Small SD Models for BIG ISSUES – The Book
Teaching & Testing SD with Cases and Quizzes

Erik Pruyt – smallSDmodels@gmail.com

This paper presents a new SD e-book with online resources. It was developed for teaching and testing large introductory and intermediate SD courses, blended collaborative online learning, and hands-on self-teaching. It allows anybody determined to acquire quantitative SD skills to do so in the shortest possible time. From day one on, students are supposed to make models, simulate them, analyze and interpret their outcomes, and use them to design adaptive policies and test their robustness. Models relate from day three on to real current dynamic issues. Full tracks of cases relate to health and drug policy, housing policy and urban planning, energy transitions and resource dynamics, wildlife and ecosystem management, safety and security, criminality and policing, education and innovation, economics and finance, and management and business. Those interested in just one of these application domains can acquire these skills by exercising only with cases within their domain of interest.

Keywords: System Dynamics, Case-Based Teaching, E-Book, Blended Learning

0.1 A Free E-Book / Course

This article is a slightly modified version of the preface of a new SD101 book. The e-book version of the book can be downloaded for free[1] from: http://simulation.tbm.tudelft.nl. The book is in fact a case book with online materials for blended online learning. The audience aimed at is students in the broadest sense: it can be used in introductory SD courses (semester or quarter), executive education (2 to 5 days), and self-study (minimum 5 days). At Delft University of Technology, it is used for the theory/practice part of the Introductory System Dynamics courses (5 weeks x 10 hours/week). Professors are free to use the cases and self-study students can use the book to acquire basic to intermediate SD modeling and simulation skills in about 70 hours by following one of the learning paths.

The rationale for the e-book is introduced in section 0.2. Section 0.3 introduces the type of models that correspond to the cases, that is, small models on big issues. Section 0.4 introduces symbols used in this article and the e-book. The structure of the e-book, as well as the exercises and cases in each of the parts are presented in section 0.5. Additional materials are discussed in section 0.6. A suggested Generic Learning Path –crucially important for this blended learning approach– is introduced in section 0.7. Nine thematic specific Learning Paths in are presented in section 0.8. And a suggested SD project is presented in section 0.9. New experiences and opportunities for SD curricula are discussed in section 0.10. And concluding remarks are made in section 0.11.

[1]The copyright and user agreement correspond largely to Creative Commons license BY-NC-SA.

0.2 Aim and Rationale

The Aim of this E-Book

Over the past seven years, I developed more than a hundred SD exercises and cases and hundreds of multiple choice questions for teaching and testing large SD courses (45+ and 200+ students per year) at Delft University of Technology. This e-book contains most of the fully specified exercises and cases I developed from 2007 until the summer of 2013[2]. These exercises and cases were developed in view of teaching basic/intermediate SD modeling and simulation skills. The emphasis of these introductory SD courses is on model building and simulation, and to a lesser extent on model conceptualization and (detailed and aggregate) diagramming, model testing and analysis, and policy testing and other model uses.

The e-book is in line with these courses: Its main aims are to allow anyone to learn basic and some intermediate SD modeling skills by means of a case-based blended-learning approach, and along the way, introduce the SD methodology and convey the necessary SD reflection skills. The explicit learning goals of the first part of the introductory courses this e-book was developed for 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, (*iii*) to have a basic understanding of SD model use, and (*iv*) to have gained some SD modeling experience. There are no prerequisites for this e-book: although at Delft University of Technology, students enter the SD101 courses with a basic knowledge on differential equations and policy analysis, such prior knowledge may be useful, but is not required. What is required, though, is the desire to acquire these skills, and sufficient perseverance and discipline: the cases in this e-book require –because they are fully specified– 99-95% of transpiration, i.e. applying new skills, and only 1-5% of inspiration and insight. Open cases in the project part of these courses (see below) require about 50% transpiration and 50% inspiration and insight.

One of the courses for which these materials were developed is from 1 September 2013 on available as a fully certified Collaborative Online Learning (COL) course to external students and professionals enrolled for this SD course or the COL Policy Analysis program this course is part of. COL courses are online courses with a mix of online teaching, supervision, coaching, online collaboration and team work via online media. Blended COL courses alternate reading, short explanatory videos, hands-on activities (here: modeling and simulation), structured feedback, formative quizzes, targeted online lectures, online office hours and frequent evaluative testing. Contact hours are minimized through the blended-learning design, and students are supposed to work at least 5 times 10 hours for the first part of the course, although more is better. Given the diversity of activities, the limited number of contact hours, the difficulty of the subject matter, and the many exercises and cases available, it is imperative to offer a well-structured 'learning path'. This e-book offers one generic learning path and nine theme specific learning paths which hyperlink to all resources in the e-book and online resources.

The e-book was developed such that it is suited for self-teaching by anyone determined to acquire these skills but not enrolled in one of the regular or COL courses. Almost anybody with academic-level capabilities, the desire to acquire these skills, and sufficient perseverance and discipline could acquire these basic and some intermediate SD modeling skills in 1 intensive week (10 hours per day) or in 5 weeks (10 hours per week). Since guided hands-on practicing with targeted feedforward and learning-oriented feedback is in my opinion what it really takes to become a modeler, this e-book contains, on top of the material of a learning path, at least 10 times the amount of practicing materials that is necessary to acquire these basic to some intermediate modeling skills. Hence, there is also enough material for those with more time and willingness or need to practice.

The main aim of this e-book and associated online materials is thus to provide hands-on learner-oriented modeling materials to modelers *in spe* to help them acquire basic and some intermediate

[2] Exercises and cases developed from the summer of 2013 on will be added as online exercises and cases.

SD modeling skills in a minimum of about 50 to 70 hours.

Most online materials will be available as Open Course Ware (OCW) materials from September 2013 on. Regular or COL course students nevertheless have some advantages over self-teaching students, namely the advantages of being able to access additional materials such as additional lecture notes and old exams, attend dedicated lectures and interactive feedback sessions, ask questions during (online) office hours, collaborate with peers, work for strict deadlines and tests, take part in exams to obtain a certificate and/or degree, and, most importantly, being coached by experienced supervisors during their SD project work.

Why this Introductory SD E-Book?

There are already quite some excellent introductory SD books with exercises (e.g. (Forrester 1968; Goodman 1974; Richardson and Pugh 1981; Richmond 1992; Coyle 1996; Sterman 2000; Warren 2002; Morecroft 2007; Ford 2009)), books introducing SD among other computational methods (e.g. (Shiflet and Shiflet 2006)), books introducing SD to support domain studies (e.g. (de Vries 2012)), introductions to SD (Randers 1980a), a series of Road Maps (self-study guides bringing together important papers, books, and modeling exercises), exercise/case oriented books (Goodman 1974; Ford 1999; Martín García 2006), open course ware materials from several universities, et cetera. Why then add another introductory SD book?

Because I believe that a case-based blended-learning approach, which to my knowledge does not exist yet, could help many to actively acquire basic SD modeling skills through learning by doing. From experience, I know that SD skills can be acquired through hands-on modeling with exercises from day one on and with near-real cases from day three on. I also believe that the SD philosophy and wisdom as well as more advanced modeling and analysis skills can best be taught along the way, not before hands-on modeling is ventured in on, again by means of cases of increasing methodological and applied complexity with case-related feedback, as well as by sharing experiences.

As stated above, I strongly believe that, in order to really acquire modeling skills, most people actually need a lot of hands-on practicing and experience – preferably along a smart learning path with insightful feedback and useful feedforward. Hence, hands-on quantitative modeling and simulation are, right from the start, at the center of the blended-learning approach offered here. The blended-learning approach –especially (*i*) the brief explanations in several short videos and introductory chapters preceding the case chapters, and (*ii*) the feedback to each exercise/case and the feedback in recap chapters and videos reviewing the main lessons learned over all exercises/cases in a chapter– accelerate the speed of learning. And although the core of this e-book consists of exercises and cases of increasing complexity and difficulty and with different lessons to be learned, together with the electronic resources and learning paths, it is much more than just a collection of cases: it is a full introductory SD course.

The cases in this e-book are more than just educational exercises: most of the cases deal with current real-world issues, although still in a simplified way. I think these cases are as actual and real as possible for an introductory hands-on modeling course. Actual cases are excellent tools for motivating students, for illustrating the relevance of SD modeling for real world problem solving, and for showing the way in which SD could be applied to real world cases. Although such 'hot' teaching cases may be more interesting, stimulating and challenging, they are also slightly more difficult and time consuming than purely didactic exercises: many cases in this e-book require about 2 hours for modeling novices.

Although this case-based blended-learning approach was inspired by some great case-based SD books (e.g. (Goodman 1974; Ford 1999; Martín García 2006; Bossel 2007a; Bossel 2007b; Bossel 2007c)), it substantially differs from these sources of inspiration, both in style and learning approach. Like these other case-based books, this e-book may also be useful to colleagues by offering them many new cases and models. Since making teaching and testing cases is very time consuming, the best we can do is share our cases. Developing and sharing teaching and testing cases is, I believe, key in the further advancement of the SD field and model-based decision support. Hence, I am glad to share my cases, especially if it inspires others to share their cases too: *do ut* *des*! This e-book therefore also contains 126 links to new online exercises/cases to be added from the summer of 2013 on by, I hope, many colleagues around the globe that are willing to share their own cases.

0.3 Small Models for Big Societal Issues

Although most of the cases in this e-book are not as small as traditional educational exercises, they are still slightly smaller and simpler than real models. It is important to realize that these cases are still educational: none of the corresponding models could in their current form be used for real policy advice. I nevertheless strongly believe small models are much more useful than large models for real-world policy advice: in modeling, small really is beautiful! Proponents of small models argue that small models allow 'for exhaustive experimentation and sensitivity analysis, wise interpretation of parameters and parameter change' (Ghaffarzadegan et al. 2011; Pruyt 2010c). In fact, model parsimony is an important criterion of SD model quality (Saysel and Barlas 2006). Many modelers, especially novices, have a tendency to build unnecessarily large models (Barlas 2007; Repenning 2003; Forrester 1961), but '[l]arge models are not only difficult to build: they are also nearly impossible to understand, test (by the modeler or a third party), and evaluate critically' (Barlas 2007). I therefore believe it is important to teach novices to make small models, also of big issues.

This e-book mainly focuses on relatively big societal issues and important questions – often lacking a single and clear problem owner or decision maker. But that is not a major problem since for big issues, even those at the top of a hierarchy only *appear* to have influence (Forrester 2007). Often, it is the underlying structure of a system that is important for its future dynamics, not the decision-makers at the top of the hierarchy: they may not be able to make a difference, unless they truly understand the issue/system and know how to change the system structure such that more desirable dynamics are endogenously generated by the system. I hope this e-book helps to diffuse a method that can be used to generate such understanding, and hence, to make such changes.

Exercises and cases are drawn from a variety of application domains full of big issues that need to be addressed. Cases are grouped in 9 themes: health and drugs policy, wildlife and ecosystem management, resource dynamics and energy transitions, safety/security and risk, policing and public order, urban planning and housing policy, education and innovation, economics and finance, and management and organization. There are also 9 thematic learning paths that allow one to work within one theme, although more could be learned from modeling and simulating cases across different themes.

Application domains and corresponding symbols used:

- Resource dynamics and energy transitions: dynamics of technology diffusion and energy transition, depletion of mineral/metal/fossil fuel resources, and resource nexus issues
- Environmental & ecosystem management: overfishing, ecosystem collapse,...
- Health and drugs policy: drug related problems, epidemics, health system management,...
- Crime fighting and policing: fighting burglaries, robberies, and human trafficking,
- Risk analysis and crisis management: radicalization, bank runs,
- Housing policy and urban planning
- Education and innovation: student and education system management, innovation,...

- Management and business: management of clients, production, supply chains, projects, human resources, businesses,
- $ Econonomics and finance: macro-economics, bank & banking crises, economic development,
- Technical exercises

0.4 Other Symbols Used

The leading principle of this e-book being hands-on training, many hyperlinked symbols are used. Three types can be distinguished: activity related symbols, e-book related symbols, and content related symbols.

Following activity related symbols are used in the remainder of the text and in exercises/cases:

- : (Link to) hands-on modeling or other model-related activities
- ∧ : Mandatory exercises (or at least strongly suggested)
- ∨ : Additional exercises (optional or additional training)
- : Link to video or streaming
- : Link to mandatory reading in this e-book or other non-mandatory reading
- : Link to a suggested special issue of a scientific journal
- : Link to useful tutorial(s)
- : Link to additional information or to suggested articles, books, etc.
- : Link to a lecture, a presentation, or an audio fragment
- : Hand in your assignment before the deadline!
- : Peer review (to be handed in 24h after simulating your own assignment)
- ? : Interactive Q&A session
- : Non-mandatory quiz or test
- : Quiz or test with mandatory effort and/or bonus
- : Quiz or test with mandatory result (full pass is required)
- : Quiz, test, exam (full pass / partial pass / fail)

Following e-book related symbols are used in the remainder of the text and in this e-book:

`Alt` ←: Go back to previous location (Note: this is a useful combination of keys, not a symbol)

: Go to the first page

: Go to and 'quickly cycle through'[3] the table of contents

: Go back to the general learning path

: Go to the Preface

: Go to Part I – Warm-up (simple and small qualitative SD exercises)

: Go to Part II – Run-Up (simple and small quantitative SD exercises)

: Go to Part III – Hop (simple and small technical SD exercises)

: Go to Part IV – Step (basic SD cases)

: Go to Part V – Jump (intermediate SD cases)

: Go to Part VI – Fly (SD project cases)

: Link to restricted resources (for COL and regular students only)

: Link to restricted resources (for approved lecturers only)

Following content related symbols are used in this e-book:

: Zoom-in or explanatory box

: Right thing to do!

: Watch out: Slippery! Dangerous!

: Important!

: Great insight, understanding, idea. . .

: Take care!

: Beyond the current level of difficulty (solve this part at a later point in time)

0.5 Structure, Exercises, and Cases

This e-book consists of this preface, 5 core parts, and a final part for bridging the gap with project cases and real-world modeling. Each part –except for the last part– consist of four chapters:

- A very brief theory chapter with links to additional online reading;
- A chapter with exercises/cases and links to additional online exercises/cases;
- A chapter with 15 right/wrong questions, 20 multiple choice questions, mostly graphic ones, and links to hundreds of online multiple choice questions;
- A recap chapter with the most important lessons to be learned from the exercises/cases in that particular part.

SD modeling and simulation skills are gradually ramped up to an intermediate level according to a triple jump approach. Before performing the triple jump, one needs to warm-up in Part I. The warm-up consists of building qualitative SD models – after all, this book focuses after all on quantitative modeling and simulation. These qualitative SD modeling skills are particularly useful for model conceptualization and model communication. Part II is the run-up: Its focus is on hands-on modeling and simulation of small and simple exercises. Part III is a technical part that allows one to hop to the next level. Part IV consists of cases that allow one to step forward using the functions and structures from the previous part. Part V contains many intermediate level cases: extensive hands-on practicing with these cases allows one to jump towards the next level. And part VI allows one to bridge the gap with project cases and real-world modeling and offers a sneak preview into more advanced modeling and simulation issues. That is, it allows one to fly away.

A more detailed overview of the exercises and cases in these six parts is provided below. The tables give an idea of the main themes exercises/cases are part of, their approximate level of difficulty (for students in a first SD course at the time of their exam), the indicative time required to solve them, their focus, and whether demonstration videos and background papers are available.

Part I: WARM-UP – Introductory Qualitative Exercises

This part is just a brief and superficial introduction to qualitative SD modeling, since quantitative SD modeling is the focus of this e-book, not stand-alone qualitative SD modeling. Qualitative modeling is introduced here for conceptualization and communication purposes in support of quantitative modeling. Students interested in stand-alone qualitative modeling are referred to that part of the SD literature. For this course, the time spent on this first part should be limited to about 5 hours. It is sufficient to do exercises 2.1, 2.2, 2.3, one from 2.4–2.12, and possibly 2.13 or 2.14.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time	Specifics	Demo /links
	2.1 p.18	Competition in the faculty	simple	0:05	qual.: unisolated loops	
	2.2 p.19	Managing assets & clients	simple	0:10	qual.: missing loops, control	
	2.3 p.19	Resource Dynamics	simple	0:05	qual.: aging chains and loops	
	2.4 p.20	Overly prescr. approach	simple	0:10	qual.: real policy advice	
	2.5 p.21	COLCs and MOOCs	simple	0:10	qual.: alt. diffusion models	
	2.6 p.22	Fish and Ships	simple	0:10	qual.: be trapped!	
	2.7 p.23	Housing policies	simple	0:10	qual.: housing cycles	
	2.8 p.23	Student passing policy	simple	0:15	qual.: CLDs versus ADs	
	2.9 p.24	Fighting high impact crime	simple	0:10	qual.: reinforced seasonality	
	2.10 p.24	Conflict in the Middle East	simple	0:15	qual.: intractability & policy	
	2.11 p.26	Mapping bank runs	simple	0:15	qual.: alternative mechanisms	1
	2.12 p.28	Entrepreneurs & transitions	medium	0:15	qual.: successive mechanisms	1
	2.13 p.29	Soft Drugs Policies	medium	1:30	qual.: multiple perspectives	1 2
	2.14 p.31	Climate Change	medium	1:30	differences CLDs & SFDs	

Part II: RUN-UP – Introductory Quantitative Exercises

This part focuses on small and simple exercises. Given the fact that these exercises are extremely small and simple, time spent on this second part should be limited to a maximum of 5 hours. It is sufficient to model exercises 6.1, 6.2 and one of choice from exercises 6.3–6.11.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
| |	6.1 p.59	On cocaine	intro	0:05	1 stock, 1 loop	| |
| |	6.2 p.60	Muskrat plague	intro	0:15	2 stocks, 2+ loops	| |
|$|	6.3 p.60	Econ. Overshoot & Collapse	simple	0:20	2 stocks, 6 loops	| |
| |	6.4 p.61	Management of societal aging	simple	0:20	aging chains	| |
| |	6.5 p.62	Feral pig plague	simple	0:20	small & simple	| |
| |	6.6 p.63	Gangs and Arms Races	simple	0:20	dynamics of escalation	| |
| |	6.7 p.64	Unin. fam. planning benefits	simple	0:20	aging chain	| |
| |	6.8 p.65	Pneumonic plague (A)	simple	0:15	SIR and diffusion	| | 1
| |	6.9 p.66	System Dynamics Education	simple	0:30	multi-model/theory	| |
| |	6.10 p.67	Diffusion of micro-CHP	simple	0:25	S-shaped growth or nothing	| |
| |	6.11 p.68	Housing stock dynamics	simple	0:30	with delays ⇒ oscillations	| |

Part III: HOP – Technical Exercises

Many specific functions that are needed in subsequent chapters are introduced in this part. Time spent on solving these technical exercises should be limited to 5 hours. Additional debugging exercises may take another hour. After these exercises, one should be prepared for parts IV and V.

	ex.nmbr. & page	Title / Topic	Difficulty for SD101	Time	Specifics: technical	Demo /links
	10.1 p.92	Step, ramp, Time, sine	simple	0:05	exogenous inputs	| |
	10.2 p.93	Max, Min, MinMax	simple	0:10	hard floor & ceiling	| |
	10.3 p.93	Stock distortions	simple	0:15	stocks-flows dynamics	| |
	10.4 p.94	Material & Information Delays	simple	0:10	different delay types	| |
	10.5 p.95	Higher Order Delays	simple	0:10	different delay orders	| |
	10.6 p.96	(With) Lookups, Time Series	simple	0:10	Pneumonic Plague (B)	| | 1
	10.7 p.96	Softmin, Softmax	simple	0:10	soft floor & soft ceiling	| |
	10.8 p.97	Pulses and Pulsetrains	medium	0:10	sudden & repetitive inputs	| |
	10.9 p.98	Random function vs sampling	medium	0:10	random nmbrs & parameters	| |
	10.10 p.99	Special Structures	medium	0:15	monitoring, testing,...	| |
	10.11 p.100	A Damped Mass-Spring System	medium	0:10	2nd order diff. equation	| |
| |	10.12 p.101	Shale Gas	simple	0:10	min, max, stock-flow	| |
| |	10.13 p.101	Mass starvation in OVP	medium	0:45	pulsetrains, randomizers	| | 1
	10.14 p.103	Verification and Debugging	simple	0:10	floating points	| |
	10.15 p.103	Sensitivity and Uncertainty	simple	0:10	univariate, L.H.,...	| |

Part IV: STEP – Introductory Cases

This part is the first of two core parts. It consists of a set of relatively simple intermediate cases. Those with a time limit of 50–70 hours, should spend about 15 hours on this part.

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
	14.1 p.125	Managing a faculty	medium	0:45	small & simple	
	14.2 p.126	Supply chain management	medium	1:00	oscill. & bullwhip	
	14.3 p.127	Debt crisis in dev. nation	medium	1:30	bifurc. & phase plane	*
	14.4 p.128	Env. Mgt in Miniworld	medium	1:30	overshoot or not	*
	14.5 p.130	Next pandemic shock	medium	1:45	staged, SIR/SEIR	1 2 3
	14.6 p.133	New town planning	medium	1:45	clear sectors	1 2
	14.7 p.135	Tolerance, hate, aggression	medium	1:45	threshold & bifurcation	
	14.8 p.137	EVs and lithium scarcity	medium	1:00	staged, open end	1
	14.9 p.139	Cholera in Zimbabwe	medium	2:00	simpl. aqua. route	1
	14.10 p.141	Signalled bank run	medium	2:00	too simplistic	1
	14.11 p.144	Fighting HIC on nat. level	medium	2:00	reinforced seasonality	1
	14.12 p.146	Overfishing of NBF tuna	medium	2:00	staged	1
	14.13 p.148	Production Management	medium	2:00	oscill. & bullwhip	1
	14.14 p.150	District redevelopment	medium	2:00	abstract/aggreg.	1 2
	14.15 p.152	Mineral/metal scarcity I	medium	2:00	spec. functions	1 2 3
	14.16 p.154	De/Radicalisation I	medium	2:00	counterintuitive	1 2 3
	14.17 p.156	Fundamental behaviors	medium	1:00	core structures	

(*) based on (Bossel 2007a; Bossel 2007b; Bossel 2007c); (**) based on (Martín García 2006)

Part V: JUMP – Intermediate Cases

This part is the second of two core parts. Those with a maximum time budget of 50 to 70 hours, should spend a maximum of 20–30 hours on these cases and related online materials.

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
	18.1 p.180	Policy analysis, design, testing	simple	—	on previous exercises	
	18.2 p.180	Unemployment	medium	1:30	gov. sercives & debt	*
	18.3 p.182	Hospital Management	medium	1:30	correct for outflows	1
	18.4 p.184	Collapse on the Kaibab Plateau	medium	1:30	ecosystem collapse	**
	18.5 p.186	Prostitution & H.Trafficking	medium	2:00	± staged	1 2
	18.6 p.189	Seasonal flu	difficult	2:30	staged, SEIRS	1
	18.7 p.191	Real estate boom & bust	difficult	2:30	right/wrong	1
	18.8 p.194	DNO asset management	difficult	2:30	aggregated, gaming	1
	18.9 p.195	Fighting HIC regionally	difficult	2:30	waterbed effect	1
	18.10 p.198	Innovation in health care	difficult	2:30	subscripts & xls	
	18.11 p.198	Carbon and climate change	difficult	2:00	ST affects LT	*
	18.12 p.200	An Orchestrated bank run	difficult	2:30	operational	1
	18.13 p.202	De/Radicalisation II	difficult	2:30	counterintuitive	1
	18.14 p.204	Project management	difficult	2:30	staged	1
	18.15 p.207	Mineral/metal scarcity II	difficult	3:00	1 major loop	1
	18.16 p.209	Energy transition management	difficult	2:30	specification	1 2 3
	18.17 p.211	Fighting HIC across districts	difficult	2:00	regional waterbed	1
	18.18 p.214	Antibiotic resistance	difficult	2:00	thresholds & timing	1
	18.19 p.217	Globalization	difficult	2:00	effects free trade	*
	18.20 p.218	Higher education stimuli	difficult	2:30	batches, etc	1
	18.21 p.221	Housing market crisis	difficult	2:30	financial uncertainty	1
	18.22 p.224	Collapse of civilizations	difficult	2:00	from Maya to others	**

With a steep descend of the learning curve, one should be able to finish at least four to five cases and work through the materials suggested in the learning path.

Exam cases used in the introductory SD courses at Delft University of Technology are typically 'difficult' for an introductory modeling course and mostly relate to actual or otherwise important issues. During the exam, students have 3 hours to answer 15 multiple choice questions related to SD methodology/insight/. . . , and for solving an exam case with multiple choice questions and open questions ( ).

Part VI: FLY – Project Cases

The last part contains just two chapters: one chapter with advise before starting to model and simulate project cases or real cases, and one chapter with some (links to) pre-structured SD cases. However, one of the planned follow-up e-books will contain many more SD project cases as well as advanced SD topics. The other planned follow-up e-book will contain many 'exploratory' SD cases, that is, issues that are deeply uncertain and dynamically complex, as well as explanations on how to use the sampling and machine learning techniques and tools used in Exploratory System Dynamics Modeling and Analysis (E*SD*MA).

	Case nmbr. & page	Title / Topic	Difficulty for SD101	Time (min)	Specifics	Demo /links
| |	22.1 p.249	Food or Energy?	difficult	5:00	closed ⇝ project	1 2
| |	22.2 p.254	Cod or not?	difficult	5:00+	open ⇝ project	1
| |	22.3 p.255	Wind Force 12	difficult	3:00+	closed ⇝ project	1
| |	22.4 p.264	Strategic Mgt & leadership	difficult	3:00+	partly open, gamimg	1
| |	22.5 p.268	Evidence-based HIC Fighting	difficult	5:00+	open, xls	1
| |	22.6 p.269	Heroin	difficult	3:00+	⇝ project	–

0.6 Materials: Cases and MCQs

Cases

Most of the exercises and cases consists of four versions of the case description (a standard case description in italics without guiding MC questions, a case description in italics and with guiding MC questions ( ), a case description without italics without guiding MC questions ( ), and a case description which consists of a short problem sketch and a research question ( )), links to videos showing the case being modeled and solved, to Forio simulators to compare models to, to pdfs with an indicative solution, to videos with case-specific feedback, to simulation models (different softwares), to pdfs with references and links to the literature. . . .

Following symbols are used in the header of exercises and cases:

: Link to case description with level 1 support, i.e. with *italics* and MCQs

: Link to case description with level 3 support, i.e. without *italics* and MCQs

: Link to case description with level 4 support, i.e. the story and research questions

: Link to this exercise/case in Dutch and/or other languages if available

: Link to versions of the exercise/case written for other SD software packages

: keys, hints, clues, additional help

: Link to (a zip file with) simulation model(s) and/or other supplementary files

: Link to online simulators

: Link to a feedback document (pdf)

: Link to a feedback video

⊕ : Link to additional exercises and cases

Some of the teaching/testing cases in the table above were already made publicly accessible, albeit in just one format and without the online resources. Many cases were published either as cases or as part of research papers, mostly as proceedings articles of the ISDC available on the web site of the System Dynamics Society. Case descriptions are available in (Pruyt 2009c; Pruyt 2009a; Pruyt 2009d; Pruyt 2010a; Pruyt and Hamarat 2010a; Pruyt 2010a; Pruyt 2011; Pruyt 2012; Pruyt and Ribberink 2013; Pruyt 2013). Real-world analyses, i.e. beyond the case level, can be found in (Pruyt 2004; Pruyt 2007a; Pruyt 2008a; Pruyt 2008b; Pruyt 2009b; Pruyt 2009a; Pruyt 2009d; Pruyt and Hamarat 2010b; Pruyt 2010b; Pruyt and Hamarat 2010a; Pruyt and Kwakkel 2011; Pruyt et al. 2011; Pruyt and Kwakkel 2011; Pruyt et al. 2011; Kővári and Pruyt 2012; Hamarat et al. 2013; Pruyt and Ribberink 2013). Case 14.6 is based on George Richardson's URBAN1 model and case 18.14 on George Richardson's Project Management model. Case 2.14 is based on (Ford 1999, p92–96) and (Pruyt 2007a; Sterman and Booth Sweeney 2002; Houghton 2004; Fiddaman 2002). Exercises 6.1, 6.2, 10.11, and the first part of exercise 2.5 are adapted from (van Daalen et al. 2006). Exercises 6.10, 6.11, and the first part of exercise 14.2 were based on Vensim example models (Ventana Systems 2000). Exercises 6.3, 6.6, 14.3, 14.4, 14.7, 18.2, 18.11 and 18.19 are either based on, or adaptations from, cases by Hartmut Bossel (2007d), Bossel (2007a), Bossel (2007b), Bossel (2007c). Case 18.18 is based on (Homer et al. 2000), and 18.10 is based on Jakar Westerbeek's BSc thesis.

Multiple Choice Questions: Chapters and Online MCQ Bank

In this e-book, there are also five chapters with 15 right/wrong questions and 20 multiple choice questions (MCQs). The MCQs in the e-book are mainly graphical MCQs with graphs and diagrams, since they are somewhat more difficult to enter in the online question bank. The online resources contain MCQ banks with hundreds of formative MCQs, i.e. questions with hints and answers. They are organized in different ways to allow students to select the theme, category, methodological topic, and/or level of difficulty they would want to practice. The MCQs mainly relate to the cases dealt with in that part and to general issues from nine categories that are difficult to capture in exam cases:

1. SD Philosophy, SD Methodology, or 'SD speak'
2. SD Diagramming ('Count the loops', SFD to CLD to SFD conversion)
3. Specification (Delays, Special Functions, . . .)
4. Calculation, and basic Modeling and Simulation
5. Verification, Simulation Settings, Units
6. Validation, Sensitivity Analysis, Extreme Value Testing, and Uncertainty Analysis
7. Reading Graphs, Interpreting Behavior, Linking Structure and Behavior
8. Model Analysis and Use, especially Sensitivity Analysis and Policy Analysis

9. Applied Systems Thinking, and Archetypes

0.7 Generic Learning Path for the Theory/Practice Part

The course this blended COL approach was developed for in the first place consists of two parts: a theory/practice part and a project part. This e-book is most useful for the first part, but also for bridging the first and second part, and a little for supporting the project process in the second part (only for regular and COL students). One generic learning path and nine theme specific learning paths were developed for the first part. All those with broader interest than just one or two application domains are strongly recommended to follow the generic learning path. More can be learned from modeling and simulating rather different cases. Hopefully, new themes will be added in the near future. For a start, future theme 10 may be reached here. No matter what theme is followed, everyone is strongly advised to solve all MCQs and learn from the weekly/daily feedback across all application domains.

The following generic hyperlinked learning path is used for the first part[4]:

WEEK 1: INTRODUCTION TO SYSTEM DYNAMICS MODELING AND SIMULATION

|| Video: Intro week/day 1

Chapter 1: Introduction to System Dynamics

- Qualitative SD modeling
  - || Tutorial introduction to SD software (1)
  - || Tutorial software interface (2)
  - || Tutorial hands-on example (3)
  - || Tutorial causal loop diagramming (4)
  - || Video qualitative modeling
  - Introductory qualitative modeling exercises
    - ∧ ex.2.1, ex.2.2, ex.2.3
    - ∧ 1 exercise of choice from ex.2.4–2.12 (|| || || || || || || |$| ||)
    - ∨ all other exercises from ex.2.4–2.12 (|| || || || || || || |$| ||)
    - ∨ ex.2.13, ex.2.14
  - || Video feedback across all introductory qualitative exercises
  - || Written feedback across all introductory qualitative exercises
  - || MCQs in chapter 3
  - || MCQs in online quizzes
- Quantitative SD modeling
  - Chapter 5: Elementary System Dynamics Modeling
  - || Video: quantitative model building (settings, stocks, flows, auxiliaries, simulation)
  - || Tutorial stock and flow diagramming (5)
  - || Tutorial building a simulation model (6)
  - Introductory quantitative SD exercises
    - ∧ ex.6.1, ex.6.2, 1 from ex.6.3–6.11 (|$| || || || || || || || ||)
    - ∨ other exercises from ex.6.3–6.11 (|$| || || || || || || || ||)
    - |⊕|: additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

[4]The tutorial numbers correspond to the Vensim tutorials

|| Video feedback across all introductory quantitative exercises
|| Written feedback across all introductory quantitative exercises
|| MCQs in chapter 7
|| MCQs in online quizzes

|| Test 1

|?| Q&A: Interactive Q&A and ramp-up session (on site and online)

WEEK 2: SYSTEM DYNAMICS MODEL FORMULATION

|| Video: Intro week/day 2

Chapter 9: Basic System Dynamics Model Formulation

|| Video model formulation: step, ramp, Time, sine
Exercise 10.1: step, ramp, Time, sine
|| Video model formulation: min, max, minmax
Exercise 10.2: min, max, minmax
|| Video model formulation: delays & smoothing
Exercise 10.3: stock distortions
Exercise 10.4: delays & smoothing
Exercise 10.5: higher order delays
|| Video model formulation: lookups, with lookups, and time series
|| Tutorial building table functions (8)
Exercise 10.6: lookups, with lookups, and time series
|| Video model formulation: softmin & softmax
Exercise 10.7: softmin & softmax versus min & max
|| Video model formulation: pulses & pulsetrains
Exercise 10.8: pulses & pulsetrains
|| Video model formulation: random sampling & randomizers
Exercise 10.9: randomizers & randomly sampled parameters
|| Video model formulation: Special structures
Exercise 10.10: special structures
|| Video Second order ODEs
Exercise 10.11: Damped Mass-Spring System

Exercises

∧ 10.12 (un/conventional gas), 10.13 (mass starvation in the OVP)
|⊕|: additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

|| Video feedback across all week/day 2 exercises and cases

|| Written feedback across all week/day 2 exercises and cases

|| MCQs in chapter 11

|| MCQs in online quizzes

|| Test 2

|?| Interactive Q&A and ramp-up session (on site and online)

WEEK 3: SYSTEM DYNAMICS MODEL BUILDING & TESTING

|| Video: Intro week/day 3

- Chapter 13: Building & Testing System Dynamics Models
  - Model verification and debugging
    - || Video: model verification and debugging
    - || Tutorial function and simulation errors (7)
    - Exercise 10.14: Model verification and debugging
  - Sensitivity, uncertainty, scenarios, and robustness
    - || Video: sensitivity, uncertainty, scenarios, and robustness
    - || Tutorial Sensitivity testing (15)
    - || Tutorial Uncertainty analysis (13+)
    - Exercise 10.15: sensitivity, uncertainty, scenarios, and robustness I
    - Exercise 10.16: sensitivity, uncertainty, scenarios, and robustness II
- Hands-on practice:
  - ∧ 1 case of choice from cases 14.1–14.8 (|| || |$| || || || || || ||)
  - ∧ 1 case of choice from cases 14.8–14.16 (|| || |$| || || || || || ||)
  - ∨ 1 case of choice from cases 14.1–14.8 (|| || |$| || || || || || ||)
  - ∨ 1 case of choice from cases 14.8–14.16 (|| || |$| || || || || || ||)
  - |⊕| additional exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|
- More model debugging to prepare for the exam:
  - || Video: Practical advise regarding model debugging and testing for the exam
  - |⊕| additional debugging exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

|| Video feedback across all week/day 3 cases

|| Written feedback across all week/day 3 cases

|| MCQs in chapter 15

|| MCQs in online quizzes

|| Test 3

|?| Interactive Q&A and ramp-up session (on site and online)

WEEK 4: POLICY ANALYSIS, DESIGN & TESTING & ADVISE

|| Video: Intro week/day 4

- Chapter 17: Using System Dynamics Models

|| Video on policy analysis, design, testing, and advise
|| Tutorial customising output (10)
|| Tutorial input and output controls (12)

Policy Design and Testing on Previous Exercises & Cases: tech.ex.18.1

|| Video: feedback

Hands-on Practicing on New Cases

∧ 1 case of choice from cases 18.2–18.10 (|$| || || || || || || || ||)
∧ 1 other case of choice from 18.2–18.10 (|$| || || || || || || || ||)
∨ cases from ch18 (|$|||||||||||||||||||$||||||||||||||||$||||||)
|⊕| additional debugging exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

|| Video feedback across all week/day 4 cases
|| Written feedback across all week/day 4 cases

|| Test 4

|?| Interactive Q&A and ramp-up session (on site and/or online)

WEEK 5: SYSTEM DYNAMICS MODEL USE AND COMMUNICATION

|| Video: Intro week/day 5

Chapter 21: How to Fly

|| Video on model use and communication

Hands-on practicing

∧ 1 case from 18.11–18.22 (|| |$| || || || || || || |$| || || ||)
∧ 1 case from 18.11–18.22 (|| |$| || || || || || || |$| || || ||)
∨ other ch18 cases (|$|||||||||||||||||||$||||||||||||||||$||||||)
|⊕| additional debugging exercises |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

|| Video feedback across all week/day 5 cases
|| Written feedback across all week/day 5 cases
|| MCQs in chapter 19
|| MCQs in online quizzes
|?| Final interactive Q&A and ramp-up session (on site and online)
|⊕| Exam preparation: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10| |11| |12| |13| |14| |15| |16| |17| |18| |19| |20|
|| Recent exams: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10| |11| |12| |13| |14| |15| |16| |17| |18| |19| |20|
|| Exam part I: 15 MC questions
|| Exam part II: 1 new case on the computer with MC and open answers

New exercises and cases may be available per level via one of the following links:

|⊕| WARM-UP: Introductory (Qualitative) SD Exercises

|⊕| RUN-UP: Introductory (Quantitative) SD Exercises

|⊕| HOP: Technical SD Exercises

|⊕| STEP: Small and Simple SD Cases

|⊕| JUMP: Intermediate SD Cases

|⊕| FLY: SD Project Cases

0.8 Nine Thematic Learning Paths

In this version of the e-book, there are enough exercises and cases –some of them shared– to compose thematic learning paths for the following nine application domains:

|♥| Health Policy, Epidemiology & Drugs

|| Environmental & Ecosystems Management

|♻| Resource Dynamics & Energy Transitions

|| Safety, Security & Risk

|| Policing & Public Order

|| Housing Policy & Urban Planning

|| Education & Innovation

|$| Economics & Finance

|| Management & Organization

One example of a thematic learning path is provided below. For each theme, the minimal thematic learning path is displayed in a box. The symbols are linked to the texts, tutorials, videos, exercises, cases, overall feedback videos, overall written feedback, and quizzes. The topics of the exercises and cases in the minimal thematic learning paths are displayed **in bold** below these boxes. Additionally, exercises and cases *in italics* are suggested: although they are not part of a particular minimal thematic learning path, they may be of interest to those interested in that particular learning path. Potential project cases beyond the purpose of this e-book are displayed in normal fonts, i.e. not displayed in bold nor in italics.

These thematic learning path pages can be reached from each and any page by clicking on the corresponding symbol at the bottom or the headers of exercises and cases. For example, those interested only in Environmental & Ecosystems Management can reach their thematic learning path page by clicking on ||. On the thematic page, click on the next activity in line (or an additional suggested exercise or case), do it, use the `Alt` ← combination or click on the theme symbol to go back to the learning path pages, and use the `Highlighted text` tool in the pdf reader to keep track of progress.

Since exercises and cases in a thematic learning path are often rather similar, it is recommended to also solve additional exercises and cases, or suggested exercises and cases from other themes of interest.

0.8.1 Example: Resource Dynamics & Energy Transitions

The Resource Dynamics & Energy Transitions theme groups –as the name of the theme indicates– exercises and cases related to resource dynamics & energy transitions. The main emphasis is on material scarcity and transitions of energy generation systems towards more renewable ones. The suggested minimal learning path for this theme, i.e. only those exercises and cases that are strictly necessary, is as follows:

W1: | | | | | | | | | | | | 2.3 | 2.12 | | | | | | | | | | | | | | 6.10 | | | | | | ? |

W2: | | | | | | | | | | | | | | | | | | | | | | | | | | 10.12 | | | | | | | | ? |

W3: | | | | | | | | | | | 14.8 | 14.15 | | | | | | | ? |

W4: | | | | | | | | 18.8 | 18.11 | | | | | |

W5: | | | | 18.15 | 18.16 | | | | ? | | |

. . . : | 22.1 | 22.3 |

With (necessary learning path ex./cases in bold & additional suggested ex./cases in italics):

- 2.3 (p.19) **Resource dynamics**
- 2.12 (p.28) **Entrepreneurs & transitions**
- 2.14 (p.31) *Climate change (qualitative)*
- 6.10 (p.67) **Diffusion of micro-CHP**
- 10.12 (p.101) **Un/conventional gas**
- 14.8 (p.137) **Lithium and the diffusion of electrical vehicles**
- 14.15 (p.152) **Mineral/metal scarcity I**
- 18.8 (p.194) **DNO asset management**
- 18.11 (p.198) **Climate change (quantitative)**
- 18.15 (p.207) **Mineral/metal scarcity II**
- 18.16 (p.209) **Energy transition management**
- 22.1 (p.249) Food or energy? Is that the question?
- 22.3 (p.255) Wind Power Potentiality: Wind Force 12
- |⊕| More resource dynamics and transitions cases: |1| |2| |3| |4| |5| |6| |7| |8| |9| |10|

Other themes of interest to those interested in this theme include: Environmental & Ecosystems Management (| |), Housing Policy & Urban Planning (| |), and Education & Innovation (| |).

0.9 Generic 'Project' Path

After taking the theory and practice part, on-site and COL students have to take a mandatory SD project part/course. During this 5 week project, pairs of students need to solve larger cases, either structured cases of 14-25 pages as the one in the appendix of (Meyers et al. 2010) or an 'open project', i.e. a project of their own choice. Students are supervised and coached on a weekly basis while doing so. The workload should correspond to about 2.5 ECTS or 75 hours of work. Where students acquire the SD language and technical modeling skills during the first 5 'theory and practice' weeks, they only really learn what modeling, simulation, and model-based policy analysis is in the project part of the course. The project phase of this course is crucially important. It requires good supervision and coaching in an environment in which failing is allowed and learning is the goal. Although the process of the second part of this course is outlined below, it is offered to on-site and COL students only. During these 5 project course weeks, pairs of students need to work independently, are peer reviewed and supervised/coached by experienced supervisors following the course schedule below.

WEEK 6: QUESTIONS AND CONCEPTUAL MODELS

- Video: Beyond 'Introduction to SD' (project cases, advanced SD, real-world cases)
- Video: SD Project – issues, research questions, information gathering, boundary choices, and conceptual model
- Issue choice, definition of research questions, information gathering, boundary choices, conceptual model, dynamic hypothesis
- Submission of lab report version 1
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 7: FIRST ITERATION QUANTITATIVE MODEL BUILDING

- Video: Building your first iteration 'quick and dirty' simulation model
- first iteration 'quick and dirty' model building and simulation
- Submission of lab report version 2
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 8: SECOND ITERATION QUANTITATIVE MODEL BUILDING & TESTING

- Video: Second iteration model building and model testing
- second iteration model building and testing
- Submission of lab report version 3
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 9: POLICY ANALYSIS, DESIGN AND TESTING

- Video: Third iteration model building and policy analysis
- third iteration model building & use
- Submission of lab report version 4
- Peer review across themes/classes
- Interactive feedback session per theme/class

WEEK 10: POLICY SUPPORT AND REPORTING

- Video: Interpretation, advise, reporting
- interpret results, formulate advise, report
- Submission of final (bullets) report + lab report + simulation models
- Peer review and grading across themes/classes
- Final individual feedback and grades

The deliverables of the SD project are a SD simulation model, analyses performed with the simulation model, a bulleted report, and a very short presentation.

Chapter 22 is a surrogate for those who do not have the opportunity to practice under supervision: it allows (i) students to practice on larger and more open ended cases before starting the project, and (ii) self-study students without supervision to practice on larger and more open ended cases. The latter is by no means a full substitute for a supervised project course.

After passing the SD project part of the course at Delft University of Technology, students are allowed to write a BSc thesis in SD, follow the Advanced SD course, take Simulation Master Classes, and write a BSc or MSc thesis in SD, more or less as described in (Pruyt et al. 2009; Meyers et al. 2010).

0.10 Changes to the SD Curriculum

The high level attained by students after the first part of this course –among else due to the case based approach– necessitated changes to the second part. The well-specified project cases used previously during the project part of the course were (for all except a few pairs of students) replaced with fully unstructured cases with less, joint and higher-quality supervision. In 2011-2012, students worked on their projects individually, topics were warned against but still accepted if too difficult by the lecturer. Most of the 2011 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. In 2012-2013 students had to work in pairs on topics that were deemed feasible by the lecturer which resulted in more high quality work, more lessons learned with regard to successfully completing SD projects, but fewer hard lessons learned with regard to topic choice and boundary selection. Examples of conference papers based on open projects include (Kővári and Pruyt 2012; Howell and Wesselink 2013; Nassikas and Staples 2013; Rose and Kuipers 2013; Jaxa-Rozen and Handaulah 2013; Sharifi and George 2013; van Staveren and Thompson 2013).

Changes to the introductory SD courses also impacted the other SD courses in the curriculum. 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 and more and more for external clients. BSc and MSc 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 as much as possible in our research team. And a physical thesis lab is currently being established where all thesis students in modeling and simulation have computers and access to all computer programs, servers, and even supercomputers (for agent based modeling).

0.11 Concluding Remarks

This paper presents and accompanies the launch of a new SD book, more specifically an e-book developed for blended online learning. It starts and ends with hands-on quantitative modeling using many cases of near real-world complexity. This e-book with its online resources is the backbone of our on-site SD101 education, of the new off-site collaborative online learning programme, and of our SD101 open course ware. But it can be used equally well for independent study (about 70 hours), other SD introductory SD courses (of a quarter or a semester), and executive education (of 2 days + 2 days of homework).

All 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 by 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 purely educational exercises, because they need to be sufficiently close to real-world issues to be relevant and credible.

After this first part, students are ready to work on an almost real-world project –with little supervision of each pair of students but with high quality supervision in group– in which an unstructured and complex issue is structured, modeled, tested, simulated, analyzed, used for policy testing, and communicated in time by means of a (bulleted) modeling report.

By sharing all these materials to anybody interested in acquiring SD modeling skills through self-study, I hope to contribute to expanding and deepening the field of SD, and improving model-based policy making, especially for big issues.

Bibliography

Barlas, Y. (2007). Leverage points to march upward from the aimless plateau. *System Dynamics Review 23*(4), 469–473. Link. 4

Bossel, H. (2007a). *System Zoo 1 Simulation Models: Elementary Systems, Physics, Engineering*. Norderstedt, Germany: Books on Demand GmbH. link to system zoo models. 3, 9, 11

Bossel, H. (2007b). *System Zoo 2 Simulation Models: Climate, Ecosystems, Resources*. Norderstedt, Germany: Books on Demand GmbH. link to system zoo models. 3, 9, 11

Bossel, H. (2007c). *System Zoo 3 Simulation Models: Economy, Society, Development*. Norderstedt, Germany: Books on Demand GmbH. link to system zoo models. 3, 9, 11

Bossel, H. (2007d). *Systems and Models: Complexity, Dynamics, Evolution, Sustainability*. Norderstedt, Germany: Books on Demand GmbH. link to system zoo models. 11

Coyle, R. (1996). *System Dynamics Modelling. A Practical Approach*. London: Chapman and Hall. 3

de Vries, B. J. M. (2012). *Sustainability Science*. Cambridge University Press. Link. 3

Fiddaman, T. (2002). Exploring policy options with a behavioral climate-economy model. *System Dynamics Review 18*(2), 243–267. 11

Ford, A. (1999). *Modeling the Environment: an introduction to system dynamics models of environmental systems*. Environmental Studies. Island Press. 3, 11

Ford, A. (2009). *Modeling the Environment: an introduction to system dynamics models of environmental systems*. Environmental Studies. Island Press. second edition. 3

Forrester, J. (1961). *Industrial Dynamics*. Cambridge, MA: MIT Press. 4

Forrester, J. (1968). *Principles of Systems*. Cambridge, MA: Wright-Allen Press, Inc. 3

Forrester, J. W. (2007). System dynamicsthe next fifty years. *System Dynamics Review 23*(2-3), 359–370. Link. 4

Ghaffarzadegan, N., J. Lyneis, and G. P. Richardson (2011). How small system dynamics models can help the public policy process. *System Dynamics Review 27*(1), 22–44. Link. 4

Goodman, M. (1974). *Study Notes in System Dynamics*. Wright-Allen Press, Inc. Link. 3

Hamarat, C., J. H. Kwakkel, and E. Pruyt (2013). Adaptive robust design under deep uncertainty. *Technological Forecasting and Social Change 80*(3), 408 – 418. Link. 11

Homer, J., J. Ritchie-Dunham, H. Rabbino, L. M. Puente, J. Jorgensen, and K. Hendricks (2000). Toward a dynamic theory of antibiotic resistance. *System Dynamics Review 16*(4), 287–319. Link. 11

Houghton, J. (2004). *Global Warming: the Complete Briefing* (3rd ed.). Cambridge: Cambridge University Press. First edition: 1994. 11

Howell, R. and O. Wesselink (2013). Aids in uganda and. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Jaxa-Rozen, M. and M. Handaulah (2013). The impacts of biomass exploitation and carbon valuation on boreal forest management. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Kővári, 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. 11, 19

Martín García, J. (2006). *Theory and practical exercises of System Dynamics*, Volume March. Barcelona: Juan Martin Garcia. 3, 9

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. Link. 18, 19

Morecroft, J. (2007). *Strategic Modelling and Business Dynamics: A Feedback Systems Approach*. Chichester, UK: John Wiley & Sons. Link. 3

Nassikas, M. and G. Staples (2013). The epidemiology of cytomegalovirus. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Pruyt, E. (2004). System dynamics models of electrical wind power potentiality. In J. Coyle (Ed.), *Proceedings of the 22nd Conference of the System Dynamics Society, Oxford*. 11

Pruyt, E. (2007, January). *Decision-Making and Dynamically Complex Multi-Dimensional Societal Issues: Combining System Dynamics and Multiple Criteria Decision Analysis to Explore the Energy-Climate Change Issue*. PhD Thesis, Vrije Universiteit Brussel, Solvay Business School, Brussels. 11

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. Link. 11

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. Link. 11

Pruyt, E. (2009a, July). Cholera in Zimbabwe. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. 11

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. 11

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. 11

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. 11

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. System Dynamics Society. Link. 11

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. Link. 11

Pruyt, E. (2010c, July). Using Small Models for Big Issues: Exploratory System Dynamics for Insightful Crisis Management. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. System Dynamics Society. Link. 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. System Dynamics Society. 11

Pruyt, E. (2012, July). Making System Dynamics Cool IV: Teaching & testing with hot cases & quizzes. In *Proceedings of the 30th International Conference of the System Dynamics Society*, St.-Gallen, CH. International System Dynamics Society. 11

Pruyt, E. (2013, July). Small models for BIG ISSUES – The Book. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 11

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. 19, 20

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. System Dynamics Society. Link. 11

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. System Dynamics Society. Link. 11

Pruyt, E. and J. Kwakkel (2011, July). De/radicalization: Analysis of an exploratory SD model. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. System Dynamics Society. 11

Pruyt, E., J. Kwakkel, G. Yucel, and C. Hamarat (2011, July). Energy transitions towards sustainability i: A staged exploration of complexity and deep uncertainty. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. System Dynamics Society. 11

Pruyt, E. and M. Ribberink (2013, July). Model-based policing to fight high impact crime. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA. International System Dynamics Society. Link. 11

Pruyt, E., J. Segers, and S. Oruc (2011, July). The leadership game: Experiencing dynamic complexity under deep uncertainty. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. International System Dynamics Society. Link. 11

Randers, J. (Ed.) (1980). *Elements of the System Dynamics Method*. MIT Press/Wright-Allen Series in System Dynamics. Cambridge, MA: The MIT Press. 3

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

Richardson, G. and A. I. Pugh (1981). *Introduction to System Dynamics Modeling*. Productivity Press: Portland. Previously published by MIT Press. 3

Richmond, B. (1992). *An Introduction to Systems Thinking: ithink Software Guide Book*. Lebanon, NH: isee systems. 3

Rose, A. and J. Kuipers (2013). Keeping students with the curriculum: Using a systems dynamics approach to elementary education. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Saysel, A. K. and Y. Barlas (2006). Model simplification and validation with indirect structure validity tests. *System Dynamics Review 22*(3), 241–262. Link. 4

Sharifi, M. and I. George (2013). Domestic violence and sexual harassment against women and children: A model-based analysis. In *Proceedings of the 31st International Conference of the

System Dynamics Society, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Shiflet, A. and G. Shiflet (2006). *Introduction to Computational Science: Modeling an Simulation for the Sciences*. Princeton University Press. 3

Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world*. Irwin/McGraw-Hill: Boston. 982 p. 3

Sterman, J. and L. Booth Sweeney (2002). Cloudy skies: assessing public understanding of global warming. *System Dynamics Review 18*(2), 207–240. 11

van Daalen, C., J. Groenendijk, Z. Verwater, and M. Hendriks (2006). *Continuous Systems Modelling: Manual and Exercises VisSim and Powersim*. Delft: Delft University of Technology. 11

van Staveren, R. and A. Thompson (2013). Legalizing soft drugs in the USA. In *Proceedings of the 31st International Conference of the System Dynamics Society*, Cambridge, MA, USA. International System Dynamics Society. Link. 19

Ventana Systems (2000). *Vensim DSS Reference Manual*. Harvard, MA: Ventana Systems. 11

Warren, K. (2002). *Competitive strategy dynamics*. Chichester: Wiley. 3

Seasonal Flu

Introduction

Given your experience in building a SD model of the 2009 flu pandemic, you are invited by the European Centers of Disease Control to make a SD simulation model of seasonal Influenza A outbreaks in Europe (EU borders are non-existent for flu), which should help to increase the understanding of possible dynamics of seasonal flu and allow for virtual experimentation and policy testing.

Modeling Seasonal Flu

There are some 885 million Europeans. Depending on the time of the year (flu season or not), their condition and history, people are part of the *immune population*, the *susceptible population*, the *exposed population*, the *asymptomatic infected population*, the *symptomatic infected population*, or the *recovered population*. Suppose that initially 750 million Europeans are susceptible, 100000 Europeans are exposed, and 135 million Europeans are (temporarily) immune. Set the *asymptomatic infected population*, the *symptomatic infected population*, the *recovered population* and the *cumulative number of flu deaths* equal to zero at the start of the simulation.

People that are part of the *susceptible population* move to the *exposed population* through *infections*. The number of *infections* could be modeled by means of the product of the *susceptible population*, the *infected fraction*, the 5% *infection rate*, and the *contact rate*. Assume the *contact rate* is a function of the *infected fraction* such that it is equal to 500 persons per person per month if the *infected fraction* equals 0, that it is equal to 450 if the *infected fraction* equals 0.2, that it is equal to 300 if the *infected fraction* equals 0.5, that it is equal to 255 if the *infected fraction* equals 0.75, and that it is equal to 250 if the *infected fraction* equals 1.

Part of the exposed population is already contagious before flu symptoms show up and the contact rate of those who develop flu symptoms strongly reduces. The *infected fraction* could therefore be modeled as the sum of the *symptomatic infected population* multiplied by (1-*decrease in contact rate of the symptomatically infected*) and the *exposed population* multiplied by the *percentage symptomatic*, divided by (that is, the sum divided by) the *total population*. The *percentage symptomatic* is in the order of 66% for flu. And assume for now that the *decrease in contact rate of the symptomatically infected* amounts to 50%. This decrease in contact rate may seem small but is plausible given the facts that (*i*) every infected person on average only infects about 2 others, (*ii*) the flu virus survives for 2 days on door knobs and 17 days on bank notes, and (*iii*) the smallest droplet in the air or briefest hand-to-mouth or hand-to-eye contact may be sufficient to get infected. This also explains the very high (indirect) *contact rate* (see above).

Those who are exposed, either go through a *symptomatic development* phase to become part of the *symptomatic infected population*, or through a *asymptomatic development* phase to become part of the *asymptomatic infected population*. Model the *symptomatic development* as the *percentage symptomatic* times the *exposed population* divided by the *time before symptoms* develop. Symptoms develop after almost 2 days, or 0.06 months. Model the *asymptomatic development* as the complement of the *symptomatic development*.

Those who are infected with symptoms either die or recover. Model the flow of *flu deaths* as the *symptomatic infected population* times the case fatality ratio (*CFR*) of about 0.1%, divided by the average *duration of the illness* of 4.5 days or 0.18 month. Given these numbers, one should not be surprised by a few hundred thousand European flu deaths per flu episode. Only a small part of these deaths are reported as flu casualties. The '*symptomatic recovered*' flow is the complement of the *flu deaths* flow. The *asymptomatic infected population* does not die because of flu: they flow from the *asymptomatic infected population* to the *recovered population* via the '*asymptomatic recovered*', in spite of the fact that they do not show any flu symptoms. Model the *asymptomatic recovered* flow as a first order material delay of the *asymptomatic development* with the aforementioned *duration of the illness* as delay time.

Although the *recovered population* is immune for a particular flu variant after conquering it, it does not mean that the *recovered population* is immune against next year's flu variant: there are many flu strands and they permanently mutate (which is known as 'antigenic drift') into slightly different variants and/or recombine (which is referred to as 'reassortment') into radically new flu strands. The relentless mutation of, competition between, and high infectivity of flu strands results in annual flu outbreaks, mostly of somewhat different viruses and sometimes of radically different viruses. This actually means that each year the lion's share of the *recovered population* becomes susceptible again, be it to slightly different variants. Model the '*from recovered to susceptible through antigenic drift or reassortment*' flow between these two stocks as a 3^{rd} order delay of the *asymptomatic recovered* and *symptomatic recovered* flows, with a *recovered to susceptible delay* of 6 months.

But not everyone is susceptible to the next seasonal flu virus: people may be immune because of resistance to a closely related strand or because of the time of the year. The time of the year is rather important for European flu outbreaks since the virus survives better at lower temperatures and lower relative humidity –i.e. in winter– and vitamin D produced in human skin exposed to sunlight reinforces immunity to flu. Add therefore a flow variable '*from susceptible to immune and back*' between the *susceptible population* and the *immune population* stocks: the *susceptible population* increases towards the winter and the *immune population* increases towards the summer. The flow between these two subpopulations equals the difference between the *theoretic immune population* and the *immune population*, divided by the *immunity delay*. However, the value of this flow cannot be greater than the *susceptible population* divided by the *immunity delay* for a net flow from the susceptible to the immune population, and cannot be greater than the *immune population* divided by the *immunity delay* for a net flow from the immune to the *susceptible population*. Set the *immunity delay* equal to the time step. Model the *theoretic immune population* as the product of the *theoretic immune population fraction* and the *total population*. And model the *theoretic immune population fraction* as a sine function with a minimum of about 16% in the third week of January and a maximum of about 84% in the third week of July.

1. Make the model, verify it, choose appropriate settings.
2. Simulate the model over a period of 60 months and draw the behavior of following key performance indicators: (i) *susceptible population*, *immune population*, and *recovered population*, (ii) *from susceptible to immune and back*, (iii) *cumulative number of flu deaths*, and (iv) *infections* and *infected fraction*.
3. Validate the model. List and use at least 2 different validation tests that are useful at this point in the modeling process. Conclude. Correct your model if necessary.
4. Investigate which parameters *and* functions the model is most sensitive to. Perform at least 4 different sensitivity analyses, explain what you did, and conclude.
5. Generate –based on the insights obtained in the previous question– three very different plausible scenarios (in terms of dynamics and consequences). Draw their dynamics (*infected fraction* and *cumulative number of flu deaths*). What are the differences in assumptions?
6. Draw an extremely aggregated CLD of this model that allows you to explain the link between structure and behavior of one of these scenarios (preferably for the most dramatic one).
7. Design (preferably based on your answers to the previous three questions) an intervention to substantially reduce the negative consequences of flu epidemics. Explain: what are the negative consequences you want to address? What is the intervention you propose? Model it, test it, and plot the effects.

8. Test this intervention under uncertainty. Explain what you do, plot the results, and conclude.

The formulation of this model mainly consists of 1^{st} order material delays. Change the 1^{st} order material delays into 3^{rd} order delays. Rename the model, save it, simulate it, test it, use it and conclude: does a different formulation of the delays result in different dynamics and conclusions?

Financial Turmoil on the Housing Market

Introduction

The Dutch housing market has been in crisis for a while and will most likely remain in crisis for several years to come: average real estate prices have decreased a lot since 2008; the largest mortgage lenders changed the ease with which mortgages could be obtained from mid-2011 on; new housing construction in 2012 is only a fraction of new housing construction in previous years and of what would be required for the longer term future; fewer new construction projects have been initiated; and new mortgage related regulation and fiscal policies further depress the housing market, even though some mitigating actions were agreed upon by the Dutch cabinet and opposition. Homeowners and potential homeowners that may want/need to buy/sell a house in the coming years want to foresee the evolution of housing prices in the coming years. Policymakers want to foresee how the existing shortage on the housing market may evolve in the medium to long term. Suppose that the Ministry of Housing asks you therefore to develop a SD model that would allow them to foresee the evolution of the Dutch housing market and to assess policies related to it.

Iteration I

Assume for the sake of simplicity that the Dutch housing market only consists of houses for sale (no apartments; no renting market and no social housing market). Houses are either *new* (younger than 15 years old) or *old* (15 years or older). The supply of *new houses*, equal to 1500000 in the year 1985, increases through *completion of brand new houses* and decreases through *aging of houses* after which they are added to the *old houses*. The supply of *old houses*, initially 3665000 houses in 1985, decreases through *demolishing of old houses*.

The *completion of brand new houses* could be approximated by dividing the *houses in planning and under construction* by the *planning and construction time*. The number of *houses in planning and under construction* increases only through the *inflow into planning and construction* and decreases only through the *completion of brand new houses*. Suppose that the *initial amount of houses in planning and under construction* in 1985 was 175000. Suppose that the *planning and construction time* is a function of the number of *houses in planning and under construction* divided by the *initial amount of houses in planning and under construction*: the *planning and construction time* equals 1 year if this ratio is equal to 1, equals 1.5 years if the ratio is equal to 2, equals 2.5 years if the ratio is equal to 5, equals 3.25 years if the ratio is equal to 9, equals 4.5 years if the ratio is equal to 20, and it equals 0.75 years if the ratio is close to 0.

The *inflow into planning and construction* could be modeled as the '*housing gap*' multiplied by the *profitability multiplier* and divided by the *delayed direct effect of uncertainty*. Suppose in this first iteration that the *profitability multiplier* is 1. Model the *delayed direct effect of uncertainty* as a 3^{rd} order delay of *uncertainty* with a delay time of 1 year. Assume the *uncertainty* on the housing market was normal, i.e. 100%, from 1985 until mid 2007, after which uncertainty suddenly doubled. The uncertainty most likely remains twice as high until the end of 2013, and could be assumed to decrease linearly from double to normal between the end of 2013 and the beginning of 2015 – remaining normal ever after, or so one would hope.

The non-negative *housing gap* is equal to the *estimated number of households* times the number of *houses per household* minus the *expected total housing supply*. The *estimated number of households* amounted to 5,430,000 in 1985, to 5978000 in 1990, to 6798000 in 2000, to 7397000 in 2010, to 7470000 in 2011, and is assumed to amount to 8500000 in 2050, and to 9000000 in 2085. Assume that households do not have more than one house: i.e. the number of *houses per household* is 1. The *expected total housing supply* is the sum of *new houses*, *houses in planning and* *under construction*, and *old houses*, minus the houses expected to be demolished over the course of the year.

The *aging of houses* follows the *completion of brand new houses* with a delay time equal to the *life expectancy as new houses* of exactly 15 years. Model the *demolishing of old houses* as the number of *old houses* over the *average life expectancy of old houses* of about 60 years multiplied with a *demolishing multiplier of old houses*. Suppose the latter multiplier could be modeled as the 3^{rd} order delay of 1/*housing scarcity ratio* with a delay time of 1 year. The *housing scarcity ratio* is directly proportional to the *estimated number of households* and inversely proportional to the *expected total housing supply*.

1. Model the description above.
2. Simulate the behavior from the year 1985 until the year 2085.
3. Draw a an extremely aggregated CLD which could be used to explain the general dynamics of the *housing gap*. Explain the general dynamics of the housing gap using, and referring to, this extremely aggregated CLD.

Iteration II

Suppose that the *profitability multiplier* is a function of the *profitability of construction of new housing* in such a way that this multiplier equals 0 if the *profitability of construction of new housing* is equal to -100%, that it equals 0.01 if the profitability is equal to -50%, that it equals 0.02 if the profitability is equal to -20%, that it equals 0.2 if the profitability is equal to -10%, that it equals 0.8 if the profitability is equal to 0, that it equals 1 if the profitability is equal to 10%, that it equals 1.1 if the profitability is equal to 20%, that it equals 1.2 if the profitability is equal to 50%, and that it equals 1.25 if the profitability is equal to 100%.

The *profitability of construction of new housing* could be formulated simplistically as:

$$\frac{(1 + acceptable\ \%\ additional\ cost\ for\ living\ in\ a\ new\ house) * average\ house\ price - construction\ cost\ new\ house}{construction\ cost\ new\ house} \quad (1)$$

with an *acceptable % additional cost for living in a new house* of 5%. The *average construction cost of a new house* equals the *initial average construction cost of a new house* of €95000 per house times the *cumulative inflation since 1985*. The *cumulative inflation since 1985* could be calculated as the integral of:

$$inflation\ rate * cumulative\ \ inflation\ \ since\ \ 1985 * MAX((1 - (uncertainty - 1)), 0) \quad (2)$$

with an initial value equal to 1. Assume for the sake of simplicity that the *inflation rate* was, is, and will be 2% per year. The *average house price* corresponds –given the simplification that every household has at most 1 house– to the delayed product of the *average spending limit for buying one house per household* and the *housing scarcity ratio*, with an average delay of one year. The *average spending limit for buying one house per household* equals the *average salary per household* times $(1 + salary\ loan\ multiplier)$. Suppose that the *average salary per household* is the product of the *initial average salary per working person* of €27,000 per year, the *cumulative inflation since 1985*, and the *expected work force* divided by the *estimated number of households*. Add following time series: suppose that the *expected work force* amounted to 5.75 million in 1985, to 7.5 million in 2012, to 8 million in 2020, to 7.6 million in 2040, to 7.3 million in 2050, and to 6 million in 2085. The *salary loan multiplier* used to calculate the average mortgage lending capacity of an average household is then:

$$\frac{normal\ salary\ loan\ multiplier * (1 - loan\ risk)}{delayed\ direct\ effect\ of\ uncertainty} \quad (3)$$

The *normal salary loan multiplier* increased linearly between 1985 and the end of 2011 from 3 to 6, but fell back (given the stricter rules for banks and mortgage transactions, and the gradual decline of the mortgage interest relief) between 2011 and 2013 to 4, and could be expected to slowly fall back to 3.5 by 2050 and stay there ever after. Suppose finally that the *loan risk*, i.e. the risk of non repayment of loans, could be approximated by a 3^{rd} order delay of $MAX(0, uncertainty-1)/6$ with an average delay time of 2 years.

4. Model the above description. Verify and simulate the model. Compare the dynamics of the *average house price* and the '*housing gap*' of the first and the second iteration model.
5. Validate the second iteration model: list 2 good validation test for this phase in the modeling process, execute them, and describe the results.
6. Some inputs, exogenous future evolutions (time series) and endogenous relations are rather uncertain. Test the sensitivity of the most important indicators (*average house price* and *housing gap*) for changes in at least 1 uncertain parameter and 1 uncertain time series or endogenous relation. Explain briefly (what? why? how? result?).
7. Simulate –on top of the *base case* scenario– two very different scenarios with respect to the *average house price* and/or the *housing gap*. What is the narrative of the three scenarios? Plot their dynamics for the two key performance indicators.
8. What is undesirable about these plausible futures? Design a policy to turn undesirable dynamics into desirable dynamics. Describe briefly, test in your model, draw and compare the undesirable and desirable dynamics.
9. EITHER: Test this policy under uncertainty: do, briefly describe, and conclude. OR: Write a short model-based recommendation concerning the real estate market: what do you advise to the government, and/or to current homeowners, and/or to future homeowners?