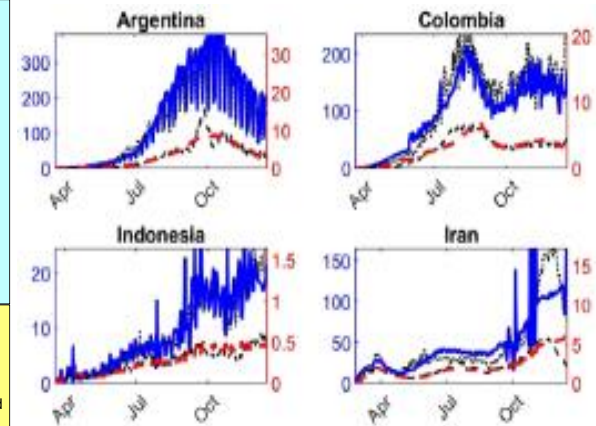
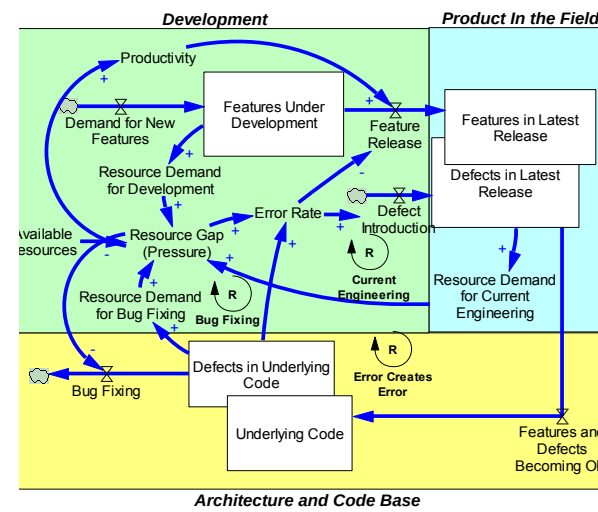
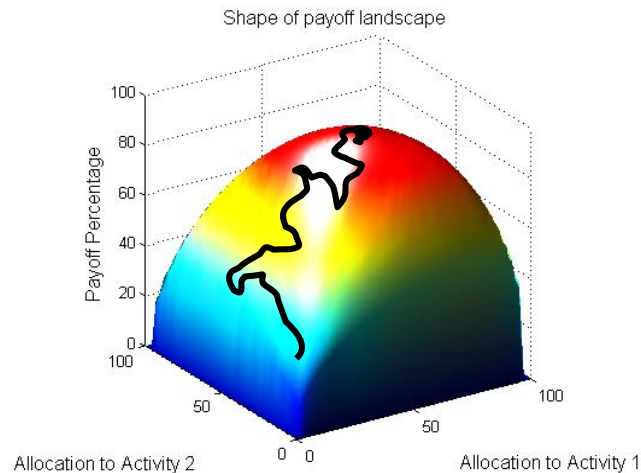
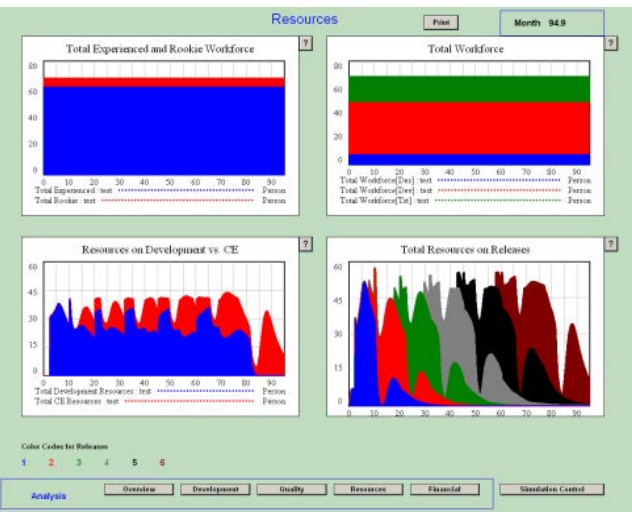


15.879, Spring 2025



Course Objectives

- Develop rigorous dynamic modeling skills
 - The focus is on building models independently, from scratch
 - Fill in the gap between basic courses in SD and ability to conduct serious modeling
 - Pre-requisite: 15.873 or equivalent (e.g. having gone through most of Business Dynamics)
- ➔ This is a hands-on course. The goal is to go beyond abstract concepts and learn things that you can use in research and practice.

Personal Introductions

- Instructor: Hazhir Rahmandad
 - Professor of System Dynamics. Ph.D. in System Dynamics from MIT; Taught at Virginia Tech (Industrial Engineering) before joining MIT faculty in 2015
 - Streams of work:
 - Strategy: Understanding variance in performance due to human resource strategies; aligning employee and firm outcomes
 - Public health and policy: COVID-19, obesity, city dynamics
 - Methods: Estimating dynamic models

Class Preparation and Timing

- Before the class
 - Modeling tasks are provided two weeks in advance. Each week students:
 1. Work on building the model for upcoming session
 2. Read and think through the problem for the week after
- Class sessions (except today) broken into two parts:
 - Discussion of modeling task of the week (~ 60% of time)
 - Deep dive critiquing randomly selected student submissions (Vensim models, occasionally written documents)
 - Setting the stage for next week problem:
 - Discussion of a clear problem definition and architectural choices that follow

Self-Study Protocol for (future) Online Learners

- Go through the weekly material in order:
 - Start by doing the weekly exercise
 - Then review and critique models submitted by class participants, focusing on those discussed in the session
 - Next watch the video of our discussion of those models and compare with your own critique, paying special attention to gaps between the two
 - Finally, critique and improve your own model

SYSTEM DYNAMICS MODEL TYPES, AND MODELING PROCESS

SD Models Can Serve Different Purposes

- Process consultation
- Generic insights and theory building
- Theory testing
- Prediction
- Policy design and decision support
- Training
- ...
- The purpose determines architectural choices, level of detail, data integration, and expected cost of project

Different Types of Models

- Small Exploratory Model
 - Understand dynamics of problem
 - Create and explore simple policies

Process consultation
Dynamic exploration

- Small calibrated model
 - Build and test theory

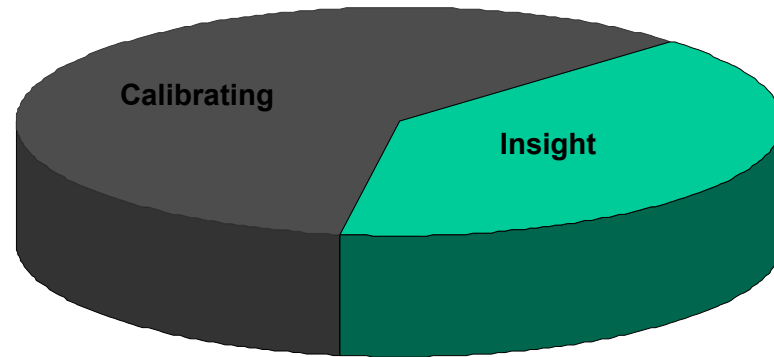
High level managerial insights
Publication
Theory building and testing

- Big calibrated model
 - Strategic decision support
 - When should we do X
 - How much should we do X
 - What is the benefit of X

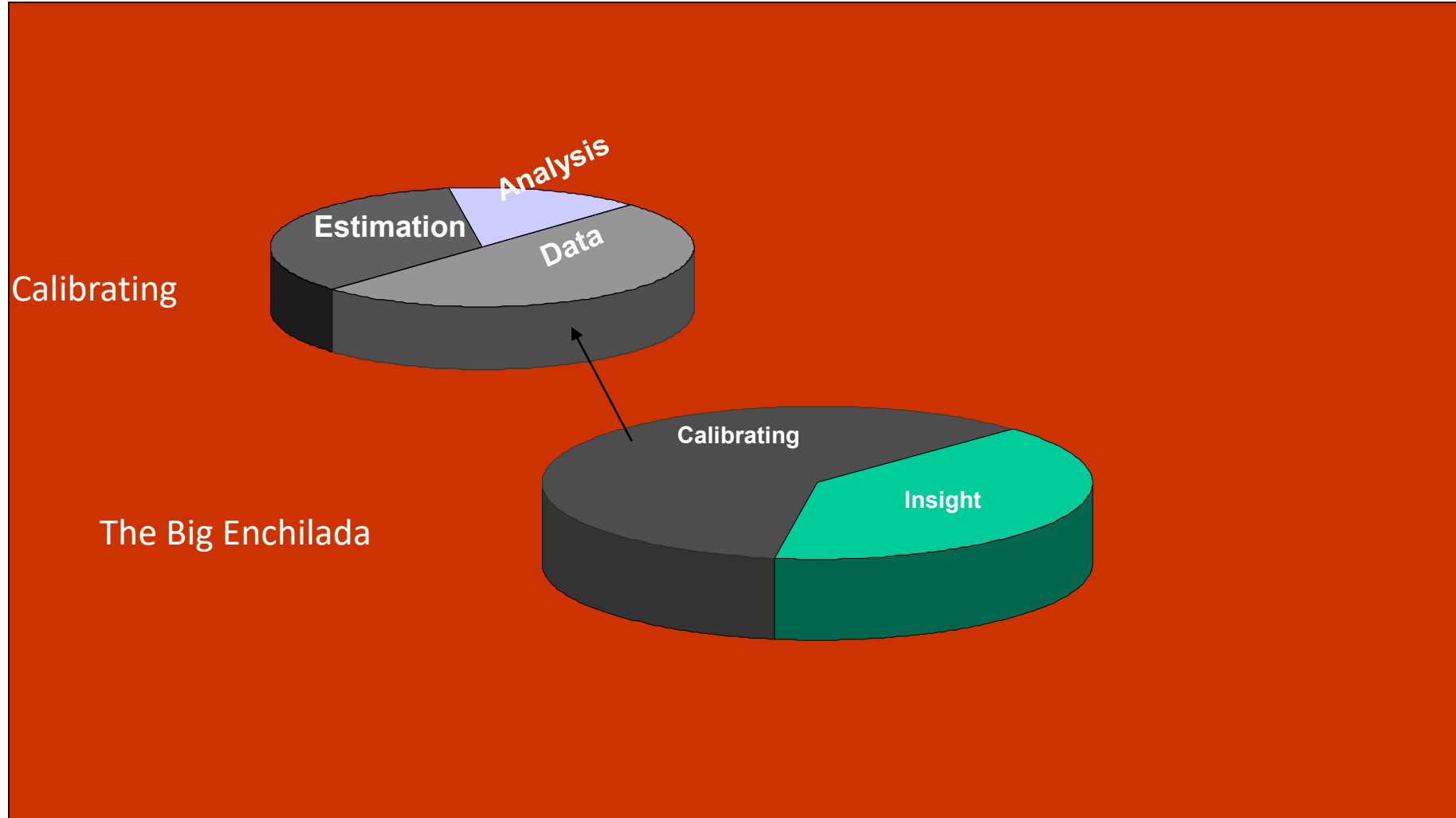
Prediction
Expert consultation
Decision support

Time Distribution for Big Calibrated Models

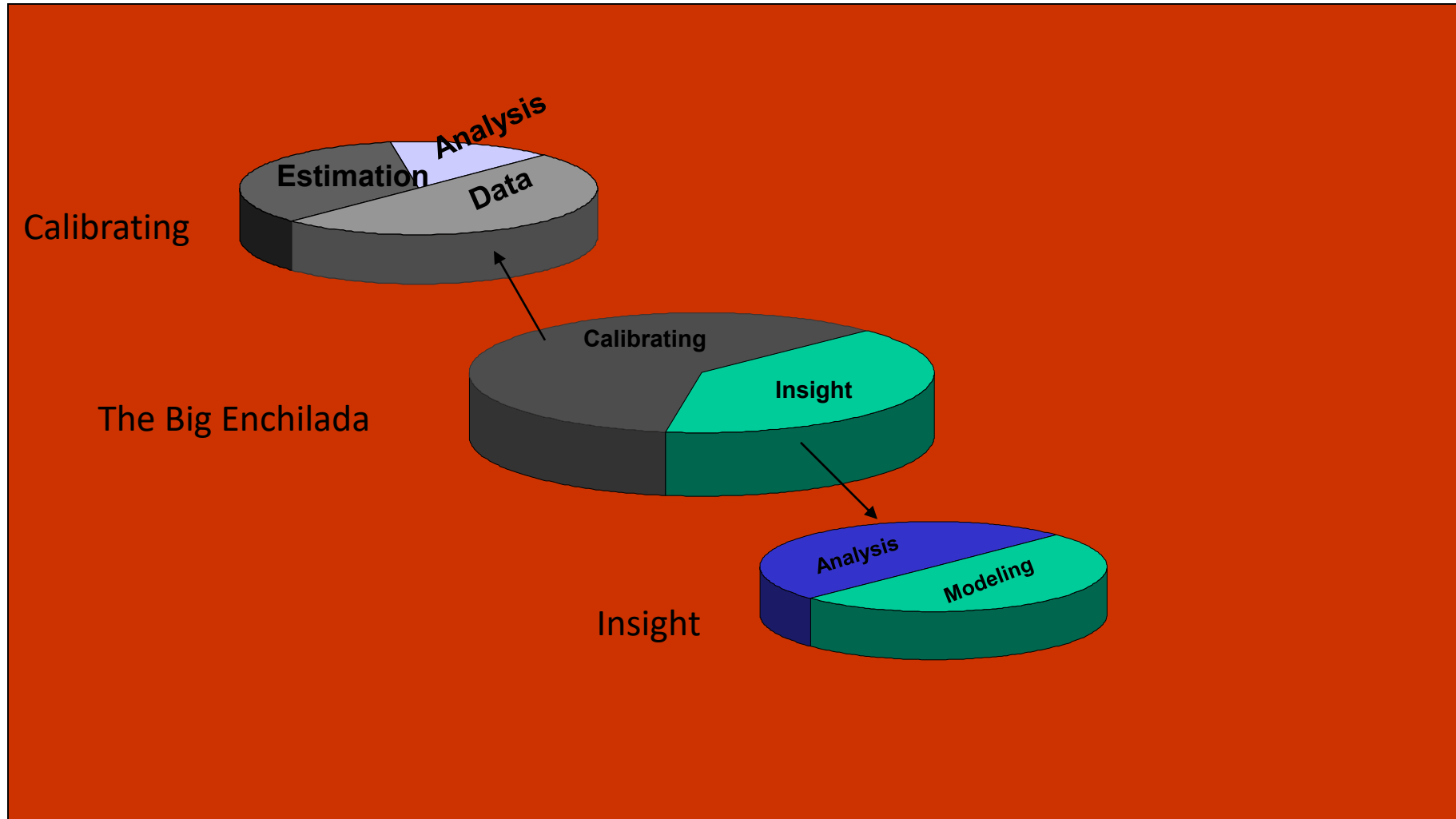
The Big Enchilada
Time Distribution



Calibrating



Generating Insight: Modeling and Analysis Iterations



Acknowledgement: This slides was originally developed by Prof. Jim Hines

Modeling Process Overview

- 1) Problem definition

- a) List of variables
- b) Reference modes
- c) Problem statement
- d) Momentum policies

- 2) Qualitative model

Weekly assignment definition +
Class Discussion pre-modeling

- 3) Simulation model

- 4) Calibration and estimation

- 5) Analysis and insights

Weekly modeling work +
Class Discussion post-modeling

Iterative Modeling-Analysis Process

Common Failure Modes for Aspiring Modelers

- Unclear Problem Definition
- Getting Stuck at the Start
- Poor Aggregation Choices
- Overlapping and Unclear Constructs
- Poor Stock Selection
- Bad Formulations
- Chasing a Desired Behavior

Common Failure Modes for Aspiring Modelers

- Unclear Problem Definition
 - Start with a clear problem definition
 - Specify important architectural choices
- Getting Stuck at the Start
- Poor Aggregation Choices
- Overlapping and Unclear Constructs
- Poor Stock Selection
- Bad Formulations
- Chasing a Desired Behavior

Importance of “Problem” focus

- Determines the purpose of modeling/analysis:
 - What should be included (model boundary)?
 - What level of aggregation is appropriate?
 - What questions and hypotheses are relevant?
 - What data is critical to have?
 - What analysis is needed to nail the point?
- Critical to clarify it early on (specially with ‘client’ or thinking about ‘audience’)

Common Methods for Problem Definition

- **Reference mode driven:** Explaining a historical behavior over time (most straight forward)
- **Mechanism driven:** Given some key structural features of a problem context, what behaviors could arise
- **Policy driven:** What are the important feedbacks and accumulations we should capture to be able to answer a set of policy questions (e.g. prioritizing different policy levers)

Key Architectural Choices

- **Boundary of model:** what is in and what is out? List and prioritize candidates
- **Time horizon**
- **Aggregation level:** How detailed we go in representing concepts?
- **Sources of inertia** and candidate stocks

Common Failure Modes for Aspiring Modelers

- Unclear Problem Definition
- **Getting Stuck at the Start**
 - Start simple and add structure in iterations
- Poor Aggregation Choices
- Overlapping and Unclear Constructs
- Poor Stock Selection
- Bad Formulations
- Chasing a Desired Behavior

Iterate between two steps

- Model
 - Start with modeling a single stock (or connected stock and flow chain)
- Analyze:
 - Put the model into equilibrium
 - Analyze and understand before adding anything
 - Pick a behavior
 - Come up with a hypothesis through causal tracing
 - Test your hypothesis explicitly
 - Test and confirm your understanding

Common Failure Modes for Aspiring Modelers

- Unclear Problem Definition
- Getting Stuck at the Start
- **Poor Aggregation Choices**
- **Overlapping and Unclear Constructs**
- **Poor Stock Selection**
- Bad Formulations
- Chasing a Desired Behavior

Aggregation, Clarity, Inertia

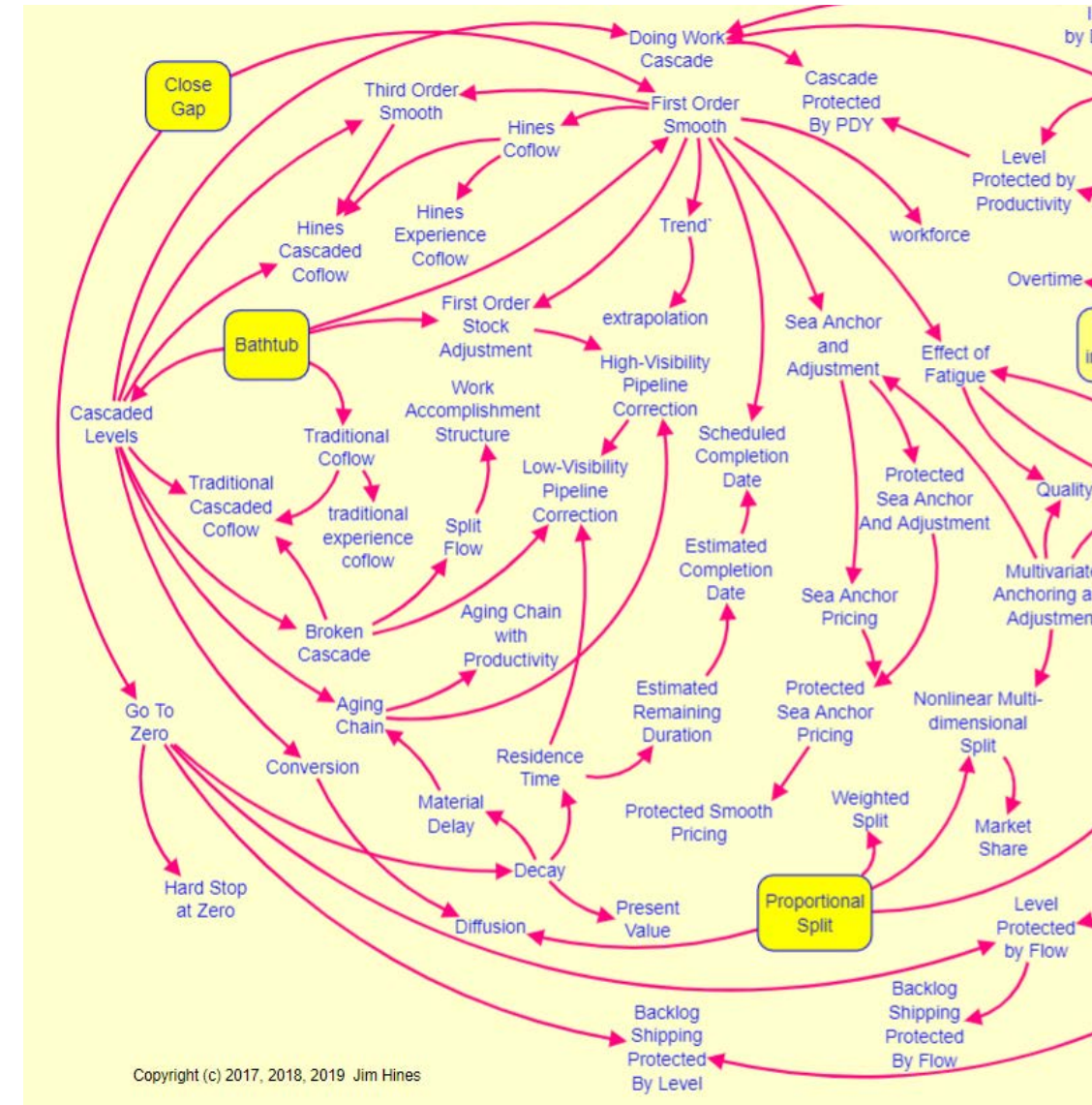
- Think through aggregation choices explicitly. Use the most aggregate version that satisfies your requirements.
- Stay consistent in level of aggregation across different components
- Stay close to a case to have concrete examples for concepts
- Define variables clearly and avoid conceptual overlap
- Start with sources of inertia (snapshot test; perceptions; physical accumulations; common options (e.g. people, resources, products, tasks)). Prioritize them.
- Identify the driving stock(s) for each source of inertia
- Use MECE principle for stocks (and beyond)

Common Failure Modes for Aspiring Modelers

- Unclear Problem Definition
- Getting Stuck at the Start
- Poor Aggregation Choices
- Overlapping and Unclear Constructs
- Poor Stock Selection
- **Bad Formulations**
- Chasing a Desired Behavior

Use standard formulations

- Molecules are a good starting point (<https://sdmolecules.org/> also in Vensim). Study them so you can:
 - Write down the equations without help
 - Identify key inputs and outputs, as well as parameters
 - Come up with 3-4 example applications
 - Predict behavior of outputs for standard inputs (e.g. pulse, step, and ramp)
- Replicate classical models
- Do NOT innovate!



Other Formulation Tips

- Set explicit requirements and impose in formulations:
 - Intended objectives of the chunk?
 - Inputs and outputs and their acceptable ranges?
 - How enforce acceptable output ranges?
 - Well-established regularities between inputs and outputs?
 - Extreme condition tests?
 - Flexibility to adjust the strengths of key mechanisms?
- Limit inputs to formulations (rule of 3 or fewer)
- Avoid discrete formulations (IF, Max, Min, etc)
- Ensure unit consistency

CLASS EXERCISES

Architectural Choices

- For each of the two problems discuss the following:
 - What is a good problem definition and audience?
 - What is a good time horizon for the problem?
 - What high level mechanisms should be included in the model, and what should be left out?
 - What is the right level of aggregation?
 - What are the key sources of inertia and what are good stock variables?
- Prioritize

Thoroughbred Horse Market

- The reference mode for Thoroughbred horses in the US (from Sterman 2000)

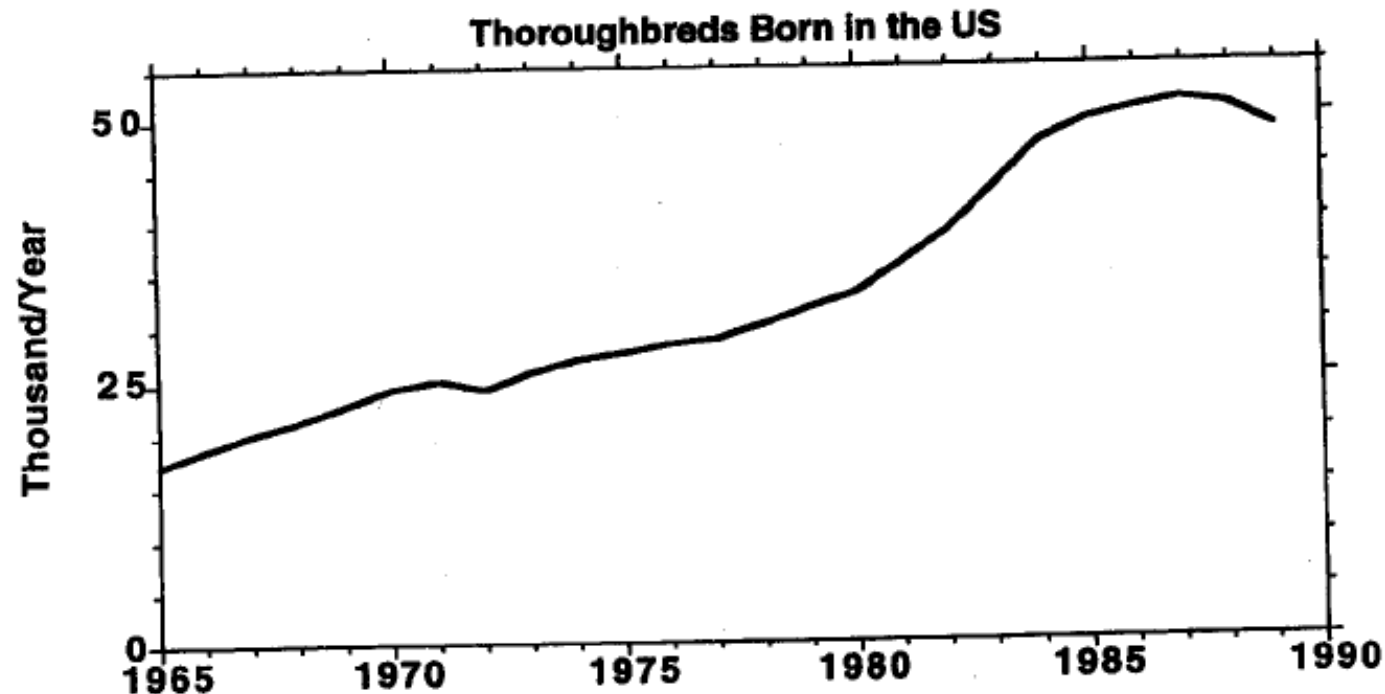


Exhibit 5-18 The expansion of thoroughbred supply

Source: Hermann and Link (1990)

Thoroughbred horse market CLD

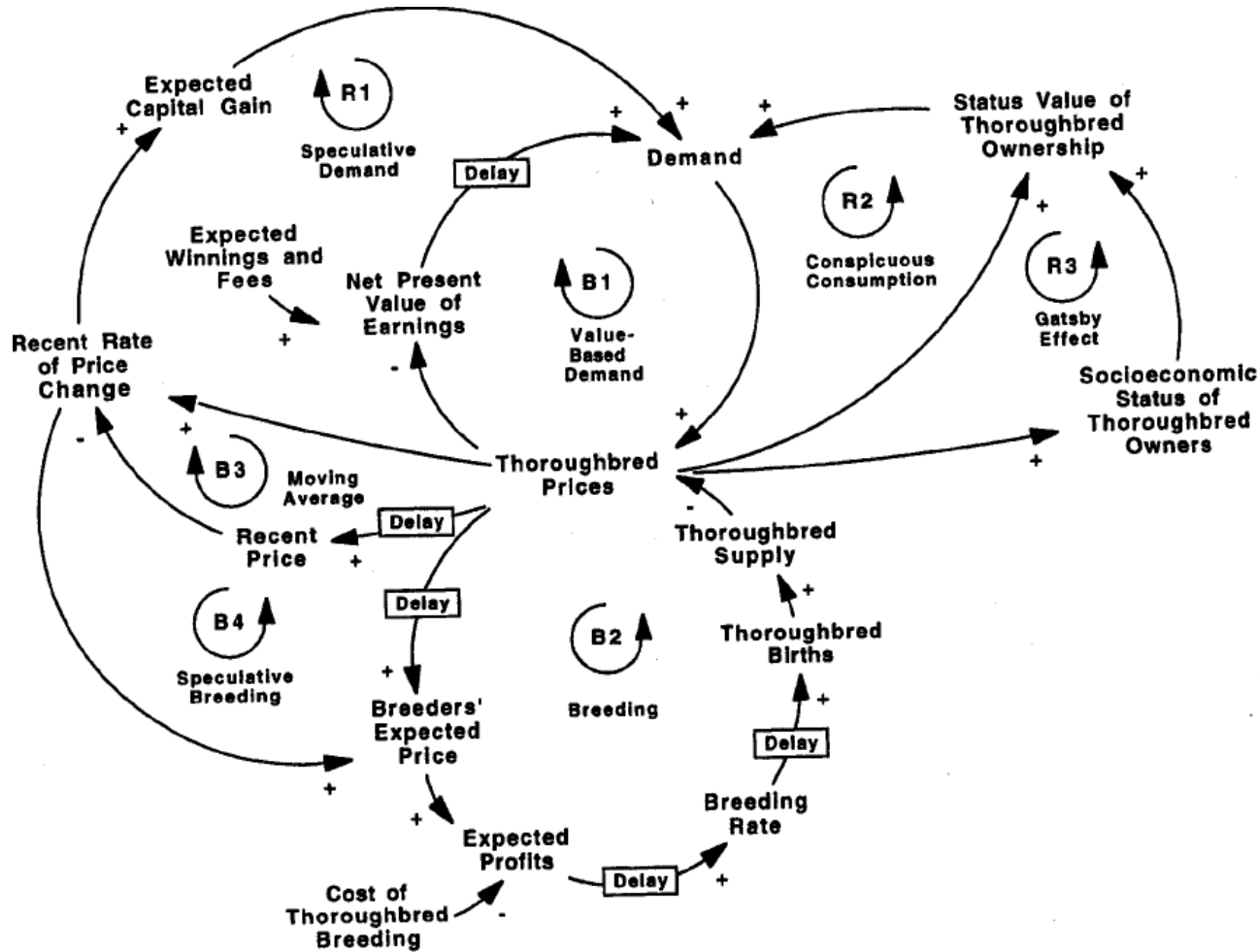
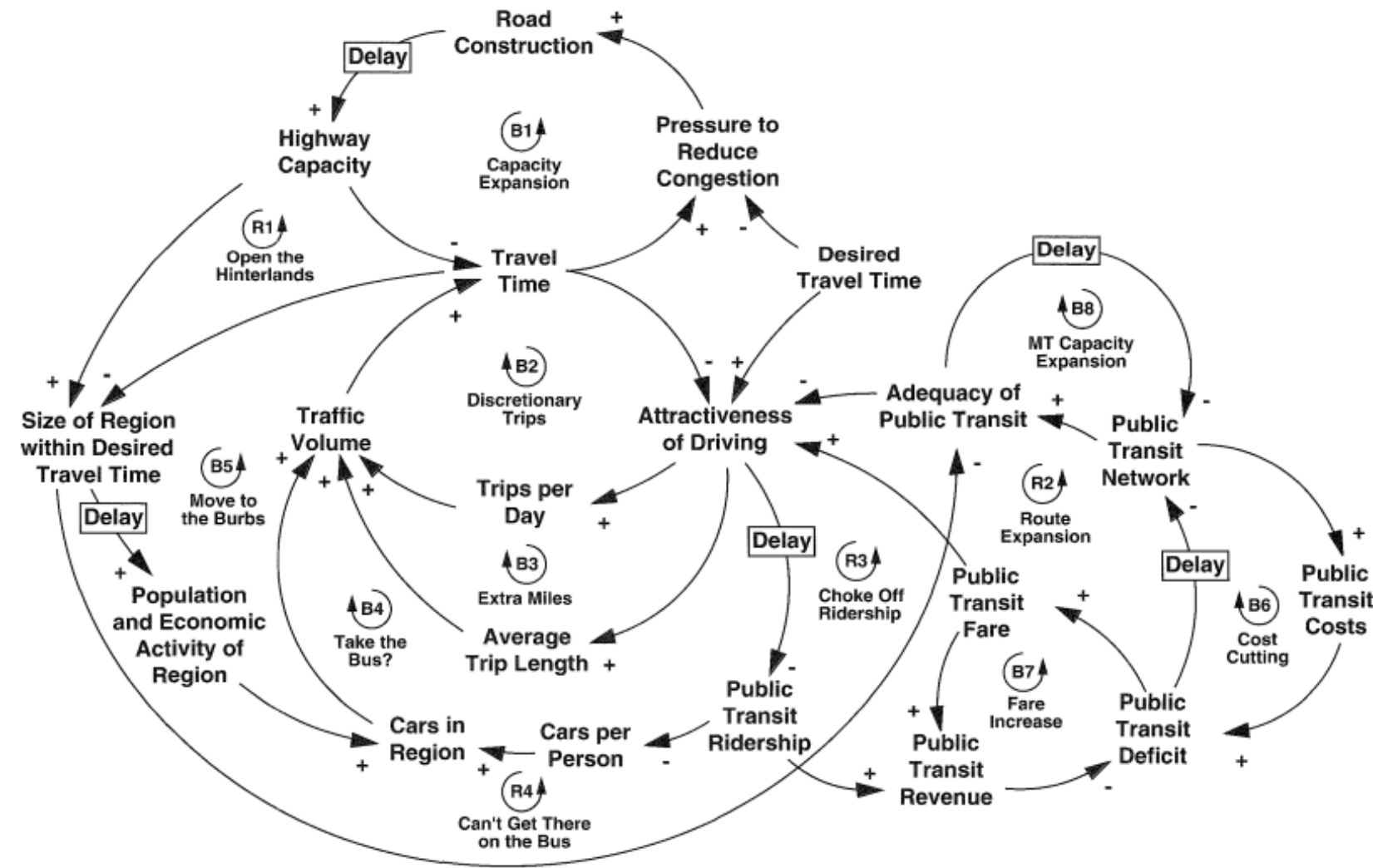


Exhibit 5-16 The thoroughbred horse market

Source: Sterman 2000, Instructor Manual

- What is a good problem definition and audience?
- What is a good time horizon for the problem?
- What high level mechanisms should be included in the model, and what should be left out?
- What is the right level of aggregation?
- What are the key sources of inertia and what are good stock variables? Prioritize

Congestion and Transportation CLD



Source: Sterman 2000, Figure 5-37

Figure from Sterman, John, *Business Dynamics: Systems Thinking and Modeling for a Complex World* © McGraw-Hill Education. All rights reserved. This content is excluded from our Creative Commons license. For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.

- What is a good problem definition and audience?
 - What is a good time horizon for the problem?
 - What high level mechanisms should be included in the model, and what should be left out?
 - What is the right level of aggregation?
 - What are the key sources of inertia and what are good stock variables?
- Prioritize**

Preparing for Next week: Extending SIR model

- Exercise 2 focuses on extending SIR model to include 1) Behavioral responses to risk. 2) Waning of immunity (and equilibrium) 3) Vaccination.
- Given this:
 - What is a good audience, and purpose for your model?
 - How can you keep your model simple enough to enable analytical equilibrium?
 - What stocks would you need to add to the model?

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15.879 Building Serious System Dynamics Models from Scratch
Spring 2025

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