# Validity and robustness of system dynamics global models: the case of World3

Mathilde Jochaud du Plessix

## 1 Introduction

World3 is a flagship model, the first of its kind concerning global socio-environmental trends and global systemic risks. In particular, it was the first model to point out risks of global collapse, although the issue had been raised previously but not in such focused and argumented terms. The conclusions of this study have attracted a lot of attention, as well as a lot of criticism, in the years following its inception and publication (beginning of the 70s'). Some of them are reflecting more a misunderstanding of the model content, methods and conclusions, than a true scientifically founded critique.

The interest in the model has been revived in the last decade or so, in light of the growing concerns about planetary limits and the impact of human activity on natural systems. With this revival of interest came a new wave of criticism, most of it substantially more informed and more relevant than the first alluded to right above. This time, more serious points about the relevance of the model and its conclusions have been raised, some bearing to purely mathematical and methodological aspects, and some more related to epistemological issues. This PhD thesis ambitions to address these criticisms.

As a first task, I have been studying the structure and the behavior of World3, in order to offer a new and more sophisticated validation method of this model. The objective is to provide objective tools to assess what the model developers have been pointing out about its characteristics, behavior, and the conclusions they drew from them, through an automated model analysis. Indeed, the model is complex enough that a newcomer may not easily understand its structure and meaning, and may therefore find himself in the position to believe the authors on their word without being able to make his own opinion on their inferences. By developing an independent tool, and furthermore a tool that can assess the model without having to understand the details of its inner structure, we wish to provide an independent assessment of the conclusions drawn from the model, both in terms of mathematical methods and scientific point of view.

This does not imply that the authors of World3 are incorrect in their assessment — actually, in the view of the world global trajectory since the 70s, the exact contrary is expected from this analysis — but we aim to provide more confidence in this assessment. Indeed, not all aspects of the model behavior could be explored at the time of its publication, considering the limited computational means available then, even at MIT (the institution where the model was elaborated). However, some care must be applied in the approach adopted here. In particular, some comprehensive, but faulty, sensitivity analysis were produced quite early on (Vermeulen and De Jongh; Vermeulen and de Jongh), and reached incorrect conclusion, because they were too generic in their assessment of the model input parameters.

## 2 Comprehensive sensitivity analysis

In the existing literature, only a few papers focus on the analysis of the model in its entirety. The main work in this area is the PhD thesis made by Thissen (Thissen). Also, these analyses are partial and defective in that they do not take into account the meaning of the variables and the magnitude of their possible variation (a uniform 10% variation was applied to all independently of the significance of this variation for the considered variables).

In order to reassess the model sensitivity to its input parameter, we first translated it into Python from the available Vensim language version. This makes a more massive, systematic investigation possible, especially with the help of modern computational means. This translation was made in the STEEP team before the start of my PhD thesis, and is based on the 2004 version of the model Meadows et al.. For now, I have focused on the "Business As Usual" (BAU) scenario, as set up by the models developers.

The first part of my work was to carry out a sensitivity analysis of the parameters. For this, I have first had to define meaningful intervals of variations of the model parameters.

Next, I have used two methods to perform the intended sensitivity analysis: the Morris sensitivity method and the Sobol indices method.

The Morris method (Morris) is one-step-at-a-time screening analysis method that aims at determining parameters with negligible effects, linear or non-linear effects, and effects rooted in parameters interaction. It calculates the elementary effects on the outputs of small variations of a parameter's value. The Morris indices of each parameter are the average and the standard deviation of all elementary effects of the parameter. If a parameter has a strong non-linear effect, the standard deviation of its elementary effects will be important. If it has a strong linear effect, the mean of its elementary effects will be high.

Sobol's analysis (Sobol) is a method based on variance decomposition. It considers the input parameters as random variables and is concerned only with the output's variance. The Sobol indices estimate the part of the variance of the model output induced by each modification in the input parameters. This method enables us to identify each parameter's impact when it interacts with all the other parameters (Total-effect indices), when it interacts with one other parameter (Second order indices), and its main effect (First order indices).

Based on this work, I was able to identify the most influential parameters and had a first lead to estimate the most important parts of the model.

## 3 Structural dominance analysis

This leads to the second part of my work which was to carry out a structural dominance analysis. This analysis was first made on the model sectors (Population, Capital, Non Renewable Resources, Persistent Pollution and Agriculture) separately.

As a first approach, the method proposed by Ford (Ford) was applied. This method is a behavioral approach: it implies observing the behavior of the output when each loop of interest is deactivated. The behavior is identified by calculating the sign of the second derivative over time of the variable of interest. If the sign of the second derivative changes when a loop is deactivated, this means that this loop is dominant at that moment. The method is rather straightforward, but in the sectors having a large number of feedback loops it makes it difficult to identify the predominant loops efficiently enough.

As a coneqeunce, I turned then to the LEEA - Loop Eigenvalue Elasticity Analysis - method ((Kampmann and Oliva)). This method helped me establishing a loop hierarchy according to their dominance. It showed which loops were responsible for stabilizing/destabilizing the model along the time evolution of the BAU scenario. Besides, the construction of the SILS - Shortest

Independent Loops Set - (Oliva) also allowed me to have a better understanding of each sector's behavior.

The next step along these lines is to apply the LEEA on the entire model at once.

# References


David N. Ford. A behavioral approach to feedback loop dominance analysis. 15(1):3–36. ISSN 1099-1727. doi: 10.1002/(SICI)1099-1727(199921)15:1⟨3::AID-SDR159⟩3.0.CO;2-P. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/%28SICI%291099-1727%28199921%2915%3A1%3C3%3A%3AAID-SDR159%3E3.0.CO%3B2-P.

Christian Erik Kampmann and Rogelio Oliva. Structural dominance analysis and theory building in system dynamics. 25(4):505–519. ISSN 1099-1743. doi: 10.1002/sres.909. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/sres.909.

Donella H. Meadows, Jorgen Randers, and Dennis L. Meadows. *The Limits to Growth: The 30-year Update*. Routledge, rev ed edition. ISBN 978-1-84407-144-9.

Max D. Morris. Factorial sampling plans for preliminary computational experiments. 33(2):161–174. ISSN 0040-1706. doi: 10.1080/00401706.1991.10484804. URL https://www.tandfonline.com/doi/abs/10.1080/00401706.1991.10484804.

Rogelio Oliva. Model structure analysis through graph theory: partition heuristics and feedback structure decomposition. 20(4):313–336. ISSN 0883-7066, 1099-1727. doi: 10.1002/sdr.298. URL http://doi.wiley.com/10.1002/sdr.298.

I.M Sobol. Global sensitivity indices for nonlinear mathematical models and their monte carlo estimates. 55(1):271–280. ISSN 03784754. doi: 10.1016/S0378-4754(00)00270-6. URL https://linkinghub.elsevier.com/retrieve/pii/S0378475400002706.

W. a. H. Thissen. Investigations into the club of rome's world3 model : lessons for understanding complicated models. doi: 10.6100/IR79372. URL https://research.tue.nl/en/publications/investigations-into-the-club-of-romes-world3-model-lessons-for-un.

P. J. Vermeulen and D. C. J. de Jongh. Parameter sensitivity of the 'limits to growth' world model. 1(1):29–32. ISSN 0307-904X. doi: 10.1016/0307-904X(76)90021-4. URL http://www.sciencedirect.com/science/article/pii/0307904X76900214.

P.J. Vermeulen and D.C.J. De Jongh. Growth in a finite world—a comprehensive sensitivity analysis. 13(1):77–84. ISSN 00051098. doi: 10.1016/0005-1098(77)90010-3. URL https://linkinghub.elsevier.com/retrieve/pii/0005109877900103.