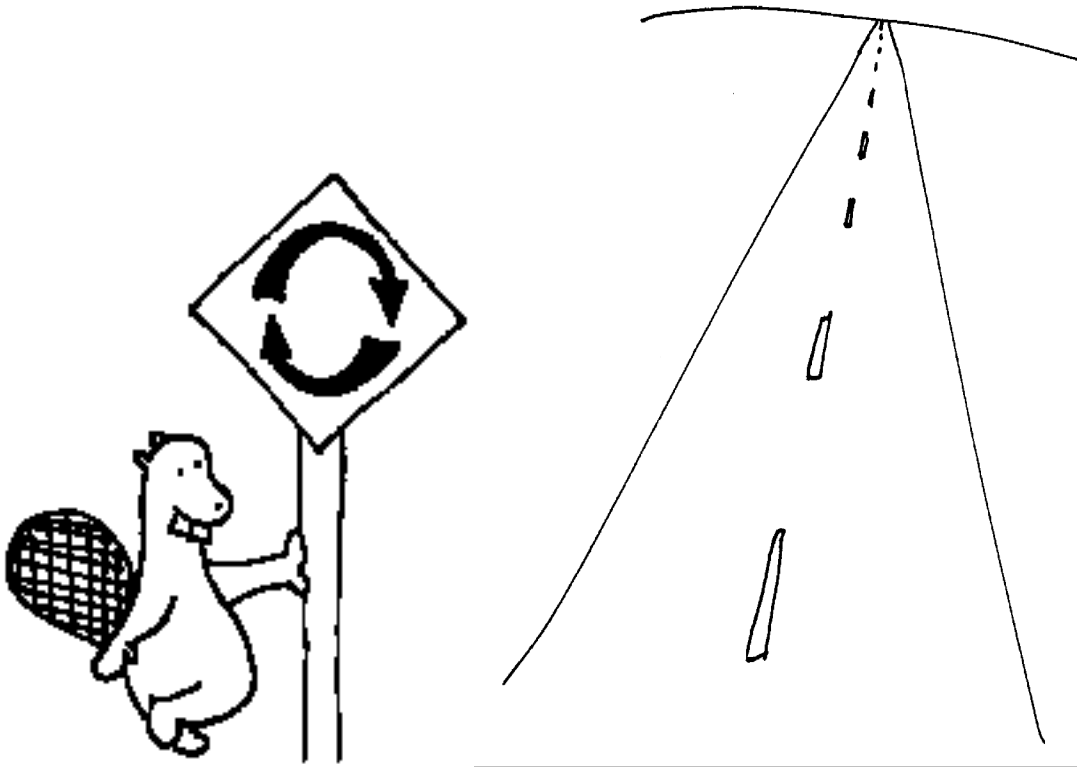
Road Maps 0

A Guide to Learning System Dynamics

0



System Dynamics in Education Project

Road Maps 0

System Dynamics in Education Project
System Dynamics Group
Sloan School of Management
Massachusetts Institute of Technology

June 21, 1992
June 21, 2000
Revised August, 2005

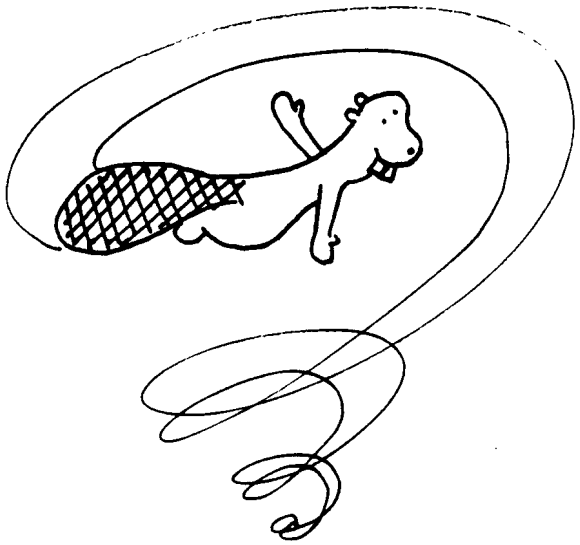
Compiled under the direction of Professor Jay W. Forrester

Welcome to Road Maps!

Many books and thousands of papers cover the field of system dynamics. With all of these resources available, it is difficult to know where to begin learning about system dynamics. The System Dynamics in Education Project at MIT is putting together Road Maps to help sort through this vast library of books and papers. Road Maps is a series of self-study guides that use modeling exercises and selected literature to provide a resource for learning about the principles and practices of system dynamics. In its present form, Road Maps is not meant to be a teaching curriculum for classroom use.

The Spiral Learning Approach

A new concept is usually not fully mastered after reading about it only once. Also, learning usually involves building one's understanding up from one level to a higher level. For this reason, Road Maps utilizes a spiral learning approach, in which each new concept is repeatedly reinforced in successive chapters. This repetition moves upward along a spiral as more advanced concepts build upon basic ones.



In constructing this spiral, Road Maps has been divided into chapters. The end of each chapter marks the completion of a particular subset of concepts, with the next chapter building on the material just learned. Each chapter comes as a separate document so the reader can request them as needed.

Organization

The Road Maps series begins with **Road Maps One**, which introduces the concepts of causal loops and circular feedback in systems. In addition, some of the applications and history of system dynamics are presented.

Road Maps Two takes you through your first system dynamics models, introducing computer simulation and the concept and methods of graphical integration. Two basic elements of system dynamics models, the stock and flow, are presented. You will need a computer and STELLA™ or Vensim™ software for this and subsequent chapters of Road Maps.

Road Maps Three presents two of the most common structures in system dynamics: the first-order positive and negative feedback loops. Systems exhibiting exponential growth and decay are examined, and the idea of loop dominance in systems is introduced.

Road Maps Four introduces generic structures and discusses the use of computer simulation games in teaching system dynamics. After playing the *Fish Banks* game, you will construct a model of the scenario and learn about the tragedy of the commons. Using your computer model, you will simulate and analyze several policies for this system.

Road Maps Five probes the structure of system dynamics models, emphasizing some important features that you may not have noticed, and explains the spread of an epidemic. Road Maps Five also introduces testing for model validity in the system dynamics context. How do you know that your model is a good representation of the real system?

In **Road Maps Six**, the dynamics of economic supply and demand are explored and more modeling exercises are provided. Also, oscillatory systems are used to show the transferability of structures. More modeling exercises sharpen your modeling skills and develop intuition about systems.

Road Maps Seven presents some unexpected behaviors that can occur in higher-order positive feedback loops. It also points out mistakes commonly found in system dynamics models and provides more independent modeling exercises.

Road Maps Eight continues to improve your modeling skills by analyzing the first stage of the process of building a model: conceptualization, and by

warning you against other mistakes commonly made in models. Road Maps Eight also increases your understanding of oscillating systems and introduces sensitivity analysis.

Road Maps Nine explores the dynamics of credit card spending, illustrates how to correctly formulate table functions, and introduces the behavior known as overshoot and collapse. More graphical integration exercises develop your intuitive understanding of the process of graphical integration.

Road Maps Ten provides further instruction on how to build a model from scratch with exercises for the second step, formulation. There are a number of other papers in Road Maps Ten which will continue to build skill in working with system dynamics models and continue the reader's understanding of system dynamics principles.

Road Maps discusses the principles and characteristics of systems, explores the interrelationship between structure and behavior of dynamic models, provides guidelines for good modeling practice, and discusses the applications of system dynamics. From Road Maps One on, the spiral of learning returns to these primary areas several times by introducing more advanced material while building on fundamental concepts. After completing Road Maps, you should have a strong working knowledge of system dynamics, have developed intuition about the fundamental principles of systems and be ready to explore the application of system dynamics in any area of interest.

Note: See Appendix for a complete table of contents.

How to Use Road Maps

First, you need to determine where you should begin in Road Maps. Some readers have had more background in system dynamics than others. This introduction should help you find a good starting point in Road Maps.

Road Maps explores several topics in system dynamics through selected readings and exercises. Before each reading or exercise is a short description of the reading and its most important ideas. After each reading or exercise, we highlight the main ideas before moving on.

Each chapter in Road Maps contains readings that introduce and strengthen some of the basic concepts of system dynamics. Other readings focus on

practicing the acquired skills through various exercises or simulation games. Most of the chapters conclude with a prominent paper from the literature in the system dynamics field.

We present the fundamental concepts of system dynamics as *System Principles* in Road Maps. These principles are enclosed in boxes that highlight them from the rest of the text to emphasize their importance. The progression of system principles in Road Maps allows you to revisit each principle several times. Each time a principle is revised in Road Maps, you will build upon your previous understanding of the principle by learning something new about the principle. The system principles are the core of Road Maps around which the readings, exercises, and papers are built.

As part of the spiral learning approach that we use in Road Maps, many concepts will be briefly introduced early on and then explained later in greater detail. Road Maps contains a number of series of papers that are spread out over successive chapters. Each of these series focuses on a specific topic in system dynamics or the developing of a particular skill. The series start out with a simple paper, and progress to further develop the idea in subsequent chapters.

Things You'll Need for Road Maps

Modeling Software

In order to complete Road Maps Two and subsequent Road Maps, you will need to have access to modeling software. The Road Maps guides and most papers included in Road Maps were written with the use of STELLA II. STELLA II is currently available for both the Macintosh and the Windows platforms. If you have any questions about STELLA II, contact isee systems (see Appendix). Ask about prices for educational use.

Vensim, Powersim, and DYNAMO are other software programs designed for building system dynamics models. Vensim is produced by Ventana Systems, which offers a free introductory version of its software, Vensim PLE, that can be downloaded off the World Wide Web. See the Appendix for more information about obtaining Vensim and Powersim.

Notice written June, 2000:

We have written a guide on how to use Vensim modeling software for each section of the Road Maps series that involves computer modeling. Each guide is located in the back of the exercise document. When Chapters 1-9 of the Road Maps series were written, STELLA II software was the most common beginner modeling program available. Now you may choose from a number of system dynamics modeling software packages. If you would like more information on Vensim, please go to http://www.vensim.com. A free version called Vensim PLE is located there.

For more detailed information on using Vensim software in the Road Maps series, please refer to the paper titled: "Vensim Conversion Guide (D-4856)" in the Appendix section at the end of Road Maps.

A Computer

To run the latest versions of any of the software packages, check with the software producers for the computer requirements for their particular package. In any case, if you plan on continuing to model, it may be a good idea to have access to a computer with more memory, hard disk space and a faster processor than the minimum required.

Books

1) Goodman, Michael R, 1974. *Study Notes in System Dynamics*. Pegasus Communications, 388 pp. (Road Maps 2 onwards)

2) Forrester, Jay W., 1969. *Urban Dynamics*. Pegasus Communications, 285 pp. (Road Maps 3 onwards)

If you have any problems in getting the above three books, contact Pegasus Communications (see Appendix).

3) Meadows, Donella H., Dennis Meadows, Jorgen Randers, 1992. *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future*. Post Mills, VT: Chelsea Green Publishing Co., 300 pp. (Road Maps 5) To order a copy of this book, contact Chelsea Green Publishing (see Appendix).

Good luck with Road Maps!

System Dynamics in Education Project

Project Director
Jay W. Forrester
Professor Emeritus and Senior Lecturer
MIT Sloan School of Management

Project Advisors
Nan Lux
Lees Stuntz

Contributing Authors
Kevin Agatstein
Stephanie Albin
Aaron Ashford
Lucia Breierova
Nathaniel Choge
Mark Choudhari
Celeste Chung
Alan Coronado
Aaron Diamond
Terri Duhon
Shayne Gary
Marc Glick
Matthew Halbower
Will Glass-Husain
Lei Lei
Leslie Martin
Kamil Msefer
Alice Oh
Manas Ratha
Samitha Samaranayake
Laughton Stanley
Rebekah Wahba
Joseph Whelan
Ming Zhang
Helen Zhu

Appendix I: Names and Numbers

If you do not have access to the World Wide Web, you can buy a CD with Road Maps from::

Creative Learning Exchange
27 Central St.
Acton, MA 01720, USA
Phone: (978) 635-9797
Fax: (978) 635-3737
Email:
Lees Stuntz stuntzln@clexchange.org
http://www.clexchange.org

To inquire about educational prices for STELLA ® II software, please contact:

isee systems
46 Centerra Parkway
Lebanon, NH 03766-1487
Fax: (603) 643-9502
Phone: (643) 643-9636
(800) 987-6758
Email: support@iseesystems.com
http://www.iseesystems.com/

Although Road Maps is written specifically around the STELLA II software, two other software applications are suitable for use with Road Maps, assuming the user is willing to make some interpretations and translations:

Powersim for PC:

Powersim Solutions, Inc.
585 Grove Street, Suite130
Herndon, VA 20170, USA
Phone: (703) 467-0910
Fax: (703) 467-0912
Email: sales@powersimsolutions.com
www.powersimsolutions.com

Vensim for PC or Macintosh:

Ventana Systems, Inc.
60 Jacob Gates Road
Harvard, MA 01451
Phone: (508) 651-0432
Fax: (508) 650-5422
Email: vensim@vensim.com
A free "Personal Learning Edition" of Vensim can be downloaded from:
http://www.vensim.com/

If you have any questions about obtaining books required for Road Maps, please contact their respective publishers:

Chelsea Green Publishing
PO Box 428
85 N. Main St., Suite 120
White River Junction, VT 05001
Phone: 800-639-4099
Fax: 802-295-6444
http://www.chelseagreen.com

Pegasus Communications, Inc.
1 Moody St.
Waltham, MA 02453
Phone: 781-398-9700/ 800-272-0945
Fax: 781-894-7175
E-mail: orders@pegasuscom.com
http://www.pegasuscom.com/

Appendix II: Table of Contents

Road Maps 0

1. Introduction to Road maps](D-4500-10).
This guide is a brief introduction to Road Maps, it gives a summary of the contents of each chapter, advises on the best way to use Road Maps and explains what you will need to begin your study.

Road Maps 1

1. Road Maps 1: A Guide to Learning System Dynamics (D-4501-7)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. System Dynamics and K-12 Teachers [(J. Forrester) (D-4665-5)
Introduces systems and feedback loops, two important ideas which will be further developed in more readings throughout Road Maps. A strong grasp of systems and feedback loops will build a good foundation for learning more advanced principles in system dynamics.

3. System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education (Jay W. Forrester) (D-4337)
An argument for the necessity of change in the educational process and the applicability of system dynamics in K-12 education.

4. Simulating Hamlet in the Classroom (Pamela Hopkins) (D-4540-1)
An example of a STELLA model successfully used in a high school English classroom.

5. System Dynamics Meets the Press, an excerpt from The Global Citizen (Donella Meadows) (D-4143-1)
A narration of experiences of a systems thinker and the struggle to use systems concepts correctly in today's society.

6. Counterintuitive Behavior of Social Systems (Jay W. Forrester) (D-4468-2)
An introduction to the concepts of system dynamics, discussing social policies and their derivation from incomplete understanding of complex systems.

Road Maps 2

1. Road Maps 2: A Guide to Learning System Dynamics (D-4502-9)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. The First Step (Leslie Martin) (D-4694)

A hands-on introduction to system dynamics modeling that uses a series of simple population models.

3. Beginner Modeling Exercises (Leslie Martin) (D-4347-7)
Exercises modeling constant flows. Develops understanding of the basic stock-and-flow structure through examples taken from a wide variety of systems.

4. An Introduction to Feedback (Leslie Martin) (D-4691)
A first look at the positive and negative feedback loops found in system dynamics models.

5. Graphical Integration Exercises Part1: Exogenous Rates (A. Oh) (D-4547-1)
An introduction to graphical integration of constant flows and step function flows.

6. Introduction to Computer Simulation, Chapter 13 [(N. Roberts et al.)
A simple and understandable explanation of levels and rates.

7. Formulating Models of Simple Systems Using Vensim PLE (Nelson Repenning) (D-4697-4)
A beginner's tutorial for Vensim PLE, available in Road Maps Appendix.

Road Maps 3

1. Road Maps 3: A Guide to Learning System Dynamics (D-4503-8)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Graphical Integration Exercises Part 2: Ramp Functions (Kevin Agatstein, Lucia Breierova) (D-4571)
Graphical integration of linearly increasing and decreasing flows.

3. Beginner Modeling Exercises Section 2: Mental simulation of Positive Feedback(Joseph Whelan) (D-4487)
Simple exercises on positive feedback systems.

4. Beginner Modeling Exercises Section 3: Mental simulation of Negative Feedback (Helen Zhu) (D-4536-2)
Simple exercises on negative feedback systems.

5. Study Notes in System Dynamics, Exercises 4,5 (Michael Goodman)
Exercises on first-order positive and negative feedback loops. Instructions on how to obtain this book are provided here as well as in Road Maps 3 (D-4503-8).

6. Introduction to Computer Simulation, Chapter 15 (Nancy Roberts, et al.)
Using simulation to analyze simple positive and negative feedback loops.

7. Study Notes in System Dynamics, Section 3.10-3.12 (Michael Goodman)
Simple examples of negative feedback systems.

8. Study Notes in System Dynamics, Chapters 4,5 (Michael Goodman)
An introduction to S-shaped growth, and a stepwise construction of a simple model.

9. Urban Dynamics (Jay W. Forrester)
An application of system dynamics to study urban problems. Instructions on how to obtain this book are provided here as well as in Road Maps 3 (D-4503-8).

Road Maps 4

1. Road Maps 4: A Guide to Learning System Dynamics (D-4504-7)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Generic Structures: First order positive feedback loops (Stephanie Albin, Mark Choudhari) (D-4474-2)
An introduction to the generic structure in positive feedback systems.

3. Generic Structures: First order negative feedback loops (Stephanie Albin) (D-4475-2)
An introduction to the generic structure in negative feedback systems.

4. Beginner Modeling Exercises Section 4: Mental Simulation: Adding constant flows (Alan Coronado) (D-4546-2)
Simple exercises on introducing a constant flow to positive and negative feedback systems.

5. Building the Fish Banks Model & Renewable Resource Depletion (Joseph Whelan, Matthew Halbower) (D-4543-2)
Description of The Fishing Game and the building of a STELLA model of a fishing system.

6. Problems with Causal Loop Diagrams (George Richardson) (D-3312-2)
A discussion of causal loop diagrams and the inherent problems associated with them.

Road Maps 5

1. Road Maps 5: A Guide to Learning System Dynamics (D-4505-8)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Introduction to Delays, Chapter 17 (Nancy Roberts, et al.)
Introducing the uses of delays in computer simulation.

3. Answers to Exercises for Chapter 17: Introduction To Delays from Introduction to Computer Simulation (Kamil Msefer, Mark Choudhari) (D-4415-6)
Solutions to exercises introducing the use of delays in computer simulation.

4. Beginner Modeling Exercises Section 5: Mental simulation of Combining Feedbacks in First-Order Systems (Laughton Stanley, Helen Zhu) (D-4593-2)
Simple exercises on systems producing S-shaped growth.

5. Generic Structures: S-shaped growth I (Terri Duhon, Marc Glick) (D-4432-2)
An introduction to generic structures in systems producing S-shaped growth.

6. Dynamic Simulation Models: How Valid Are They? (Raymond Shreckengost) (D-4463)
An outline of several tests that can be applied to a model to test validity.

7. Teaching System Dynamics: Looking at Epidemics (Will Glass-Husain) (D-4243-3)
Material for teaching system dynamics concepts through a game based on the spread of an epidemic.

8. Graphical Integration Exercises Part 3: Combining Flows (Kevin Agatstein, Lucia Breierova) (D-4596)
Graphical integration of combined inflows and outflows.

9. Beyond the Limits (Donella Meadows, et al.)
An insightful book about the need for a transition to a sustainable world. Instructions on how to obtain this book are provided here as well as in Road Maps 5 (D-4505-8).

Road Maps 6

1. Road Maps 6: A Guide to Learning System Dynamics (D-4506-7)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Economics Supply and Demand(Joseph Whelan, Kamil Msefer) (D-4388-2)
A system dynamics perspective on supply and demand.

3. Generic Structures in Oscillating Systems I (Celeste Chung) (D-4426-3)
Two real-life scenarios illustrating the transferability of an oscillation structure.

4. Exploring S-Shaped Growth (Leslie Martin) (D-4476-2)
Development of the concept of generic structures in systems producing S-shaped growth.

5. Modeling Exercises: Section 1 (Joseph Whelan) (D-4421-2)
The first of a series of independent modeling experiences.

6. Systems thinking: critical thinking skills for the 1990s and beyond (Barry Richmond) (D-4565)
An argument for teaching systems thinking through learner-centered learning as well as the application of systems thinking to the acquisition of various critical thinking skills.

Road Maps 7

1. Road Maps 7: A Guide to Learning System Dynamics (D-4507-4)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Unexpected Behaviors in Higher-Order Positive Feedback Loops (Aaron Ashford) (D-4455-2)
A discussion of possible behaviors that can occur in higher-order positive feedback loops.

3. Mistakes and Misunderstandings: Examining Dimensional Inconsistency (Michael Shayne Gary) (D-4452-1)
Examination of a model in which a dimensional inconsistency mistake was made, and a suggested improvement of the model.

4. Modeling Exercises: Section 2 (Joseph Whelan) (D-4451-3)
The second in a series of independent modeling experiences exploring an urban dynamics model and offering an exercise on mental simulation.

5. Graphical Integration Exercises Part 4: Reverse Graphical Integration (Laughton Stanley) (D-4603)
Explanation and methods of the process of reverse graphical integration: determing the graph of the net flow from the graph of the stock.

6. System dynamics, systems thinking, and soft OR (Jay W. Forrester) (D-4405-1)
The author's opinion on the differences between system dynamics, systems thinking, and soft operations research.

Road Maps 8

1. Road Maps 8: A Guide To Learning System Dynamics (D-4508-4)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. Building a System Dynamics Model Part 1: Conceptualization (Stephanie Albin) (D-4597)
A series of papers on the process of model-building starts with the first stage: conceptualization.

3. Mistakes and Misunderstandings: Use of Generic Structures and the Reality of Stocks and Flows (Lucia Breierova) (D-4646-2)
Examination and correction of a model, forced to fit a generic structure, in which the stocks do not represent real-world accumulations.

4. Oscillating Systems 2: Sustained Oscillation (Kevin Agatstein) (D-4602-2)
A detailed explanation of the structural causes of sustained oscillation illustrated with two real-life examples.

5. An Introduction to Sensitivity Analysis (Lucia Breierova, Mark Choudhari) (D-4526-2)
An introduction to the concepts and methods of sensitivity analysis of system dynamics models.

6. Learning through System Dynamics as Preparation for the 21st Century (Jay W. Forrester) (D-4434-1)
Prof. Forrester's keynote speech at the 1994 Systems Thinking and Dynamic Modeling Conference for K-12 Education proposes objectives that should be achieved through a system dynamics education.

Road Maps 9

1. Road Maps 9: A Guide To Learning System Dynamics (D-4509-4)
This guide will lead you through the readings. The guide provides a summary of the important insights and highlights the system principles learned in each chapter of Road Maps.

2. The Credit Card Model (Manas Ratha) (D-4683-2)
A model-building exercise that uses a simple credit-card model to demonstrate a characteristic behavior of complex systems: short-term benefit, long-term cost.

3. Mistakes and Misunderstandings: Table Functions (Leslie Martin) (D-4653-2)
A mistakes and misunderstandings paper that explains how to formulate robust and dimmensionally consistent table functions.

4. Generic Structures: Overshoot and Collapse (Lucia Breierova) (D-4480)
An introduction to the generic structure producing overshoot and collapse, using several real-world examples.

5. Graphical Integration Exercises Part Five: Qualitative Graphical Integration (Manas Ratha) (D-4675)
Exercises developing an intuitive, qualitative understanding of the process of graphical integration.

6. A Skeptic's Guide to Computer Models (John D. Sterman) (D-4101-1)
An overview of various computer modeling techniques, their characteristics, capabilities, and limitations.

Road Maps 10

1. Road Maps 10 Guide: (D-4510-2)
Final chapter guide for the Road Maps series. The central focus of Road Maps 10 is how to build a model from scratch with exercises on model formulation.

2. Building A System Dynamics Model, Part I1 (Aaron Diamond and Premraj Janardanan) (D-4866)
How to formulate a model from scratch using three the fruit fly models given.

3. Mistakes and Misunderstandings: Common Formulation Errors (Lewis Kaneshiro) (D-4870-1)
Improving modeling skills.

4. Generic Structures: Exponential Smoothing (Kevin Stange) (D-4782)
A continuation of the understanding of generic structures.

5. Generic Structures: Damped Oscillations (Todd Kamin et al) (D-4690)
A second paper for the understanding of generic structures.

6. Mistakes and Misunderstandings: Time Constants and Decay Fractions (Mila Getmansky) (D-4679)
Learning from past mistakes is important in developing good modeling skills.

7. Mistakes and Misunderstandings: Examining Dimensional Inconsistency (M. Shayne Gary) (D-4272-7)
A second paper to learn from past mistakes.

8. Tests for Building Confidence in System Dynamics Models (Jay Forrester and Peter Senge) (D-2926-7)
A classic paper from the MIT System Dynamics Group archives.

9. Confidence in Models of Social Behavior--With Emphasis on System Dynamics Models (Jay Forrester) (D-1967)
Even early in the field of system dynamics, Forrester believed the best use of modeling was to help us have a better understanding of social systems.

Road Maps Appendix

1. Road Maps Glossary (D-4498)
A dictionary of commonly used terms in the Road Maps series.

2. Formulating Models of Simple Systems Using Vensim PLE (Nelson Repenning) (D-4697-4)
A beginner's tutorial for Vensim PLE.

3. Vensim Conversion Guide (Aaron Diamond) (D-4856)
Highlights some of the differences in modeling with STELLA II and Vensim PLE.

4. System Dynamics Model Correctness Checklist (Rebekah Wahba and Danny Lai) (D-4851)
A paper that describes some important steps for constructing a system dynamics model.

5. Table Functions (Lei Lei and Nathaniel Choge) (D-4587)
Table functions are helpful in formulating no-linear relationships between two variables.