity and results of conceptual preparation of production (Sołtysiński, 1963; Bik, 1974; Liwowski, 1977; Skowronek, 1989). To ensure timely delivery of materials to the production process, it is necessary to determine the type of manufactured goods and their quantity. The next step is to establish standards of material usage per unit of product. This allows for the calculation of demand resulting from the assumed production plans. If you plan to purchase due to the size of demand, stocks held as collateral against the occurrence of discontinuities in the flow of materials targeted for production should be also included. Stocks may be current and minimum. Current stocks are associated with the progressive wear of the materials in the production process and often end before the next supply of materials. Their size is therefore dependent on supply frequency and size of a single delivery. Minimal stocks are protection against delays in deliveries and are used only when a company wears fully supply current. In determining the size of the store, the minimum time should be specified, in which it will be possible to maintain the undisturbed course of production, thanks to the supply from the minimum stocks, while the current stocks are exhausted.

The main warehouse processes related to material management may include the following (Niemczyk, 2010, p. 119):

- receiving the materials from external suppliers, both in the physical sense as the unloading of materials, as well as in terms of register in the form of reports of acceptance;
- storage of materials associated with the location of stocks in the warehouse;
- completing, including taking materials in accordance with the assortment and quantity specification to create a collection of materials required for specific stages of production;
- handing over materials connected to the physical delivery of a set of completed materials to the production line confirmed by delivery reports.

Modeling of material management system in the company Alpha

Alpha is a medium-size clothing company based in Podkarpacie, in Poland. The scope of business includes sewing smart men's trousers to the Polish market and to overseas markets. Customers are primarily other clothing companies, clothing stores and warehouses, as well as individuals. For the production of trousers, company need the following materials: a top cloth, buttress (stiffening strip bar), plywood, zip, buttons and thread.

Initially, the key mental model variables of the system of materials management at Alpha have been defined. The variables are presented in Table 2.

Table 2. Variables of mental model

Variable	Description
Receipt of materials	Stream of materials flowing to the warehouse of materials, resulting directly from " Desired size of the supply of materials "
Desired quantity of the supply of materials	Desired quantity of materials to be delivered to the company, resulting from the sum of the variables "Desired weekly usage of materials" and "Adjustment for materials inventory"
Desired weekly usage of materials	Desired amount of raw materials needed to produce finished products, resulting from "Materials usage per unit" and "Desired production"
Materials usage per unit	Number of sets of materials needed to produce one unit of the finished product
Desired production	The level of desired production, which results from orders – exogenous variable
Adjustment for materials inventory	Adjustment the quantity of materials to the desired level
Desired level of materials inventory	Number of sets of materials needed for the manufacturing process, resulting from "Desired weekly usage of materials" and "Time of maintaining stocks"
Time to correct the level of materials inventory	The time between placing an order for the materials, and the actual receipt from the supplier
Minimum level of materials inventory	The lowest number of stocks of materials, which the company maintains in warehouse of materials
Time maintaining materials inventory	Planned length of time, in which the company keeps inventory of materials in the warehouse of materials
Materials inventory	The quantities of materials inventory in warehouse of materials, increased by "Receipt of materials" and decreased by "Usage of materials"
Usage of materials	A stream of materials issued to production
Limit for usage of materials per week	Possible amount of materials that can be given to the production, due to their availability in the current stock of materials and depended on time to prepare them for usage
Time to prepare materials for usage	The duration of all activities necessary for the preparation of materials for giving them on the production line
Possible production of the availability of materials	Possible production volume of finished products, due to the availability of materials taken from stocks of materials

In the next step a diagram showing direct and indirect cause - effect relationships between variables was constructed (Figure 1).

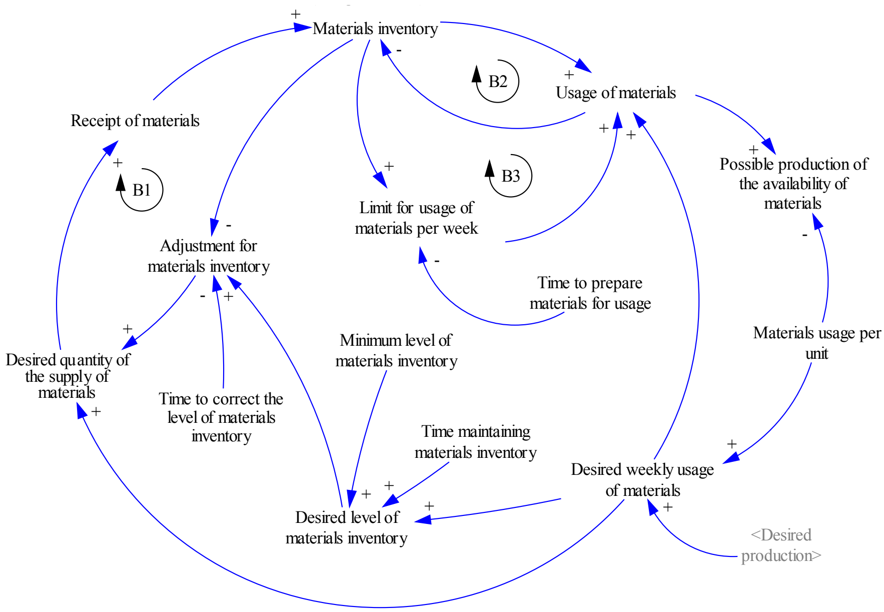


Figure 1. Cause – effect diagram of the materials management system

Source: Author's elaboration in Vensim DSS Version 5.9e.

Next the authoress converted the above diagram into a simulation model of the system of materials management at Alpha. Mental model variables were presented as mathematical variables and constants. Needed coefficients were added. The accumulation, flow variables and auxiliary variables (information) and the mathematical relationships existing between them were indicated. Model was built in the simulation systems Vensim DSS Version 5.9e, so the mathematical apparatus was presented with the available functions and mathematical expressions.

The Figure 2 shows the resulting model, consisting of two parts. The first part of the model is related to the stocks of materials A and the second - the stocks of materials B. The stocks of materials A include: buttress (stiffening strip bar), plywood, zip, buttons and thread. The stocks of materials B include: the top cloth. Separation of materials A and B resulted in the similarity to each other by "Time to correct the level of materials inventory". In case of materials A, that time was 0.2 week and in case of materials B – 2 weeks. These differences have an impact on the behaviour of the individual parts of the model.

While the "Materials A inventory" is used in each case, "Materials B inventory" can be activated or not, by changing the "Turn on materials B inventory". The variables and constants in the model "Materials B inventory" are the same as in the "Materials A inventory" but to distinguish their name, the authoress placed symbol B.

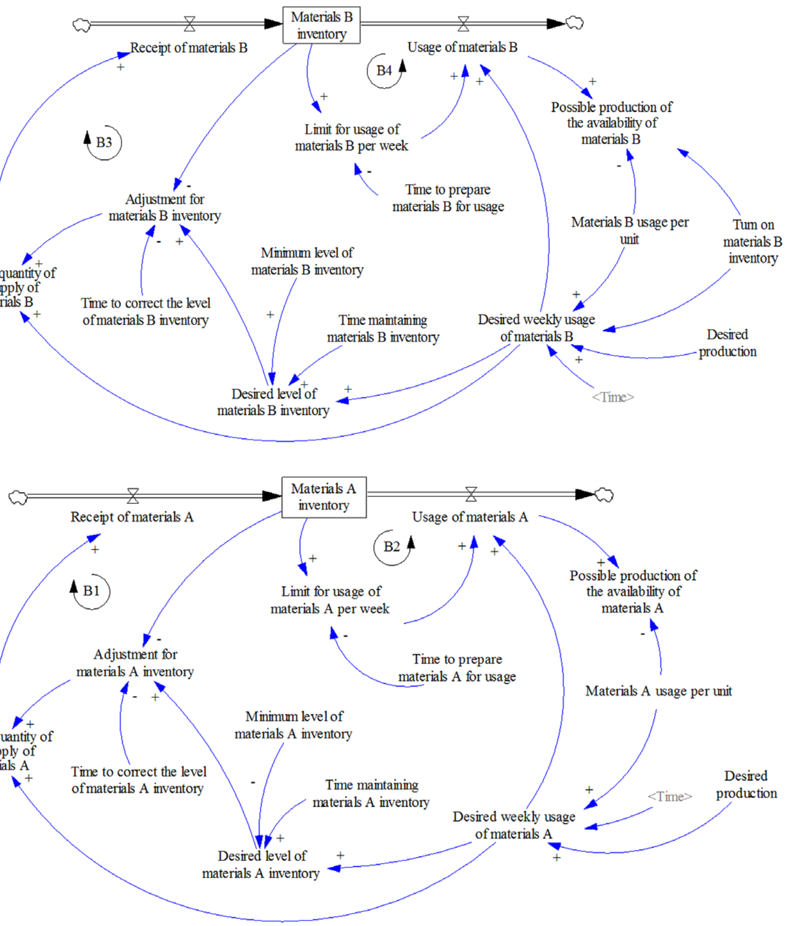


Figure 2. Simulation model of the materials management system

Source: Author's elaboration in Vensim DSS Version 5.9e.

Accumulation variables in above models are:

a) "Materials A inventory" increased by a flow variable "Receipt of materials A" and reduced by a flow variable "Usage of materials A";

b) "Materials B inventory" increased by a flow variable "Receipt of materials B" and reduced by a flow variable "Usage of materials B".

Definitions of variables and mathematical constants contained in parts of the simulation model are presented in Table 3.

Table 3. Definitions of model vabiables/constans

Variable/constant	The definition of a variable / constant	Unit
Desired production	[(0,0)-(51,250)],(0,61),(1,135),(2,0),(3,8),(4,29),(5,10),(6,47),(7,37),(8,87), (9,76),(10,61),(11,185),(12,169),(13,216),(14,72),(15,118),(16,79),(17,143),(18,69),(19,128),(20,58),(21,35),(22,73),(23,29),(24,59),(25,0),(26,0),(27,0),(28,35),(29,25),(30,52),(31,83),(32,114),(33,15),(34,72),(35,92),(36,81),(37,85),(38,99),(39,80),(40,103),(41,120),(42,93),(43,129),(44,122),(45,92),(46,74),(47,105),(48,228),(49,166),(50,151),(51,0) (empirical data)	[Widgets/ Week]
Materials A usage per unit	1	[Materials/ Widget]
Desired weekly usage of materials A	MAX(0, Materials A usage per unit * Desired production (Time))	[Materials/ Week]
Desired level of materials A inventory	MAX (Minimum level of materials A inventory, Desired weekly usage of materials A* Time maintaining materials A inventory)	[Materials]
Time maintaining materials A inventory	1 (empirical data)	[Week]
Minimum level of materials A inventory	100 (empirical data)	[Materials]
Adjustment for materials A inventory	(Desired level of materials A inventory – Materials A inventory)/ Time to correct the level of materials A inventory	[Materials/ Week]
Materials A inventory	INTEG(Receipt of materials A - Usage of materials A) Initially value: Desired level of materials A inventory	[Materials]
Time to correct the level of materials A inventory	0.2 (empirical data)	[Week]
Desired quantity of the supply of materials A	MAX(0, Desired weekly usage of materials A+ Adjustment for materials A inventory)	[Materials/ Week]
Receipt of materials A	Desired quantity of the supply of materials A	[Materials/ Week]
Usage of materials A	MIN(Limit for usage of materials A per week, Desired weekly usage of materials A)	[Materials/ Week]
Limit for usage of materials A per week	Materials A inventory / Time to prepare materials A for usage	[Materials/ Week]

Time to prepare materials A for usage	0.037 (empirical data)	[Week]
Possible production of the availability of materials A	Usage of materials A/ Material A usage per unit	[Widgets/ Week]
Turn on materials B inventory	1	[-]
Desired weekly usage of materials B	MAX(0, Materials B usage per unit * Desired production(Time)* Turn on materials B inventory)	[Materials/ Week]
Possible production of the availability of materials B	IF THEN ELSE(Turn on materials B inventory =1, Usage of materials B/ Materials B usage per unit, 0)	[Widgets/ Week]
Time maintaining materials B inventory	2 (empirical data)	[Week]
Time to correct the level of materials B inventory	2 (empirical data)	[Week]
Time to prepare materials B for usage	0.25 (empirical data)	[Week]
Minimum level of materials B inventory	300 (empirical data)	[Materials]
Other variables associated with the part, in which there are materials B, are similarly defined as in the case of materials A.		

The model differs in some details from model of Sterman. The variable “Desired Material Inventory Coverage” was replaced by one constant “Time maintaining materials inventory”, new constant “Minimum level of materials inventory” was introduced (and measured in materials) and the variable “Material Usage Ratio” was omitted.

In the next investigations, the validation of the simulation model was conducted by using the following methods:

a) assessing the correctness of the boundary of modeling, adequacy of the model structure and adopted values (constants) compared with available knowledge about the modelled system;

b) test of the accuracy and consistency of the units of variables adopted in the model;

c) test of the model behavior in extreme conditions.

The main objective of building the model was a general representation of materials management system in a manufacturing company with key decision rules of controlling this system. Accordingly, those variables were chosen, which could present quantitatively the system. Executives surveyed enterprise and the experts were attended during the selection of variables to the model, as well as during creation of the model structure. The scientific literature was used, too. The persons authorized by management provided the parameter values that have been adopted in the model. All parameter values (constants) were averaged by them. All those activity can prove the correctness of the boundary of modeling and structure of the system and the accuracy of the adopted model parameters.

One of the key measures of determining the correctness of relationship variables in the model, which is also responsible for the overall validity of the model, is to test the cohesion of units of variables adopted in the model. The test was made directly in the program, in which the model was built, by using the command *Check Units.* The test confirmed the correctness of units.

Testing of the model in extreme conditions was to check its behavior when the values of the constants have taken an amount equal to 0 or very large size. During the testing the program reported exceeding the range of size numbers by some variables for several times, what interrupted the simulation. Those were mainly variables that appeared in the equations describing the model, especially in the denominators of equation and took the value of 0. The MAX function was used in the definition of those variables to prevent such errors.

The simulation of the model of the materials management system in Alpha

After completing the model data obtained in Alpha, the simulation of the model was conducted. The 0.015625 simulation step was set. Runs of accumulation variables are shown in Figure 3.

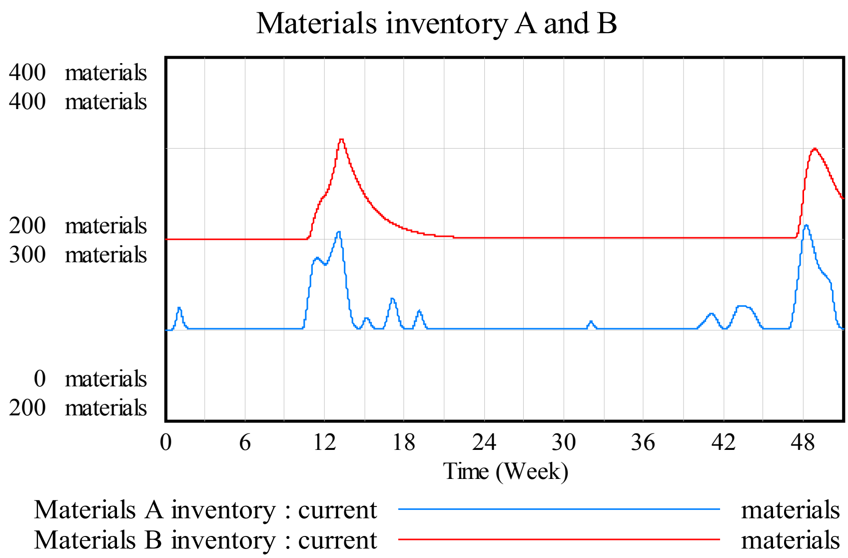
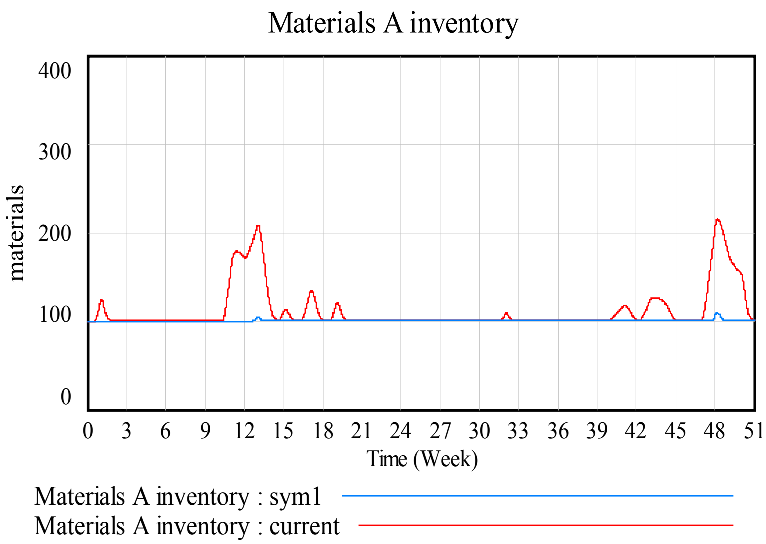


Figure3. The level of the materials inventory A and B in the Alpha

Source: Author's elaboration in Vensim DSS Version 5.9e.

In the analyzed period of time we have seen fluctuations both in the volume of "Materials A inventory" (the blue graph and the upper scale) and "Materials B inventory" (the red graph and the lower scale) resulting in incoming orders, which determined the size of "Desired production" and "Time maintaining materials inventory". The runs of "Materials B inventory" in comparison with run of "Materials A inventory" was more stable. This resulted mainly from the longer time required to correct the level of those stocks to the desired level.

In the last step of investigations, the analysis of a scenario "what ... if ...?" was conducted. The "Time maintaining A inventory" was changed from 1 week (current) to 0.5 week (sym 1), and the "Time maintaining B inventory" from 2 weeks to 1 week. Step simulation remained unchanged. Figure 4 shows the simulation results.



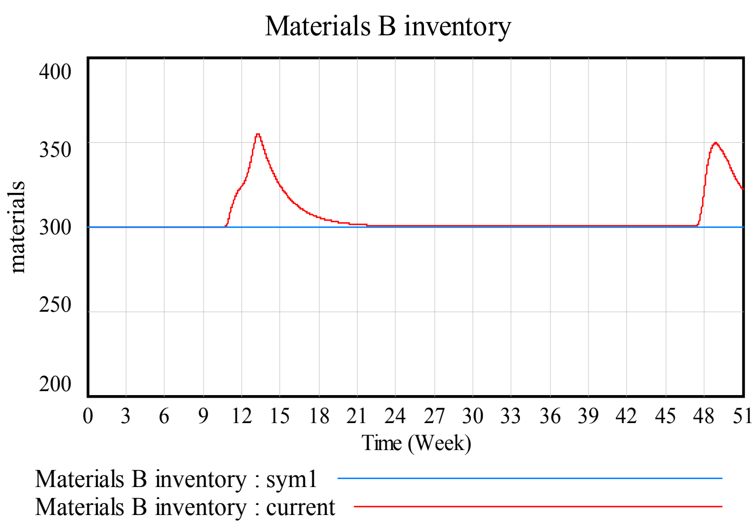


Figure 4. The level of the materials inventory A and B in the Alpha under the new scenario

Source: Author's elaboration in Vensim DSS Version 5.9e.

Analyzing the results of the simulation one can see that both the "Materials A inventory" and "Materials B inventory" would have reached a new level, equal to the minimum level of stocks of materials, which is determined in the company. The fact that the levels of those stocks would have been lower than before, however, wouldn't have affected the possible level of production resulted from the availability of those materials. This means that the company could significantly reduce the costs associated with the storage of excess materials without affecting the final results of production.

Conclusion

Simulation of the modelled material management system in the company Alpha, allowed for discovery of the behavior of that system in the real world and discovery correlations between variables building blocks of the system. Simulation “what ... if ...” showed that the small changes in control norms (constants), which control the system, could have influenced to more rational management of that system.

However, a question can arise, whether a reduction of the time maintaining inventory will not affect the increase in costs associated with more frequent delivery of materials, higher ordering, monitoring, and transportation costs. The question may be an incentive for further modeling and investigations conducting in the company Alpha.

It should be noted that the model described in this paper is a homomorphic. This means that it is a simplification of the real system, which is the material management in a manufacturing company and contains only the most important elements of the system. However, it can be used by other companies after the appropriate converting or expanding and adapting to the conditions prevailing in them.

In fact, the process of modeling is only a small part (subsystem) of a much larger system, which consists of: real world feedback information, mental models, strategies, structures and decision rules and choices. Simulation models of systems are developed by mental models of the participants and thanks to the information collected from the real world. Policies, structures and decision-making principles applied in the real world can be presented and tested in a virtual world. The results of those tests change mental models of participants and lead to the design of new strategies, structures and decision rules. New action directions, which are introduced in real world thanks to virtual decisions and feedback information leads to new changes in mental models. Modeling is therefore not a one-off activity, but it is still repeated cycle of activities between the virtual world and the real world.

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Abstrakt (in Polish)

W artykule przedstawiono kolejne etapy modelowania systemu gospodarki materiałowej w przedsiębiorstwie produkcyjnym. Na początku podano procedury modelowania, wskazane przez takich autorów, jak: Forrester, Łukaszewicz, Souček, Tarajkowski oraz Sterman oraz wytłumaczono istotę zarządzania materiałami w przedsiębiorstwie produkcyjnym. Następnie przedstawiono – krok po kroku – kolejne etapy modelowania systemu zarządzania materiałami. Zdefiniowano zmienne modelu myślowego systemu i powiązano je w pętle przyczynowo – skutkowe zwane diagramami zależności. Diagramy przekształcono w model symulacyjny, który poddano weryfikacji. Proces weryfikacji modelu obejmował: ocenę poprawności wyboru granic modelowania, poprawności struktury modelu oraz spójności przyjętych wartości parametrów (stałych modelu) w porównaniu z dostępną wiedzą na temat modelowanego systemu; testowanie poprawności i spójności jednostek zmiennych przyjętych w modelu oraz testowanie działania modelu przy narzuconych warunkach skrajnych. Badania końcowe obejmowały symulację modelu na danych empirycznych zebranych w przedsiębiorstwie Alfa oraz badanie scenariusza „a co…jeśli…". Badania modelu pokazały, że nawet niewielkie zmiany norm sterujących systemem zarządzania materiałami w Alfa mogą mieć istotny wpływ na poprawę racjonalnego zarządzania tym systemem.

Słowa kluczowe: *modelowanie symulacyjne, Dynamika Systemów, gospodarka materiałowa w przedsiębiorstwie produkcyjnym.*