Making System Dynamics Cool IV: Teaching & Testing with Cases & Quizzes

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Abstract

This follow-up paper presents cases and multiple choice questions for teaching and testing System Dynamics modeling. These cases and multiple choice questions were developed and used between January 2012 and April 2012 a large System Dynamics course (250+ 2nd year BSc and 40+ MSc students per year) at Delft University of Technology in the Netherlands. The cases presented in this paper could be useful for teaching and testing introductory/intermediate System Dynamics courses at universities as well as for self study. For these cases, students need to develop simulation models, answer multiple choice questions related to their models, as well as open questions related to their modeling and model use. Second, the use of multiple choice questions and quizzes for teaching and testing System Dynamics understanding and modeling skills is discussed and illustrated. Finally, changes to the System Dynamics curriculum enabled by further development of the teaching/testing approach of the Introductory System Dynamics Course are discussed.

Keywords: System Dynamics Education, Case-Based Teaching and Testing, Traffic in Women, Housebreaking, Radicalization

1 Introduction

Many 'hot' –i.e. current real-world– teaching and testing cases are developed and used each year in the Introductory System Dynamics (SD) courses taught at Delft University of Technology's Faculty of Technology, Policy and Management. Hot cases are excellent tools for motivating students, for illustrating the relevance of SD modeling for real world problem solving, and for showing the way SD could be applied to real world cases. Such cases were previously discussed and made publicly available in (Pruyt 2009c; Pruyt 2010a; Pruyt 2011). Most of these publicly available cases focus on basic to intermediate SD model building skills, and –to a lesser extent– on basic model use, and communication skills. Students need some modeling experience/practice in order to be able to deal with these cases, but not too much in order to be challenged by the pre-specified nature of the cases (more advanced SD courses require cases that are less pre-specified). Two computer sessions with tutorials and simple exercises are sufficient to bring students to the level required for dealing with the first (the easiest) hot cases. After these initial lectures, students need at least five lectures on various topics as well as with feedback on their cases.

Making good SD cases is time consuming, hence, the need for sharing cases, especially 'hot' ones. But traditional correction of case-based SD modeling exams, especially for large SD classes (200+ students), is extremely time consuming too. Nowadays, model specification of student exam models is therefore captured and corrected in the Introductory SD course at Delft University of Technology by means of multiple choice questions. The use of a set of case-related multiple choice questions is interesting from a time-saving point of view: although it costs some time to compose them, they save about 20 minutes of correction time per student-exam compared to traditional

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correction of the model and the open questions. The use of multiple choice questions for testing (and teaching) purposes –both for testing general SD skills/knowledge and for case-based testing SD modeling skills– was already discussed but not illustrated in (Pruyt 2011). This paper presents several cases with multiple choice questions as well as general multiple choice questions. Finally, some recent experiences are shared related to teaching SD to large groups of –both bachelor and master– students with ever fewer human resources being available for teaching and supervision.

Section 2 provides a short overview of the SD curriculum at Delft University of Technology, the SD skills focused on in the introductory SD course, cases currently used in the introductory SD course, and an overview of publicly available SD cases developed for and used in the Introductory SD courses at Delft University of Technology. The new cases are presented in more detail in section 3. The use of model-related multiple choice questions is discussed and illustrated in section 4. The use of additional quizzes and multiple choice questions (not related to the case) for testing other SD related skills and knowledge is discussed and illustrated in section 5. New experiences, opportunities for the SD curriculum and conclusions are discussed in section 6. And, last but not least, the appendices contain the new cases presented in this paper as well as 14 examples of general multiple choice questions: appendix A contains the 'Prostitution and Human Trafficking' case, appendix B contains the 'Housebreaking' case, appendix C contains the 'De/Radicalisation II' case, appendix D contains the 'New Town Planning' case, appendix E contains the 'Project Management' case, appendix F contains the 'Cod or Not?' project case, and appendix G contains 14 examples of general multiple choice questions.

2 Case-based SD Teaching & Testing

2.1 The SD Curriculum at the Faculty of Technology Policy and Management of Delft University of Technology

System Dynamics (SD) is an integral part of two of the study programmes offered at the Faculty of Technology, Policy, and Management of Delft University of Technology. See for example (Meyers, Slinger, Pruyt, Yucel, and van Daalen 2010) for a description of the different SD courses in the 2009-2010 curriculum and their learning goals, and (Pruyt et al. 2009) for an explanation of the way in which real world complexity is introduced in a quadruple jump approach over the whole curriculum.

The introductory SD course for bachelor (BSc) students and master (MSc) students focuses on introducing the SD methodology, and on conveying basic to intermediate SD modeling skills. Although most students enter the course without prior SD knowledge, at least all BSc students have followed an introductory course on differential equations and an introductory course on policy analysis. 'Hot' cases of 1 to 2.5 pages are used during the 7-week 5-contact-hours-per-week course to demonstrate the use of SD in addressing current issues. The explicit learning goals of the introductory SD course are (i) to have basic knowledge of the SD field/philosophy/method, (ii) to be able to apply the SD method using SD software packages, and (iii) to have a basic understanding of SD model use and to have gained basic experience related to the SD modeling process.

Cases used for teaching range from simple to difficult, that is, difficult for a seven-week Introductory SD course. Exam cases are always intermediate/difficult and mostly relate to current and/or important issues. During the exam, students have 3 hours to answer 15 to 20 multiple choice questions related to SD methodology/insight/... (see section 5), and for solving an exam case with multiple choice questions and open questions (see section 4). Annual passing rates range from 55% to 95% (exam + retake exam) depending on the student group: passing rates for second year BSc students are always low (between 55% and 70%), and passing rates for first year MSc students are always high (between 90% and 95%) although the exams, the course, and the lecturer are the same. Hence, the difference in passing rates can only be attributed to time spend on the course, the desire to pass the exam[1], and the maturity of (pre-selected) master students.

[1]Dutch BSc students can take the exam over and over again whereas foreign MSc students need to pass their first or second attempt.

After passing the Introductory SD course, students take a mandatory SD project course. In the BSc project course, couples of students are supervised by student assistants and lecturers over a period of 7 weeks while modeling a larger case (of about 20-25 pages – see for example the case in (Meyers, Slinger, Pruyt, Yucel, and van Daalen 2010)). From 2011 on, students in the MSc project course are supervised only by one of two senior lecturers: at the start of the project course, students made a choice between two different types of projects – a more or less traditional SD project based on a project case description (group 1), or a project of their own choice (group 2). In 2011, about half of the students went for the traditional SD project on rolling out glass fiber, and the other half worked on projects of their own choice, covering issues from plastic soup (De Vos and van den Boogaard 2011) to human trafficking (Kovari 2011; Kovari and Pruyt 2012). The two groups had about the same average score or their exam, but the latter group consisted mainly of extravert and self-confident students who were prepared to receive public feedback.

Afterwards, students are allowed to write a BSc thesis in SD, follow the Advanced SD course, take Simulation Master Classes, and do an MSc thesis in SD. Students who follow all the SD courses on offer have almost the equivalent of a one-year, fulltime master programme in SD (Pruyt et al. 2009). In their full curriculum, however, students learn a range of problem exploration and structuring methods, and study other modeling methods, such as Agent-Based Modeling and Discrete Event Modeling.

2.2 Overview of Publicly Available Hot Teaching & Testing Cases Developed for, and Used in, the Introductory SD Course

Table 1 lists most of the publicly available teaching/testing cases developed and used for this Introductory SD course. These fully pre-specified cases typically focus on basic/intermediate SD modeling and simulation skills: mainly model specification, some model testing, some sensitivity testing and scenario analysis, some causal loop diagramming (detailed and aggregate), some focus on understanding and explaining the link between structure and behavior, and some policy testing. From week two on, cases like these are used – from simple and small to difficult and large. These cases require 95-99% of transpiration (applying trained skills), and only 1-5% of inspiration/insight.

Following cases –developed and/or used in the first four months of 2012– are presented below:

- **Stop Housebreaking!** – This case is especially interesting in view of testing model specification and policy analysis skills.
- **Prostitution and Human Trafficking** – This case is special in a sense that students need to adapt their simulation settings (to Euler with a very small time step) when implementing a ban on prostitution, and that they need to engage in reflecting beyond the exam model structures (a realistic model requires the separate modeling of both legal and illegal prostitution).
- **De/Radicalisation II** – This case is a tradition single stage model case, similar to, but sufficiently different from, the first radicalization students were familiar to.
- **New Towns** – This case is a rather simple town planning case based on the Richardson's urban model.
- **Project Management** – This case is a two stage project management case based on Richardson's project model.
- **Cod or not?** – This case is a test case for a new partly-closed SD project course set-up (between the old closed form and the recent open form).

These cases are briefly presented and discussed in section 3 in increasing order of difficulty/length of the case. The case descriptions and case questions are available in the appendices.

Case name / theme	Approp. (1 to 5)	**Difficulty for SD101**	**Time needed**	**Specifics**	**References (C=case ; A=analysis)**
Dutch Soft Drugs Policy	3	easy	1:00	qualitative	C & A in (Pruyt 2009b)
Pneumonic Plague	3	easy	1:00	small	C in (Pruyt 2010a)
EVs and lithium scarcity	3	easy	2:00	staged	C in (Pruyt 2009c)
Redevelopment of social housing districts	3	easy	2:00	abstract/highly aggregated	based on (Pruyt 2008a) C in (Pruyt 2009c)
...					
Hospital Planning	1	medium	1:00	technical ex.	C in (Pruyt 2009c)
Fall of the Fortis Bank	2	medium	2:00	simplistic	C in (Pruyt 2009d)
Oostvaardersplassen	4	medium	0:45	technical ex.	C in (Pruyt 2011)
Overfishing of NBF Tuna	4	medium	1:30	staged	C in (Pruyt 2011)
New Town Planning	5	medium	2:00	clear subsectors	C in this paper
Cholera in Zimbabwe	4	medium	2:00		C & A in (Pruyt 2009a)
Flu pandemic	5	medium	2:30	staged, builds up from simple	C in (Pruyt 2010a); A in (Pruyt and Hamarat 2010b)
Concerted run on DSB Bank	4	difficult	2:30	better than Fortis case	C in (Pruyt 2010a); A in (Pruyt and Hamarat 2010a)
Prostitution	5	difficult	2:00	somewhat staged	C in this paper;
Stop Housebreaking!	4	difficult	2:00		C in this paper;
De/Radicalisation I	4	difficult	2:30	not staged counterint.	C in (Pruyt 2011) A in (Pruyt and Kwakkel 2011)
De/Radicalisation II	4	difficult	2:30	not staged counterint.	C in this paper; A in (Pruyt and Kwakkel 2011)
Energy transition	3	difficult	2:30	bridge to SD project	C in (Pruyt 2011) A in (Pruyt, Kwakkel et al. 2011)
Boom & bust in Dubai	3	difficult	2:30	right/wrong	C in (Pruyt 2011)
Project Management	2	difficult	2:30		C in this paper
The 'slow students' fine	3	difficult	2:30	pulse train, etc	C in (Pruyt 2011)
Mineral/metal scarcity I	1	very difficult	3:00	1 major loop	C in (Pruyt 2010a)
Mineral/metal scarcity II	4	difficult	2:30	many specific functions	C in (Pruyt 2011) A in (Pruyt 2010b)
Energy versus Food Security		difficult and long	5:00	bridge to SD project	C in (Pruyt 2010a) A in (Pruyt 2008b)
Cod or not?		open & large	10+	bridge to SD project	C and A in this paper

Table 1: Publicly available cases in order of difficulty/length, the author's assessment of their appropriateness for testing intermediate modeling skills from 1 (lowest) to 5 (highest), their difficulty, minimal time needed, specifics, and references

2.3 Case Related Materials

Currently, students have following materials at their disposal: a lecture notes book, a case book with nearly exercises and cases (updated annually), all case models on blackboard (but released with a delay), some case models on forio (for model verification), 130+ examples of multiple choice questions. Students attending the lectures are also exposed to three series of 20 exam grade multiple choice questions (lectures 1, 4 and 6). Moreover, students can stream recordings of the 2010-2011 lecture series (this may well be a mixed blessing). A small minority of students also downloads the indicative case solutions available on the web site of the System Dynamics Society (Pruyt 2009c; Pruyt 2010a; Pruyt 2011).

Soon, there will be, for each case, (*i*) a case description, (*ii*) example models for different packages (Vensim and Powersim), some of which available with a forio interface for verification purposes, (*iii*) a pdf with answers to the open question, (*iv*) a correction sheet for lecturers, (*v*) an mp4 recording of the modeling by the author, (*vi*) an mp4 recording of feedback related to the case, and (*vii*) several multiple choice questions. The whole package will soon be publicly available as an e-book, part of it as Open Course Ware, and all materials plus online student-professor interaction as part of an online education pilot.

3 Teaching and Testing Cases – Vintage 2011-2012

3.1 Case 1: Housebreaking and Policing

The housebreaking (HB) case is a case of intermediate difficulty about recurrent and reinforced cycles of housebreaking. First, students need to build a SD model (see Figure 1) and specify all functions, including information delays, a sinus function, max/min functions, and 'with lookup' functions. After verifying and validating the model, students are asked to draw the model behavior over time (see Figures 2a and 2), perform sensitivity analyses (see Figures 2c and 2d). Here, a decrease of the *acceptable number of HB* by 11% (sens1) and an increase of the *chance of being caught for HB in neighboring countries* by 10% (sens2) are visualized: *sens1* leads to an overall decrease of HB both by occasional thieves and by OC (Organized Crime) (more vigilance leads to fewer opportunities, and hence, a higher chance of being caught), and *sens2* leads to more HB by the OC, more vigilance, and therefore less HB by occasional thieves.

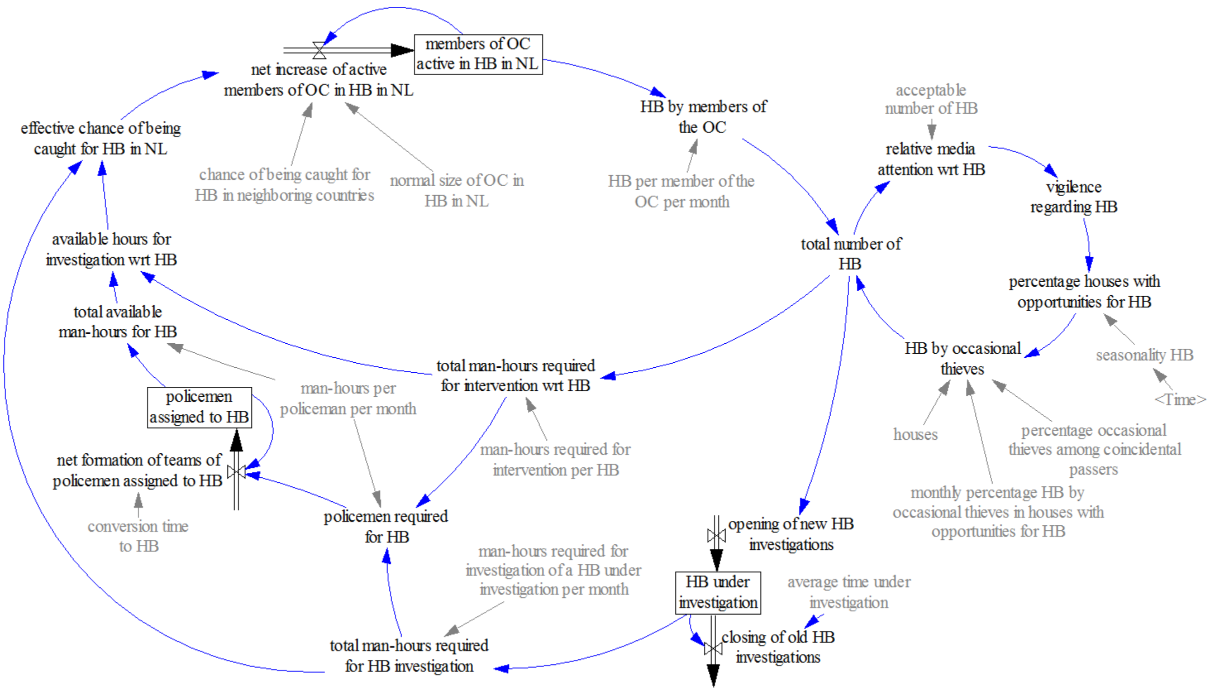
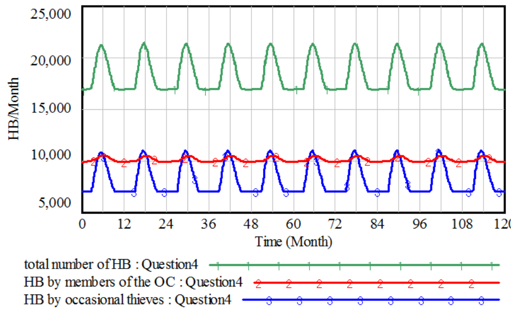


Figure 1: Stock-flow diagram of the HB model

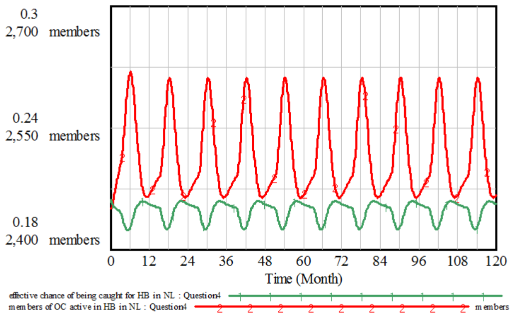
Then students are asked to make an extremely aggregate causal loop diagram (see for example Figure 2e) in order to communicate the relation between structure and behavior of the model to the chiefs of police. Using the diagram in Figure 2e, the explanation could be as follows:

> 'The *occasional HB* loop balances the exogenous seasonal pattern but with a delay: summer offers more opportunities for occasional thieves, resulting in a seasonal increase in the number of housebreakings, after a while to more media attention, more vigilance, and therefore after some time to fewer houses with opportunities for occasional thieves. However, an increase in the number of housebreakings also leads –given a given total amount of man-hours dedicated to housebreakings– to a lower relative chance of being caught, and consequently, more housebreakings by the OC, until the total amount of man-hours dedicated to housebreakings has increased, raising the chance of being caught, and reducing the number of housebreakings by the OC.'

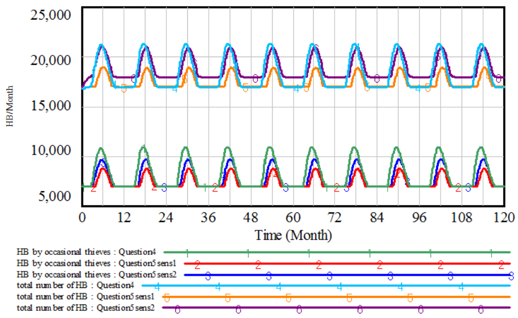
Finally, students are asked to hack the model in order to adapt it to a client's remark (see Figure 2f), and use the model for policy analysis; acceptable policy advice would for example be to reduce



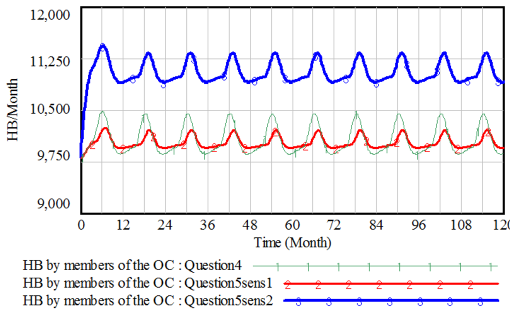
(a) Base case behavior of housebreakings and. . .



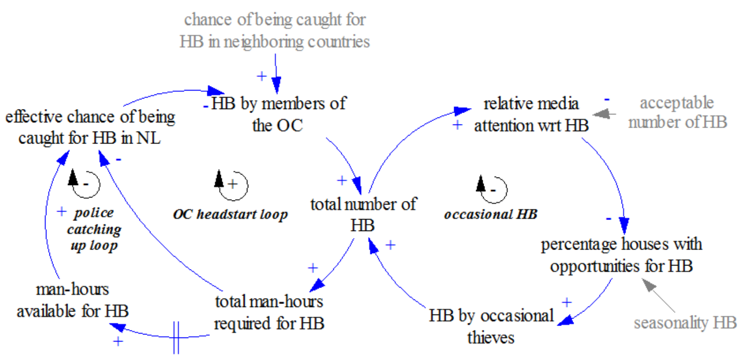
(b) . . . the chance of being caught vs OC activity



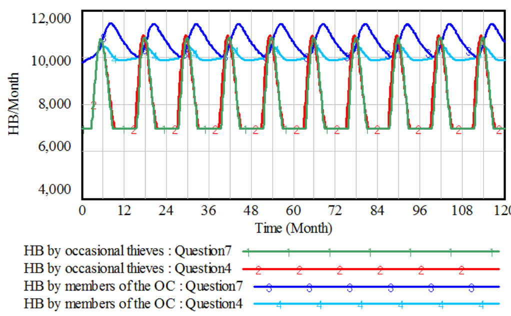
(c) sens1: *acceptable number of HB* = 4000 instead of 4500 – sens2: chance of being caught for HB. . .



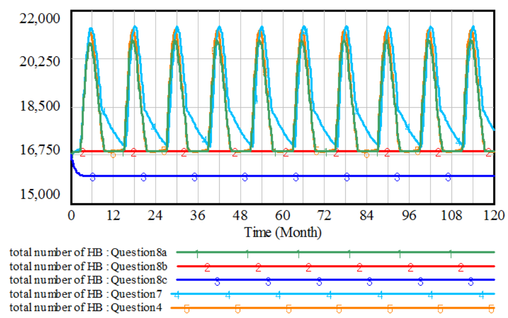
(d) in neighboring countries = 0.22 instead of 0.2



(e) CLD to explain the link between structure and behavior



(f) Hacked behavior



(g) Policies to reduce both types of HB

Figure 2: Base case behavior, sensitivity analysis, causal loop diagram, hack, and policy analysis related to the HB case

the acceptable number of HB in order to raise media attention and vigilance and proactively assign policemen to housebreaking by the OC (see Figure 2g).

Almost all students were able to build the model. Many students made specification errors, especially errors related to min/max functions. Another common –but surprising– error was the modeling of the *total number of HB* as a stock variable with two inflows and no outflows instead of a simple auxiliary variable summing the values of the *HB by members of the OC* and the *HB by occasional thieves*. During the validation phase, some students realized something was wrong and corrected their error – a few students by extending the stock-flow structure correctly beyond the model description. Many students lost many points because they did not spend sufficient time/effort at answering the open questions.

3.2 Case 2: Prostitution and Human Trafficking

The Prostitution Case was inspired by one of the SD projects for the MSc SD project course (see (Kovari 2011; Kovari and Pruyt 2012)). In this staged case, students first need to build a small population model (see Figure 3a) and make a detailed causal loop diagram (see Figures 3b) as well as an aggregate causal loop diagram of this model (see Figure 3c). Most students only made a single causal loop diagram – mostly just a detailed causal loop diagram.

Then students need to model the remainder of the case (see Figure 3d), using min(1,(max(0,. . .)) functions (*societal acceptability of prostitution*), max(0,. . .) functions (in light blue), 'with lookup' functions (in yellow), and smooth3I functions (in orange). While verifying, students also need to figure out that an additional real-world time-related variable (*delivery time*) is required to match the units between flow and auxiliary variables. The students are supposed to change the first order structure *births-children-from minors to adults* into a fixed delay of 18 years (in light green). Many students messed up doing this and did not find their error in spite of impossible outcomes caused by it.

Then students are asked to add some variables in view of simulating the effect of a sudden illegalization of the supply of prostitution (variables in red), requiring a step function (*influence of illegalisation on the societal acceptability of prostitution*), a pulse function[2] (*reduction of supply through illegalisation*), and –because of this abrupt policy change– the use of the Euler integration method with a rather small time step (e.g. 0.0078125).

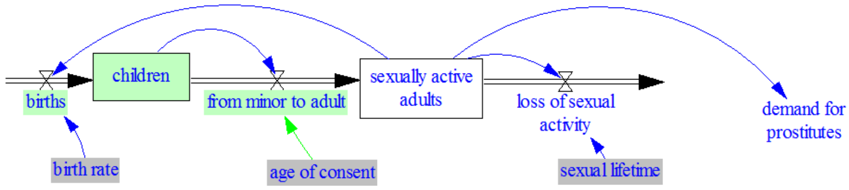
In the open questions, students need to show they can validate the model, simulate the model, draw decent graphs (see Figures 4a and 4b), and interpret the dynamics. An acceptable interpretation may sound as follows:

> A sudden ban on prostitution may eliminate the supply for some time, but not the demand. Temporarily higher prices and a permanently lower societal acceptability of prostitution may strongly depress the demand for a while, after which demand will rise again and stabilize between the initial level and the depressed level at which the price mechanism balances supply and demand. Total prostitution revenues will fall dramatically before overshooting and stabilizing at a lower level. However, illegal prostitution, organized crime, and human trafficking will rise since prostitution will be illegal after the ban, and living conditions of prostitutes will most likely deteriorate.

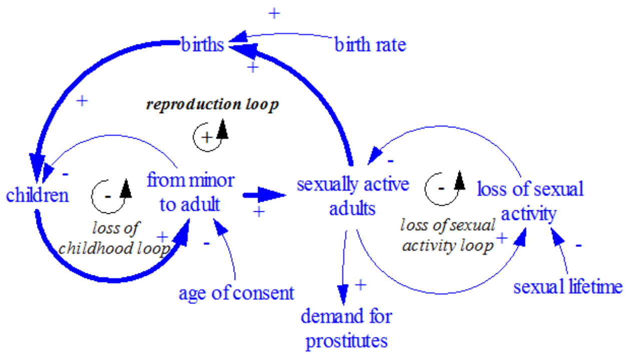
Students are also required to make an aggregate causal loop diagram of this model with this policy (see Figure 4c for a slightly aggregated diagram – more aggregated diagrams that respect the balancing nature of the system may be even better), and explain the relation between structure and behavior of this model with this policy using the diagram. A possible explanation would be:

> All feedback loops –except the *supply price demand supply loop*– are negative loops balancing supply and demand. Since demand does not fall to zero, they force the system after the initial supply shock back to a level of societally acceptable supply and demand.

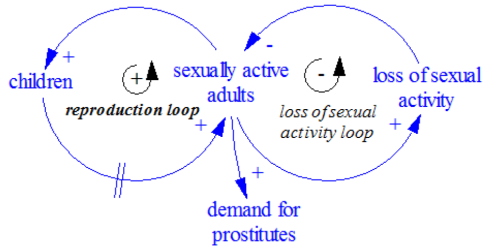
[2] More precisely, a PULSE function in Vensim and a PULSEIF function in Powersim.



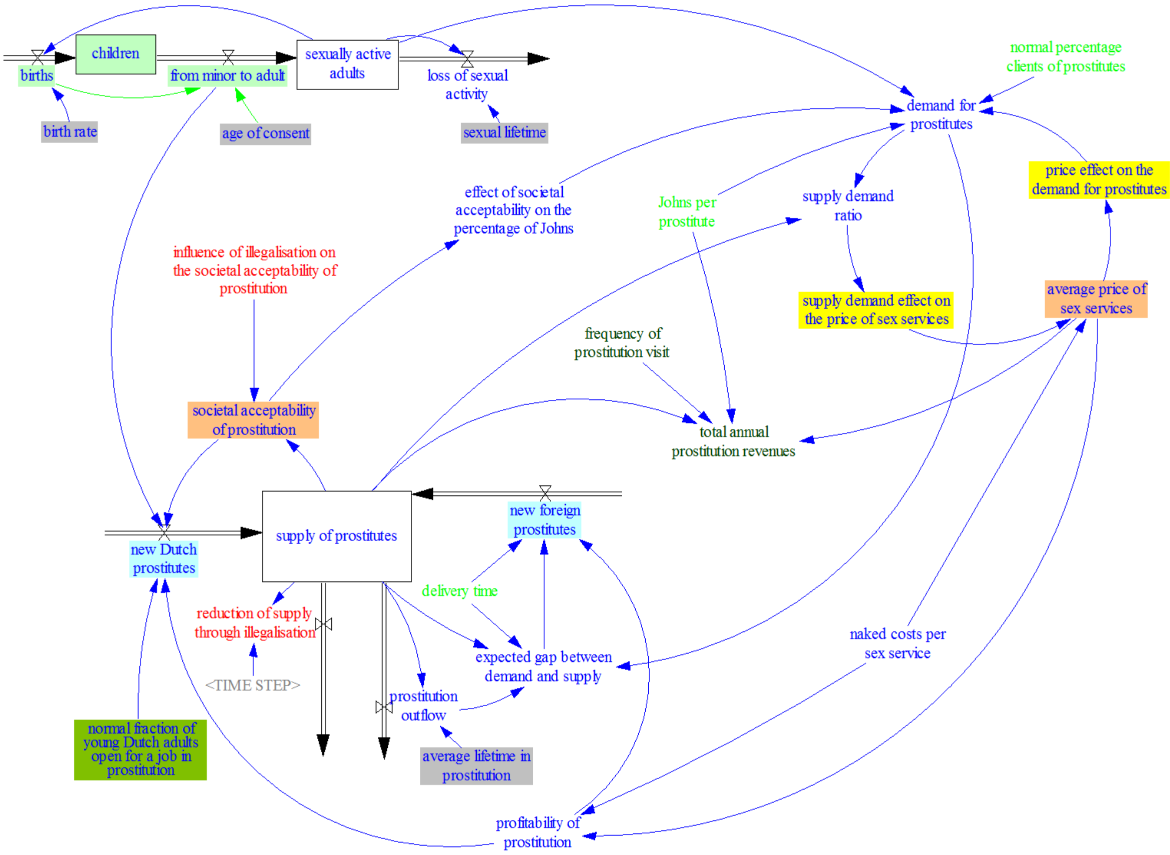
(a) Stage-one stock-flow diagram



(b) Detailed causal loop diagram

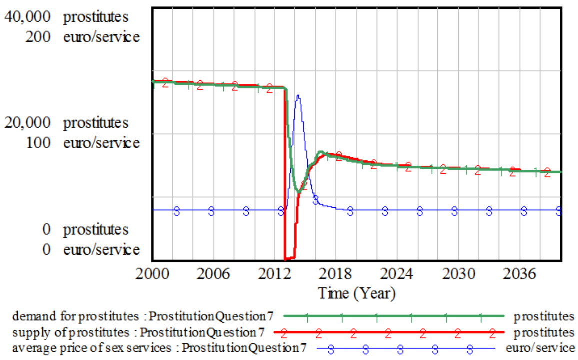


(c) Aggregate causal loop diagram

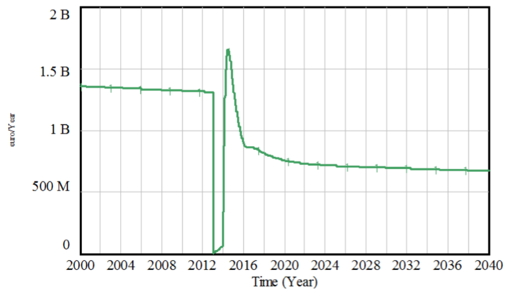


(d) Full stock-flow diagram of the prostitution and human trafficking case

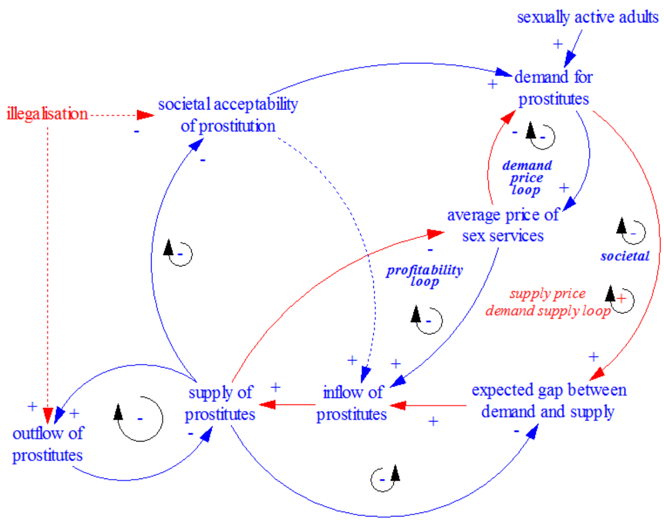
Figure 3: Stage-one stock-flow diagram and corresponding causal loop diagrams, and full stock-flow diagram of the prostitution and human trafficking case



(a) Demand for (green), and supply of prostitutes (red), with their main regulating mechanism, the price of sex services (blue)



(b) total annual prostitution revenues (green)



(c) Minimally aggregated causal loop diagram to explain the link between structure and behavior

Figure 4: Behavior of the model including the sudden illegalization of the supply side of prostitution, and causal loop diagram to explain the behavior

Finally students are asked to perform sensitivity analyses and propose an effective policy to address the trafficking and organized crime related to prostitution. The model could be used to illustrate that banning prostitution without fully eliminating the demand leads to highly undesirable outcomes: illegal prostitution and human trafficking by organized crime to fulfil demand. It is rather difficult though to test other policies with this simplistic version of the model. All common sense and systemic policy proposals were considered acceptable, for example, many students suggested (*i*) fighting human trafficking by organized crime without banning prostitution, and (*ii*) providing information about the downside of prostitution in order to reduce societal acceptance, and hence, demand.

3.3 Case 3: De/Radicalisation II

This case was used for one of the versions of the 2011 SPM2313 retake exam, as well as for the 2011/2012 EPA1322 exam. It is a traditional single stage case, very similar, but sufficiently different from, the first De/Radicalisation case available to students: this case adds structures related to activists and extremists in line with (AIVD 2010), and omits stock-flow structures related to the action level of convinced citizens.

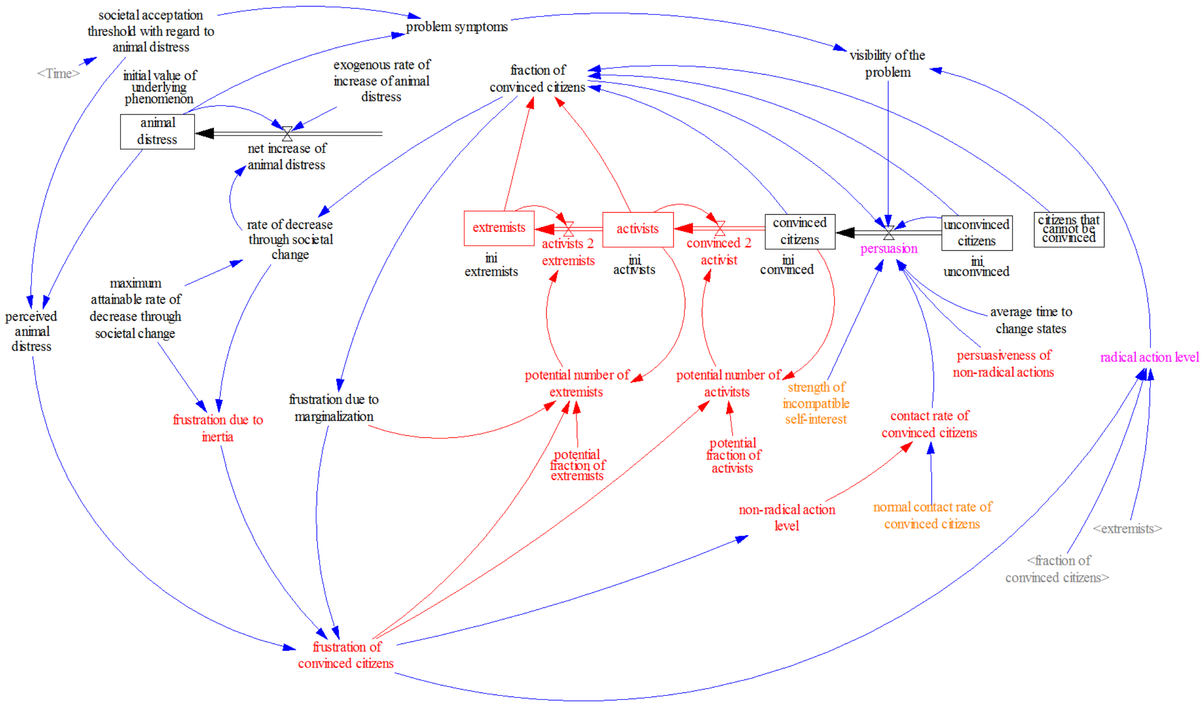
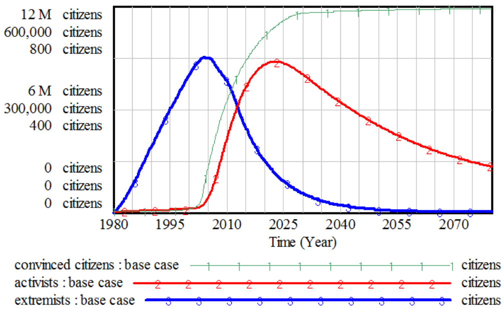


Figure 5: Stock-flow diagram of the De/Radicalization II model

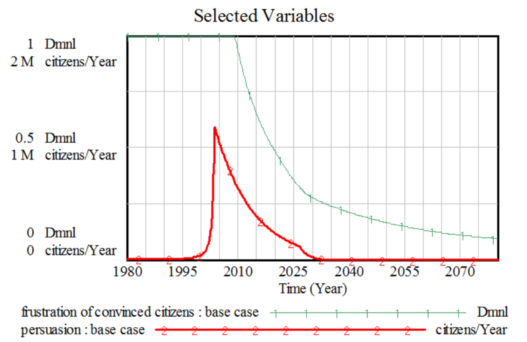
With these changes, the model student have to build (see Figure 5) generates behaviors that are sufficiently different from the first radicalization case. Then students are required to answer open questions related to model testing and model use.

First, students need to simulate the model and make behavior over time graphs (see Figures 6a and 6b), perform model validation, as well as sensitivity analysis (e.g. 6c and 6d) in view of developing different scenarios (see Figure 6e and 6f). Sensitivity analyses (e.g. 10% lower/higher) starting from these values only show numerical sensitivity of the key performance indicators to these changes. However, larger changes

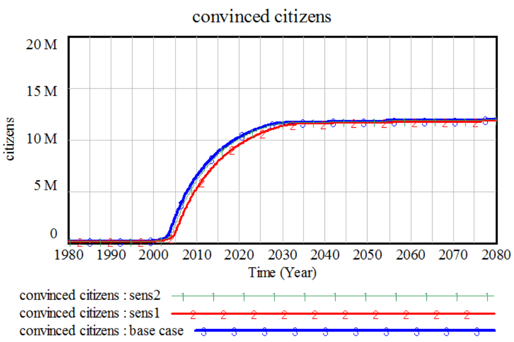
Then students are required to make a highly aggregated causal loop diagram of this model in order to explain the link between structure and behavior of one of the scenarios. An acceptable explanation might be: The SIR-like persuasion process may be triggered by extremists, who loose their extremists edge in case of success. Successful persuasion will lead to a reduction of the underlying problem, slowing and eventually stopping further persuasion. Finally, students are asked to formulate policy advice based on this exercise wrt animal right activism, and modeling advice wrt future extensions and refinements of the model. Policy advice could be to first de-marginalizing and hence de-extremize extremists through reinforced persuasion of the population and/or second to solve the underlying problem.



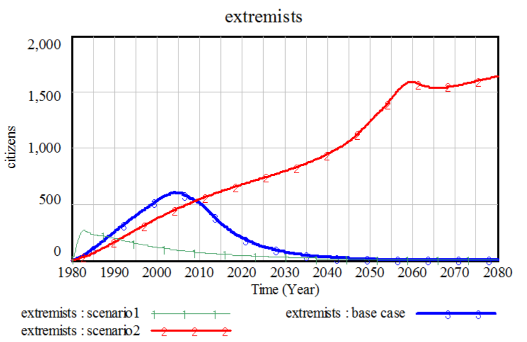
(a) Convinced citizens, activists, and extremists



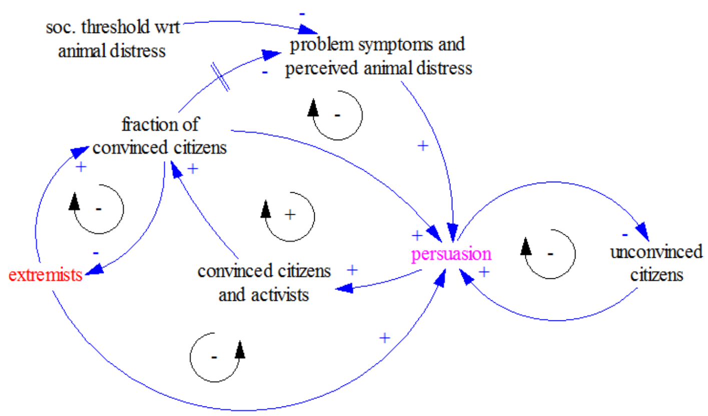
(b) Persuasion rate and frustration of all convinced citizens



(c) Sensitivity analyses (convinced citizens)



(d) Scenarios



(e) Aggregate CLD for S-shape like persuasion scenarios

Figure 6: Base case behavior, sensitivity analyses, different scenarios, and an aggregated CLD for S-shaped like behaviors

3.4 Case 4: Long Term Planning of New Towns

The long term planning of new towns case is about increased urbanization through so-called 'New Towns'. The concept of 'New Towns' relates to more or less independent new towns at large distance from existing cities. There are hundreds of new towns around the world and many new ones are under construction (especially in Asia and Africa). Although the number of inhabitants of these cities varies from less than 50000 to more than a million, and although they are very different in objective function and design, there are interesting dynamic parallels and the same 'mistakes' made over and over again. This case is directly based on a modified version of Richardson's URBAN1 model[3] and indirectly on other SD work on urban dynamics (Forrester 1969) [add references].

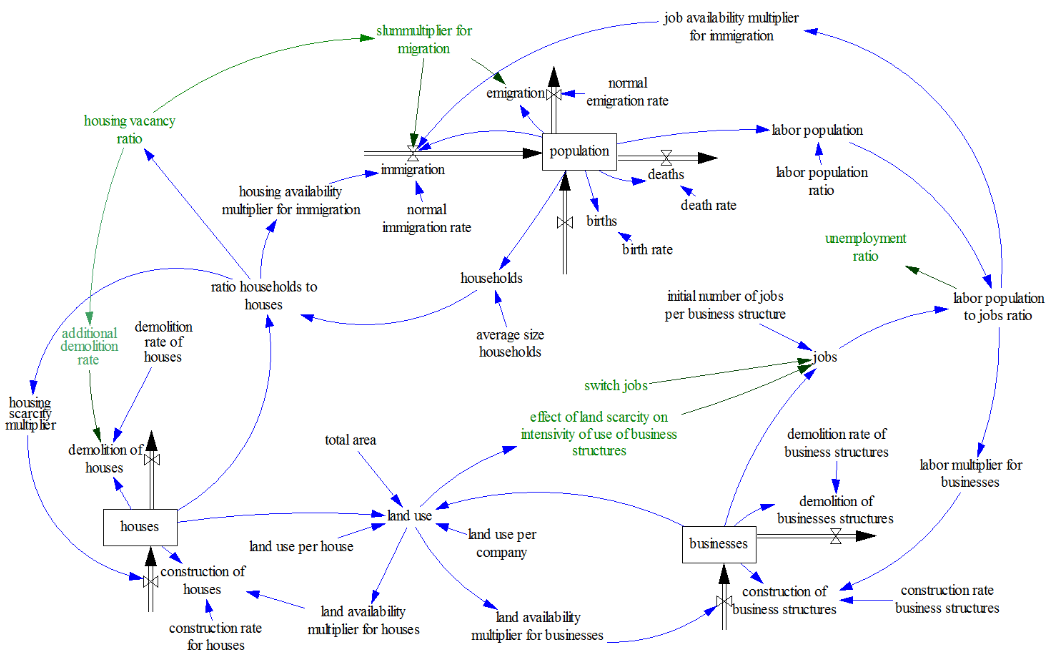
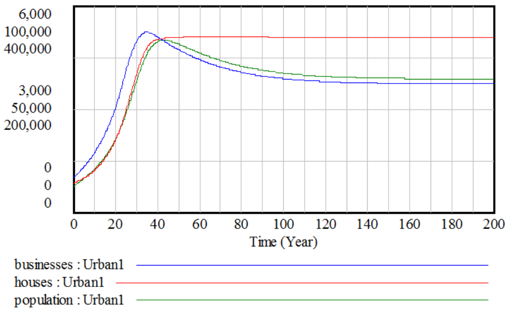


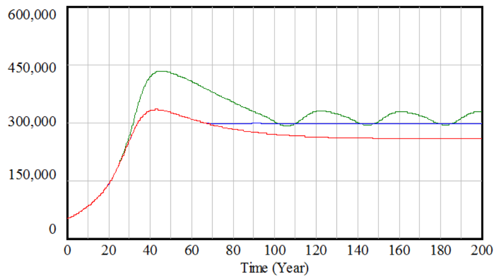
Figure 7: Stock-Flow diagram of the full New Towns model (based on Richardson)

First, students need to model and connect submodels regarding population, housing, and businesses (see Figure 7). They are asked to simulate the model over a time horizon of 200 years, make graphs of the dynamics (Figure 8(a)), and identify problems related to the dynamics of new towns. Then they have to make a strongly aggregated causal loop diagram of this system model and use it to explain the model behavior (see Figure 8(g)). Subsequently, students have to add and test the effect of (i) a slum multiplier (ie the impact of high housing vacancy ratios on migration) and increased demolition in case of high housing vacancy ratios, and (ii) the effect of land scarcity on the intensity of use of business structures (ie more jobs per acre). Comparing graphs of the resulting dynamics (see Figures 8(b-f)), students need to realize that these effects and policies positively affect the housing vacancy ratio, but do not solve the problem of high unemployment ratios. After briefly validating the model, and performing sensitivity analyses in view of resolving remaining problems, students need to suggest (and model) policies to solve them.

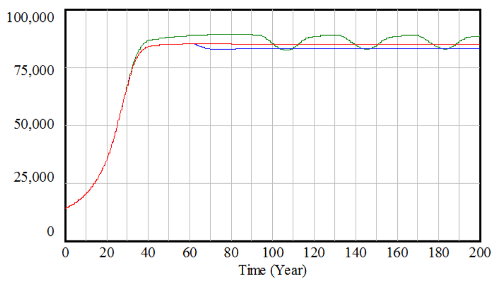
[3] URBAN1 is available at `http://www.albany.edu/faculty/gpr/PAD624/urban1.mdl`.



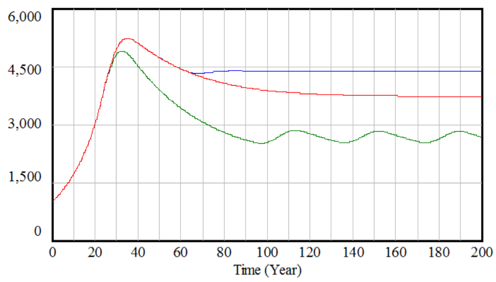
(a) New town start



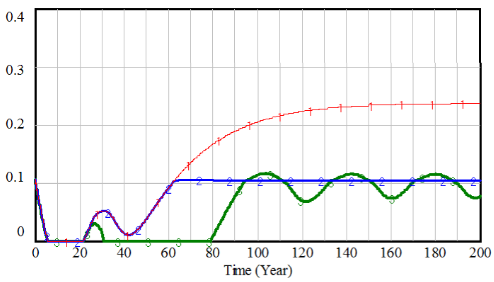
(b) Population



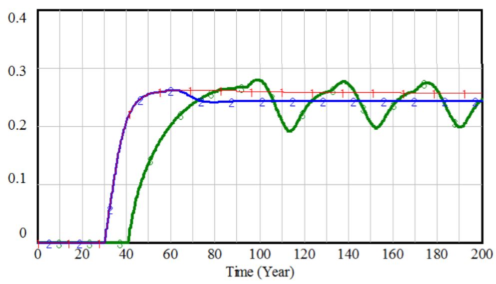
(c) Houses



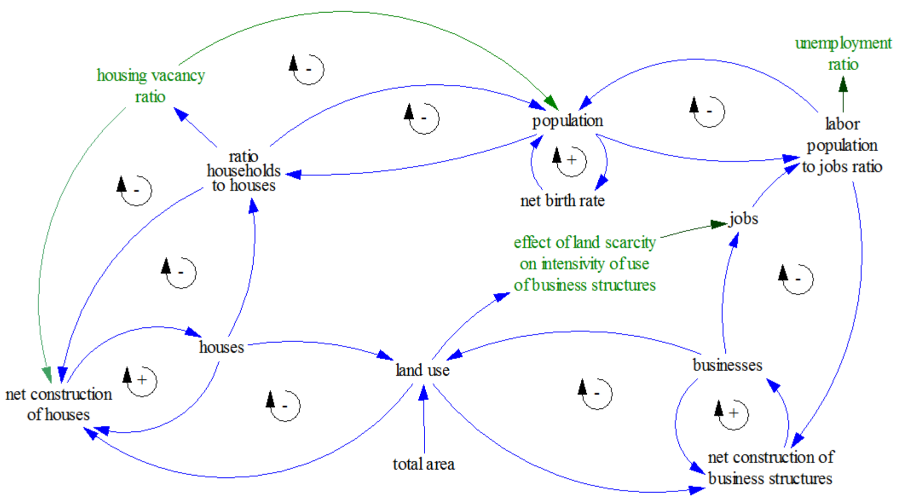
(d) Businesses



(e) Housing Vacancy Ratio



(f) Unemployment Ratio



(g) Causal Loop Diagram

Figure 8: New towns planning: Initial dynamics ((a) and red in (b)-(f)), extension 1 (slum multiplier on migration and additional demolition – blue in (b)-(f)), extension 2 (extension 1 with endogenous effect of land scarcity on intensity of use of business structures – green in (b)-(f)), and an aggregated CLD

3.5 Case 5: Project Management

This staged project management case is largely based on George Richardson's Project models[4]. In the first stage, students need to make and simulate a project model without testing and rework in which quality issues remain unnoticed (see Figure 9). In the second stage, students need to extend the first model with undiscovered rework, testing, rework, et cetera. Students then need to validate the extended model, make graphs of the dynamics (see Figures 10(a)-(c)+(d)), interpret the results, add an endogenous testing policy (see Figures 10(a)-(c)+(e)), test it, test the sensitivity of the outcomes for changes in two assumptions, and propose and test a strategy for managing extreme workforce fluctuations.

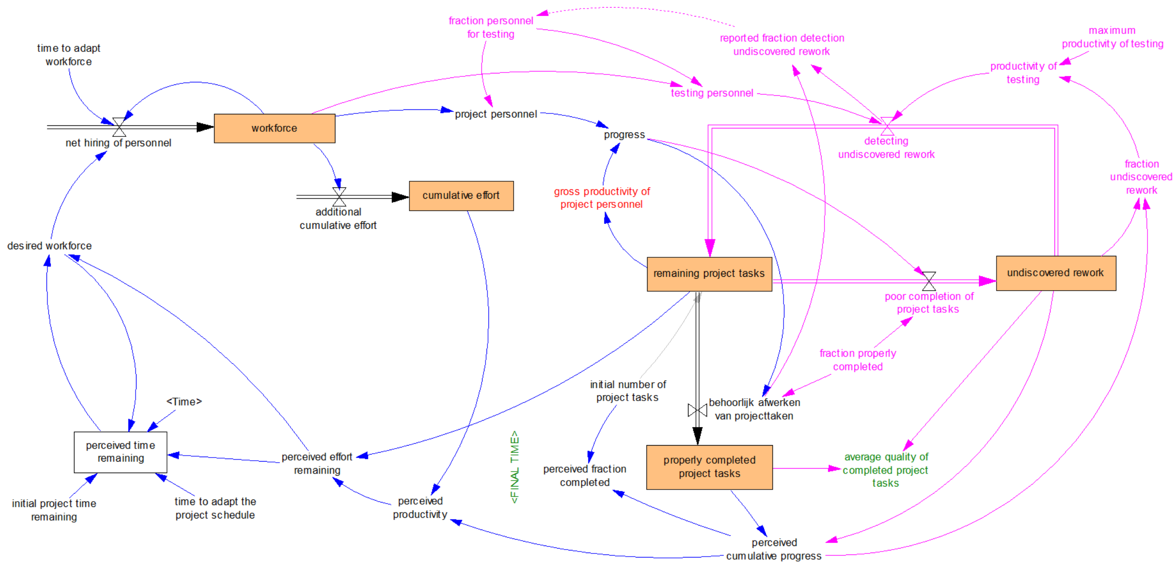
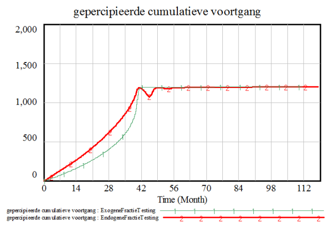


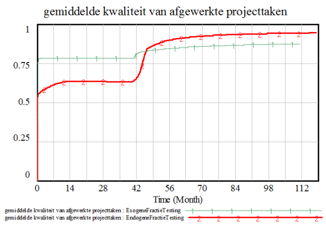
Figure 9: Stock-Flow diagram of the full Project Management model (based on Richardson's project model)

Overall, student performance on this case was relatively bad: students did not encounter problems in the first stage, but did in the second stage, and hence, lacked time. It seemed like students did not understand the fact that part of what is modeled remains hidden from the actors in the system.

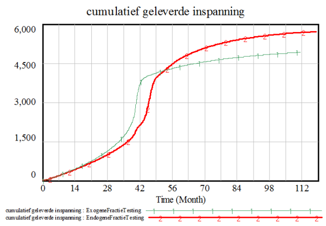
[4] Available at `http://www.albany.edu/faculty/gpr/PAD624/project1v3.mdl`.



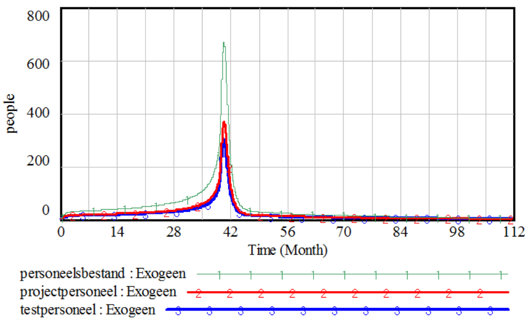
(a) Perceived cumulative progress (endogenous = red)



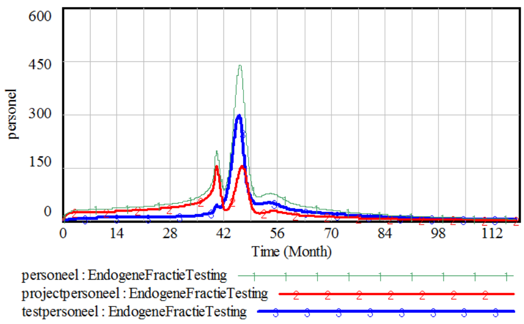
(b) Average quality completed tasks (endogenous = red)



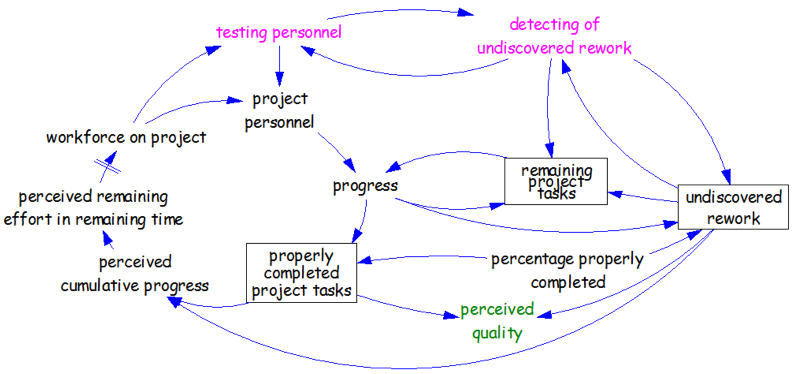
(c) Cumulative effort (endogenous = red)



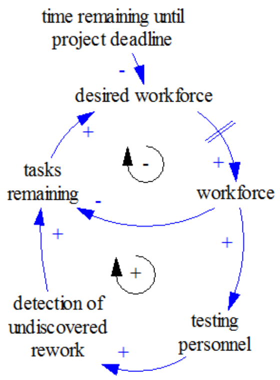
(d) Personnel (exogenous strategy)



(e) Personnel (endogenous strategy)



(f) Aggregated CLD by one of the students



(g) Strongly aggregated CLD by one of the students

Figure 10: Behavior of the model without and with endogenous testing strategy, and aggregated CLDs

3.6 Case 6: Cod or not?

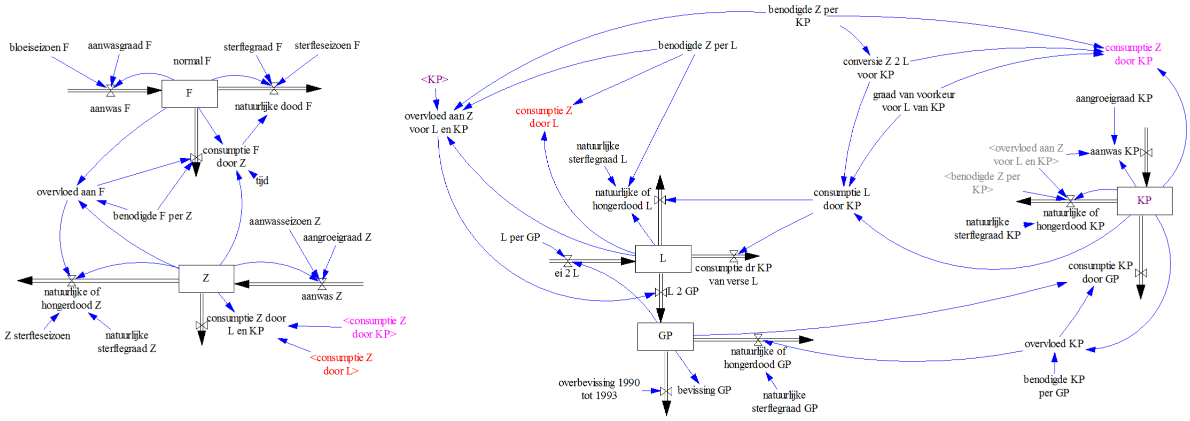


Figure 11: Stock-flow diagram of a possible model for the first part of the cod case

The short case description of the cod case, already leads to much larger simulations models (note: model*s* because even the base case is open to different assumptions and formulations) than the largest simulation models developed in the Introductory SD course (see Figure 11). All students should be able to develop a decent model. Extending the model based on article (Frank, Petrie, Fisher, and Leggett 2011) may improve the model related to the theory of Frank et al. – showing the different between average and above average students. Extending the model with (exotic) species, and/or jellyfish, and/or climate change leads to very different exploratory models – showing the difference between good and very students. Modeling the perspective of dr. B. Rothschild and using both models for policy testing will even challenge excellent students.

4 Correcting Exam Cases with MC Questions

Not only is it time consuming to make appropriate exam models, it is also time consuming to correct them properly. At least, it was. Until the end of 2010, exam models were evaluated in detail by lecturer and student assistants – on average 30 minutes per exam... Significant cuts in the number of student assistants available for the introductory course forced the author to test new ways of evaluating exam models without eroding the goals and quality of course and exams.

In January 2011, the author tested the use of multiple choice questions about the modeling and simulation in combination with quick scanning of the model (about 5 minutes per model) and compared it to detailed grading of the same models (about 30 minutes per model). Surprisingly, almost all students obtained slightly lower grades via the multiple choice questions, and higher grades via the quick model scan, resulting in the end in averages consistently similar to the detailed grades. Although it takes more time to prepare exams with multiple choice questions about the modeling and simulation, there is an enormous time gain with this new approach: for 200 exams, the difference amounts to about 60 hours (200 exams x 20 minutes difference per exam - 180 additional minutes to develop a MC version times 3 versions). Hence, from April 2011 on, all exam cases are corrected with as many multiple choice questions and as few open questions as possible.

Moreover, introducing multiple choice questions to evaluate students' modeling and simulation of the exam case led to the realization that students were over-tested because of an overlap between model-based multiple choice questions and general multiple choice questions. This lead to a reduction of the number of open multiple choice questions from 20 to 15 – freeing up some time for the remainder of the exam. The remaining 15 multiple choice questions are selected such that overlap is minimized (except for redundancy for triangulation purposes) and that aspects tested over are maximized.

5 Open MC Questions

These additional multiple choice questions are unrelated to the main modeling question and model-related multiple choice questions and cover unaddressed issues in the remainder of the exam from nine categories:

1. SD Philosophy, SD Methodology, or 'SD speak'
2. SD Diagramming (Loops, SFD to CLD to SFD)
3. Specification (Delays, Special Functions, . . .)
4. Calculation, and Quick and Dirty Modeling and Simulation
5. Verification, Simulation Settings, Units
6. Validation, Sensitivity Analysis, Extreme Value Testing, and Uncertainty Analysis[5]
7. Reading Graphs, Interpreting Behavior, Linking Structure and Behavior
8. Model Use and Policy Analysis
9. Applied Systems Thinking, and Archetypes

Examples of each of these categories (14 in total) are available in appendix G (from p40 on). Many multiple choice questions relate to (publicly available) cases worked on by the students during the computer labs (or at home) and fed back on during the lectures. Multiple choice question 1 consists of quotes –one of them incorrect– some of which were used in the lectures and some of which are used at the beginning of a book chapter of the lecture notes. Multiple choice question 2 relates to counting the minimum loop set in a case model about bluefin tuna (Pruyt 2011). Multiple choice question 3 consists of identifying the SFD corresponding to a CLD of the pneumonic plague model (Pruyt 2010a). Multiple choice question 4 relates to identifying the most appropriate aggregate causal loop diagram to communicate the link between structure and behavior of the district housing case model (Pruyt 2009c). Multiple choice question 5 relates to the formulation of delays of intermediate complexity. For multiple choice question 6 students need to perform relatively simple calculations. For multiple choice question 7, students need to build a simple case model related to gas reserves –from the exercise book and jointly built in class– and simulate it. Multiple choice question 8 is about verification, more precisely about an integration error using the pneumonic plague model (Pruyt 2010a). Multiple choice question 9 tests dimensional analysis skills related to the case on the large-scale introduction of electrical vehicles (Pruyt 2009c). Multiple choice question 10 tests the interpretation of outcomes of sensivity/uncertainty analyses related to one of the radicalization case models (Pruyt and Kwakkel 2011). Multiple choice question 11 tests wether students are able to read and interpret a graph, in this case a graph related to learning curve effects

[5] Many students mix up sensitivity analysis, extreme value testing, and uncertainty analysis. The phase sensitivity analysis is used in the introductory SD course to refer to the analysis of the effect of a small change to or the slightly different value (plus or minus 10%) of parameters and lookups from a base case on the mode of behavior (behavioral sensitivity) or choice of policy (policy sensitivity). The phrase uncertainty analysis is used to refer to the exploration of the influence of the entire uncertainty range; so if the uncertainty range of a parameter ranges from 0% to 100%, then 0% and 100% need to be tested (as well as all values in between). Under deep uncertainty, uncertainty analysis does not start from a base case. And the phrase extreme value testing is used to refer to checking whether the model structure is acceptable given extreme (even totally unrealistic) values. So we may set the Dutch population to 0 citizens in an extreme value test; it may have an uncertainty range between 14 million and 24 million 30 years from now; and we may want to test the sensitivity of some model outputs to a 10% difference in size of the population or an increase with 10% from 16670000 to 18337000 (because if that difference leads to significant changes in behavior or preferences for policies, then we may be in trouble).

of competing energy transitions (see (Mohammed and Pruyt 2012) for research conclusions related to this question). Students were asked to play a forio game related to this exercise before the exam and part of the students were familiar with learning curve effects from the energy transition case (Pruyt et al. 2011). In multiple choice question 12, students have to derive the smoothed stock variable behavior of large herbivores in the Oostvaardersplassen (Pruyt 2011) from the behaviors of the two corresponding smoothed flow variables. Multiple choice question 13 is a simple model use question related to pandemic shocks. Students received a lengthy explanation about exploratory modeling of future pandemic shocks based on (Pruyt and Hamarat 2010b) during the lecture on model use, and all students had to build the pandemic flu case model. In multiple choice question 14, students need to identify the archetype that corresponds best to a short description related to climate change.

6 Changes to the SD Curriculum

The high level attained by students after the introductory SD course –among else due to the use of these hot teaching and testing cases– also necessitated changes in the rest of the curriculum.

The well-specified cases used during the SD project may now be replaced by less structured cases with less but high-quality supervision. The project case used in the SD project course taught to about 45 master students per year was therefore changed into an almost entirely unstructured hot case for those students who believed they were up to the challenge. These students chose a topic (from a wide range of research interests of the senior lecturer responsible for the group), and preferably on joint topics. The 2011 batch of students worked on:

- the Greek economic crisis; unemployment in Greece; regional inequality in India; urban rural income inequality in India (1980 to 2010); income inequality in general; the Effects of IMF Measures on Central Eastern European Countries;
- Police Corruption and Organized Crime; Illicit Trade of Heroin to Europe; Prostitution and Human Trafficking;
- Plastics in the North Pacific Ocean; Energy Transition in the Built Environment; Cobalt scarcity and energy security;
- Antibiotic Resistance; the Obesity Pandemic; and the effect of food aid on agriculture and food security in the Horn of Africa.

Many of these projects were too ambitious – about which students were warned and advised during the first coaching session in the first and second project week. However, choosing realistic issues and setting the boundaries were two important learning goals. Many students struggled the first two weeks with their topic and the boundaries. But almost all students were able to deliver their model and report within 5 weeks. All students experienced the difficulties of modeling and simulation, and, due to the joint feedback sessions, recognized all other students went through the same phases with the same obstacles, and learned from each others projects and mistakes. However, this open SD project form is not appropriate for all students, nor for all supervisors, nor for all group sizes. Different types of semi-structured SD project may be needed for different students, supervisors, and group sizes.

The Cod Case is an example of a semi-structured case for relatively large groups (or smaller groups with students with less self-esteem) that will be tested next.

Changes to the Introductory SD course and to the SD project course also impact SD BSc thesis, until recently a closely supervised individual student project. Instead of traditional SD BSc theses, students are now asked to go beyond traditional SD projects and venture into ESDMA or Simulation and Gaming. BSc students are now supervised in small classes (instead of individually) in order to efficiently teach them different skills –new to all of them– required for ESDMA and model-based gaming, and to stimulate them to learn together and support each other. Moreover, students are embedded in one of our research teams.

Changes to the Introductory SD course and to the SD project course (will) also impact the Advanced SD course: now, even more time can be spent on truly advanced issues (eigenvalue elasticity analysis and formal analysis, multi-player serious gaming, Exploratory System Dynamics Modeling and Analysis, et cetera). These changes are on next year's agenda.

7 Conclusions, Lessons Learned, Proposal

All new testing/teaching cases developed over the last three years for this introductory SD course have been based on 'hot' issues. The use of 'hot' cases may well be the main cause of a significant improvement of the SD modeling skills: although it is difficult to prove, it seems that the use of these testing/teaching cases has accomplished more than the other measures discussed in (Pruyt et al. 2009). Moreover, using 'hot' cases is a good way to enthuse students and to arouse their interest in applying SD in case of real-world issues. Applying SD to 'hot' issues illustrates the relevance of SD for dealing with real-world complex issues, which takes SD testing/teaching models one step further than being didactically responsible exercises. Although actual real-world testing/teaching cases are often more motivating, they are also more difficult than toy exercises, because they need to be sufficiently close to real-world issues to be relevant and credible.

The main goal for introducing such cases –to bridge the gap between the introductory SD course and the SD project course by raising the level of difficulty of the introductory SD course– was reached. Students now learn all basic SD modeling skills (and more) where they ought to learn these basic skills: in the introductory course. Hence, the SD modeling skills of those passing the Introductory SD course are high enough to allow the SD project to be organized in a different –less resource intensive– mode. This allowed us to change the SD project course –at least for about half of the students– into what a SD project course should be: an almost real-world project –with little individual but high quality supervision of the whole group– in which an unstructured and complex issue is structured, modeled, tested, simulated, analyzed, used for policy testing, and communicated in time to problem owners / stakeholders.

But the work is not finished yet: new cases and especially new types of cases –beyond the types developed by Goodman (1974), Ford (1999), Sterman (2000), Martin Garcia (2006), Meyers, Slinger, Pruyt, Yucel, and van Daalen (2010), Pruyt (2009c), Pruyt (2010a), Pruyt (2011), and available as part of the D-series– are needed. Developing and sharing good cases will be key in the further advancement of the field of System Dynamics. Please join the effort!

References

AIVD (2010, February). Dierenrechtenextremisme in Nederland. Technical report, AIVD. Downloaded on 21/04/2010. 10

De Vos, A. and E. van den Boogaard (2011, December). Plastics in the north pacific ocean. SD Project Report. Delft University of Technology. 3

Ford, A. (1999). *Modeling the environment: an introduction to system dynamics models of environmental systems*. Washington (D.C.): Island Press. 19

Forrester, J. (1969). *Urban Dynamics*. Cambridge, MA: Pegasus Communications. 12

Forrester, J. (1971). *World Dynamics*. Cambridge, MA: Wright-Allen Press, Inc. 40

Frank, K. T., B. Petrie, J. A. D. Fisher, and W. C. Leggett (2011, September). Transient dynamics of an altered large marine ecosystem. *Nature 477*, 8689. doi:10.1038/nature10285. 16, 38, 39

Goodman, M. (1974). *Study Notes in System Dynamics*. Wright-Allen Press, Inc. 19

Kovari, A. (2011, December). Prostitution and human trafficking: A model-based exploration and policy analysis. SD Project Report. Delft University of Technology. 3, 7, 22

Kovari, A. and E. Pruyt (2012, July). Prostitution and human trafficking: A model-based exploration and policy analysis. In *Proceedings of the 30th International Conference of the System Dynamics Society*, St.-Gallen, CH. International System Dynamics Society. 3, 7, 22

Martin Garcia, J. (2006). *Theory and practical exercises of System Dynamics.* 19

Meadows, D. and J. Robinson (1985). *The Electronic Oracle. Computer Models and Social Decisions.* Chichester: John Wiley & Sons. 40

Meyers, W., J. Slinger, E. Pruyt, G. Yucel, and C. van Daalen (2010, July). Essential Skills for System Dynamics Practitioners: A Delft University of Technology Perspective. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. http://systemdynamics.org/conferences/2010/proceed/papers/P1096.pdf. 2, 3, 19

Mohammed, I. and E. Pruyt (2012, July). Gaming to speed up energy transitions: From experimental games to experiential games. In *Proceedings of the 30th International Conference of the System Dynamics Society*, St.-Gallen, CH. International System Dynamics Society. 18

Pruyt, E. (2008a, July). Dealing with multiple perspectives: Using (cultural) profiles in System Dynamics. In *Proceedings of the 26th International Conference of the System Dynamics Society*, Athens, Greece. International System Dynamics Society. http://systemdynamics.org/conferences/2008/proceed/papers/PRUYT424.pdf. 4

Pruyt, E. (2008b, July). Food or energy? Is that the question? In *Proceedings of the 26th International Conference of the System Dynamics Society*, Athens, Greece. International System Dynamics Society. http://systemdynamics.org/conferences/2008/proceed/papers/PRUYT372.pdf. 4

Pruyt, E. (2009a, July). Cholera in Zimbabwe. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. International System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1357.pdf. 4

Pruyt, E. (2009b, July). The Dutch soft drugs debate: A qualitative System Dynamics analysis. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. International System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1356.pdf. 4

Pruyt, E. (2009c, July). Making System Dynamics Cool? Using Hot Testing & Teaching Cases. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. International System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1167.pdf. 1, 4, 17, 19

Pruyt, E. (2009d, July). Saving a Bank? The Case of the Fortis Bank. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. International System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1273.pdf. 4

Pruyt, E. (2010a, July). Making System Dynamics Cool II: New hot testing and teaching cases of increasing complexity. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. International System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1026.pdf. 1, 4, 17, 19

Pruyt, E. (2010b, July). Scarcity of minerals and metals: A generic exploratory system dynamics model. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. International System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1026.pdf. 4

Pruyt, E. (2011, July). Making System Dynamics cool III: New hot teaching & testing cases of increasing complexity. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. International System Dynamics Society. 1, 2, 4, 17, 18, 19

Pruyt, E. et al. (2009, July). Hop, step, step and jump towards real-world complexity at Delft University of Technology. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. International System Dynamics Society. `http://www.systemdynamics.org/conferences/2009/proceed/papers/P1140.pdf`. 2, 3, 19

Pruyt, E. et al. (2011, July). Energy transitions towards sustainability: A staged exploration of complexity and deep uncertainty. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. International System Dynamics Society. 18

Pruyt, E. and C. Hamarat (2010a). The concerted run on the DSB Bank: An Exploratory System Dynamics Approach. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. International System Dynamics Society. 4

Pruyt, E. and C. Hamarat (2010b). The Influenza A(H1N1)v Pandemic: An Exploratory System Dynamics Approach. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. International System Dynamics Society. `http://systemdynamics.org/conferences/2010/proceed/papers/P1389.pdf`. 4, 18

Pruyt, E. and J. Kwakkel (2011, July 24-28). To radicalize or to deradicalize? is that the question? In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington D.C., USA. International System Dynamics Society. 4, 17

Repenning, N. (2003). Selling system dynamics to (other) social scientists. *System Dynamics Review 19*(4), 303–327. 40

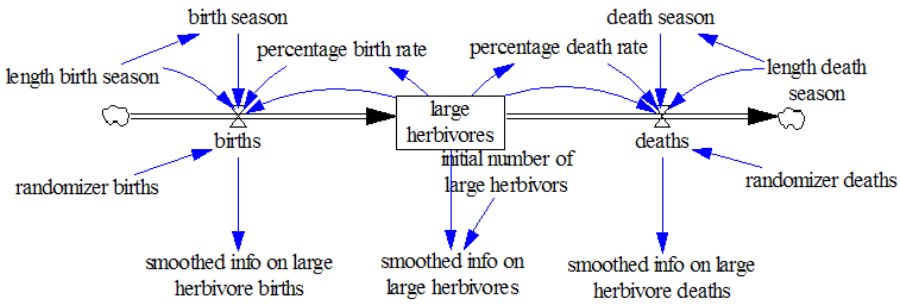
Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world.* Irwin/McGraw-Hill: Boston. 19, 40

b. 100% in micro-CHP: the surface area to the right of the intersection point is much larger than the surface area to the left

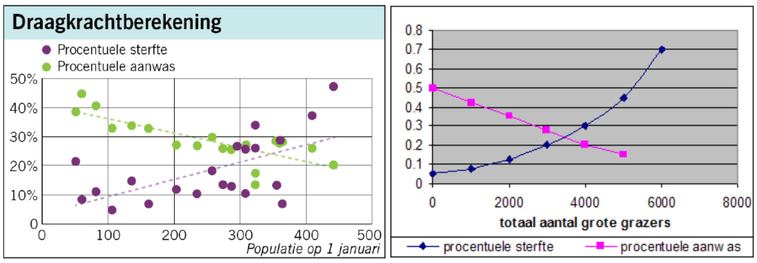
c. 100% HE-boilers for the first 10 years and 100% micro-CHP afterwards in order to take advantage of the lowest cost over the full 100 years

d. not 100% in HE-boilers nor 100% in micro-CHP, but somewhere in between (which could be calculated), in order to fully profit from the evolution of both technologies.

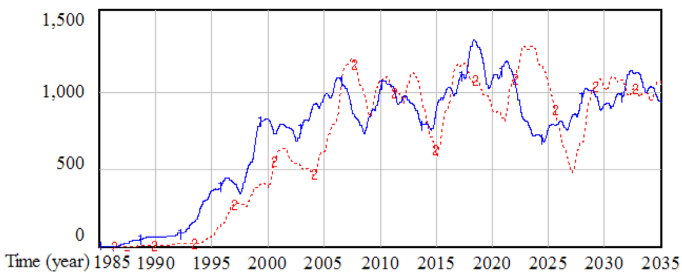
Multiple Choice Question 12 (/ 1)



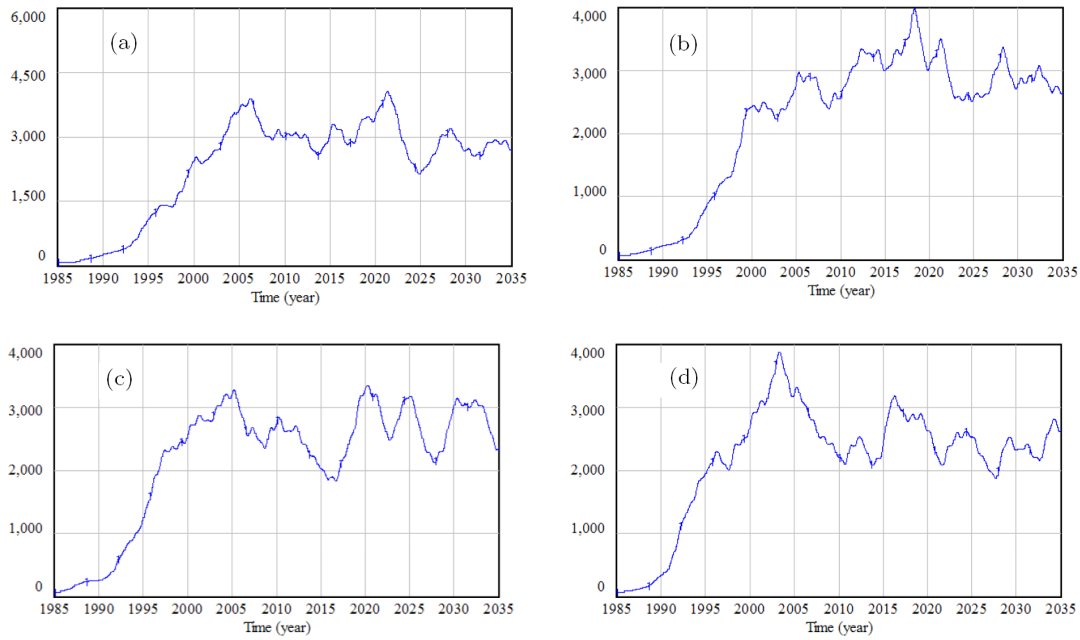
Suppose you made the SD model above concerning the large herbivores population in the 'Oostvaardersplassen' (OVP), and that you used the carrying capacity calculation in the graphs below (left for the population of Heck cows and right for all large herbivores).



Left: Carrying capacity for Heck cows in the OVP (Source: NRC Handelsblad 11/12/2010) – Right: Generalized carrying capacity curves for all large herbivores in the OVP



The graph above shows the smoothed (3^{rd} order information delay of 1 year) values of the *flow* variables (in blue: 'smoothed info on large herbivores births'; in red: 'smoothed info on large herbivores deaths'. Which of the following graphs is the graph of the corresponding smoothed *stock* variable ('smoothed info on large herbivores')?



G.8 MODEL USE AND POLICY ANALYSIS

Multiple Choice Question 13 (/ 1)

Which of the following statements about SD model use wrt potential pandemic shocks is correct?

a. SD models can be used to perfectly predict the dynamics of a future pandemic shock.

b. SD models can be used to generate all sorts of plausible dynamics of pandemics, and policies can be tested over all these dynamics.

c. SD models cannot be used to study, and test policies for, very uncertain issues like possible future pandemic shocks.

d. None of the answers above is correct.

G.9 APPLIED SYSTEMS THINKING, AND ARCHETYPES

Multiple Choice Question 14 (/ 1)

Some of the hurdles to tackle worldwide anthropogenic climate change are *(i)* the fact that the average atmospheric lifetime of CO_2 amounts to some 100 years, *(ii)* the relationship between CO_2 emissions and (development of) welfare, *(iii)* the enormous transition/effort that will be necessary to reduce worldwide emissions by 90%, and *(iv)* that the contribution to total emissions or reductions of any single actor –even the most polluting– is negligible compared to the whole. Hence, each and any actor needs to contribute, else we will collectively destroy our own world. Which archetype corresponds to this problem?

a. the '*shifting the burden*' archetype;

b. the '*fixes that fail*' archetype;

c. the '*growth and under-investment*' archetype;

d. the '*tragedy of the commons*' archetype.