



Massachusetts Institute of Technology  
Sloan School of Management

**15.871 Introduction to System Dynamics**  
Fall 2013

Assignment 2  
**Problem Definition and Model Conceptualization**

Assigned: Monday, September 16, 2013; Due: Monday, September 23, 2013

*Please do this assignment in a team totaling three people.*

Designing and evaluating high-leverage policies demands a long-term, dynamic perspective. The analyst or manager must be able to characterize the strategic problem, including its current symptoms and history. The time horizon should be explicit and must be long enough to include possible side effects, delayed responses to policies, and other feedbacks. This assignment cultivates your ability to develop a *reference mode*, a graphical characterization of the patterns of problem behavior over time. The assignment also develops your skill in constructing *causal loop diagrams* that capture the feedback structure of the system, and your ability to relate the structure in a causal map to the problem behavior in the reference mode.

Problem definition involves both textual and graphical statements of problematic behavior. Conceptualization entails identifying feedback loops that are hypothesized to underlie observed patterns of system behavior. Model formulation is the process of moving from a theory of underlying structure to a fully specified mathematical model so that the theory can be tested. This assignment focuses on problem definition and dynamic hypothesis generation. Later assignments will bring these skills together with those of formulation and analysis to focus on a variety of strategic and operational problems.

### **Assignment Guidelines**

#### **Teams**

- ☞ Teams consist of three people. No exceptions.
- ☞ Members of a team may be drawn from either section A or B of the course.
- ☞ ***Do the work together, as a group.*** While it is tempting to use a “divide and conquer” strategy and have each person work on different parts of the assignment, doing so will take longer, lower the quality of your work, and limit what you learn—and therefore your ability to complete later assignments. Your dialogue with your teammates as you work through the issues will deepen your understanding and improve your work.

In the real world, modeling is almost always done in teams including key stakeholders whose participation is essential for successful implementation. In addition to mastering the technical skills of modeling, you must also master the pragmatic skills of group modeling, including active listening, publicly testing your assumptions, and building respect and trust for others.

## **How much should you hand in?**

Use your judgment. Some words of wisdom:

“*Be careful that you write accurately rather than much.*” —Erasmus

☞ We don’t give higher grades for longer write-ups.

“*Often must you turn your stylus to erase, if you hope to write something worth a second reading.*” —Horace

☞ Allow yourself time for revisions.

“*What is written without effort is in general read without pleasure.*” —Samuel Johnson

☞ And graded without pleasure.

☞ While your graphs and diagrams should be clear and legible, *DO NOT* spend your time creating artist-quality presentation graphics. Use your time to think about the issues and develop your ideas. A legible handwritten diagram you had time to think about is preferable to a beautiful computer-generated diagram that took so much time to render you didn’t have time to think deeply about its content.

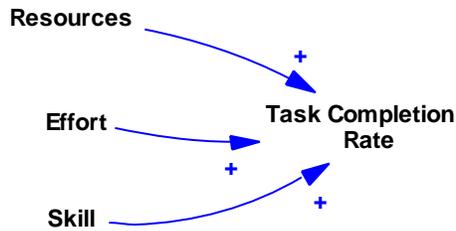
## **General hints**

- ☞ Before starting, review the assigned readings covering causal-loop diagrams as noted in the syllabus, particularly chapters 4 and 5 of *Business Dynamics*.
- ☞ Each of your diagrams must fit comfortably and legibly on single page in your writeup. Diagrams should include the loops essential in explaining the dynamics, but be simple enough to understand. Your client will not understand a diagram that includes everything.
- ☞ Be sure to follow the conventions and rules for causal diagrams and reference modes described in chapters 4 and 5. These include:
  - Show the time horizon of graphs explicitly; provide units of measure and scales for all variables.
  - Label the polarity of every link in your causal diagrams.
  - Identify the polarity of the important loops.
  - Give the important loops a meaningful name.
  - Use variables with a clear sense of direction.
  - Clearly label your graphs.

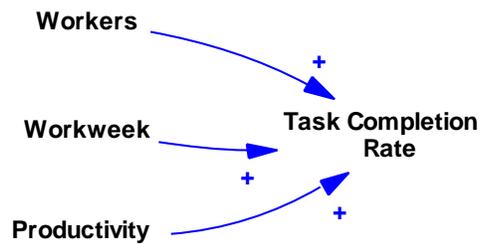
## **Operational thinking and dimensional consistency**

☞ Formulate your causal diagrams so they capture operational realities—the physics and decision making procedures—of the processes you seek to represent. The units of measure for the variables should be obvious and conform to standard practice. In many cases, the equation for a key concept should be readily inferred from the causal diagram and units.

For example, consider a model of a work process. A key formulation shows how the amount of work completed each day is determined. The following diagram states that work completion rises with resources, effort and skill:



However, the definitions and units of measure for the inputs to the completion rate are unclear. Are resources measured in people or dollars or dollars per month? What is “effort” and how do we measure “skill”? A much better diagram is:



Each variable has a clear sense of direction and obvious units of measure. From this information a reader can easily infer the equation for the Task Completion Rate:

$$\text{Task Completion Rate} = \text{Workers} * \text{Workweek} * \text{Productivity}$$

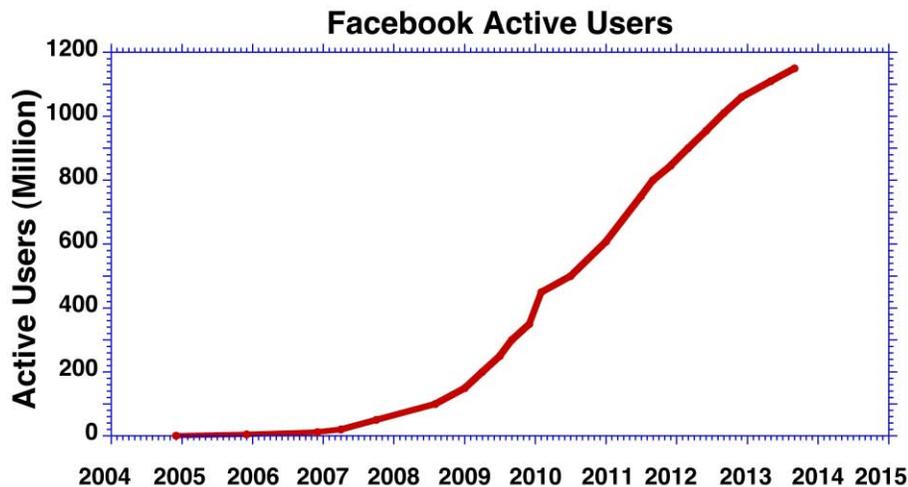
(Tasks/week)      (People) \*      (Hours/Week) \*      (Tasks/Hour/Person)

**Submitting your work:** One member of your team should submit your team’s write-up as a single word document. Make sure the write-up lists the full names of all members of your team.

## A. Identifying Feedback Structure of Growth and its Limits (5 points: 1/2 of total)

- A1. Identify the reinforcing feedbacks responsible for the exponential growth of the number of active Facebook users, shown below (data from Facebook).

Develop a causal loop diagram capturing the most important reinforcing feedbacks you believe to be responsible for the astounding growth of Facebook. Limit yourself to no more than four reinforcing feedbacks. In your writeup, provide a one-sentence explanation of each loop.



- A2. No real quantity can grow forever. Identify some of the balancing feedbacks that might eventually stop the growth of Facebook. Add them to your causal diagram. Limit yourself to no more than four balancing feedbacks. Provide a one-sentence explanation of each loop.
- A3. What is likely to happen to the number of Facebook users in the future? Specifically, use your diagram to suggest what the pattern of development for active Facebook users might be in the future. Draw a graph showing possible futures for the number of active users. Select an appropriate time horizon, and explain your choice briefly. Limit yourself to no more than three possible future paths for subscribers. Name your scenarios.
- Use the feedback structure and other features of your causal diagram (such as delays) to assess what the likely behavior of the user base might be. Chapter 4 discusses different feedback structures and the various patterns of behavior they can generate. A good answer here will explain how the structure you hypothesize generates the behavior you anticipate.
- A4. Include in your possible futures graphs showing the likely behavior of other key variables in your causal diagram. Provide scales where appropriate.
- The behavior of the other variables you show should be consistent with the feedback loop structure in your diagram. Further, the hypothesized behavior of the variables you graph for each future should form an internally consistent scenario. For example, if you argue that Facebook will continue to grow, is it plausible to also show the number of ads users are forced to endure growing, while content quality and privacy drop?

## **B. Speculative Bubbles and the Sub-prime Mortgage Crisis (5 points; 1/2 of total)**

The US is now slowly emerging from the implosion phase of a great speculative bubble in housing. Yale economist Bob Shiller estimates that real housing prices (prices adjusted for general inflation) rose about 80% between 1998 and 2006, a remarkable rate of appreciation that made housing the best investment going. Selected cities, particularly in the sunbelt, experienced much faster booms (see graph below). Such dramatic price appreciation would normally not be possible, as homes would have rapidly become unaffordable for most people, eroding demand and limiting prices.

To keep demand strong during the boom, however, financial institutions created a wide range of novel mortgage instruments, including interest-only loans, nothing-down loans, balloon payment schedules, exploding ARMS—adjustable rate mortgages with initial rates below market and much higher payments after a few years, and others. Standards to qualify for a mortgage were relaxed as lending institutions reasoned that risk was low—if a buyer could not make the payments and defaulted, the bank assumed it could foreclose and sell at a profit due to the appreciation in prices that would have occurred in the meantime.

The result was a flood of no-doc loans, loans with self-reported and unverified income and assets, and even so-called Ninja loans (“no income, no job, [no] assets”). Industry insiders spoke of “liar’s loans”—where lenders, in the words of New York *Times* business columnist Joseph Nocera, “practically begged borrowers to fib about their income.” Mortgage brokers and loan originators chased the fees these loans generated while banks and brokers packaged and resold them to investors around the world in novel forms such as CDOs (collateralized debt obligations). Appraisers and the bond rating agencies also received significant fee income, and, in some cases, kickbacks, for inflating valuations. Lured by the high profits from fee income and flipping properties, the number of mortgage brokers, real estate agents, appraisers, and others in the housing and securitized mortgage sector exploded.

But of course the bubble burst. The inventory of unsold properties skyrocketed. Prices fell rapidly (see the graph). Housing starts plummeted. Millions of people found they had negative equity, with no chance to sell. Some just walked away from their homes, so even legitimate lenders started to get “jingle mail” where the borrowers simply mailed the keys to the bank and stopped paying their mortgages. Many more, especially the working poor, struggled to pay their debts in good faith, only to find that their homes were taken from them in foreclosure. The ripple effects spilled into world financial markets as hallowed names in the banking and investment world like Lehman Brothers failed, while others were forced into mergers—Merrill Lynch, Washington Mutual, Wachovia, many others—and pillars of finance had to be bailed out at enormous cost to central banks around the world, including Fannie Mae, Freddie Mac, and AIG. Worldwide financial collapse was barely averted, despite the injection of massive funds into the banking system, widespread bailouts, short-term interest rates of zero, and fiscal

stimulus. The contagion spread into the real economy, leading to the worst world economic downturn since the Great Depression. State and federal investigators launched investigations into the many allegations of fraud and abuse (though essentially no one has been sent to jail). During the crisis the list of defunct lending operations grew weekly (see, e.g., “the Mortgage Lender Implode-O-Meter” at [ml-implode.com/](http://ml-implode.com/)).

Housing presents a spectacular, but by no means unique, example of a speculative bubble. Your task is to identify the feedback structure of speculative bubbles and apply it to the housing crisis.

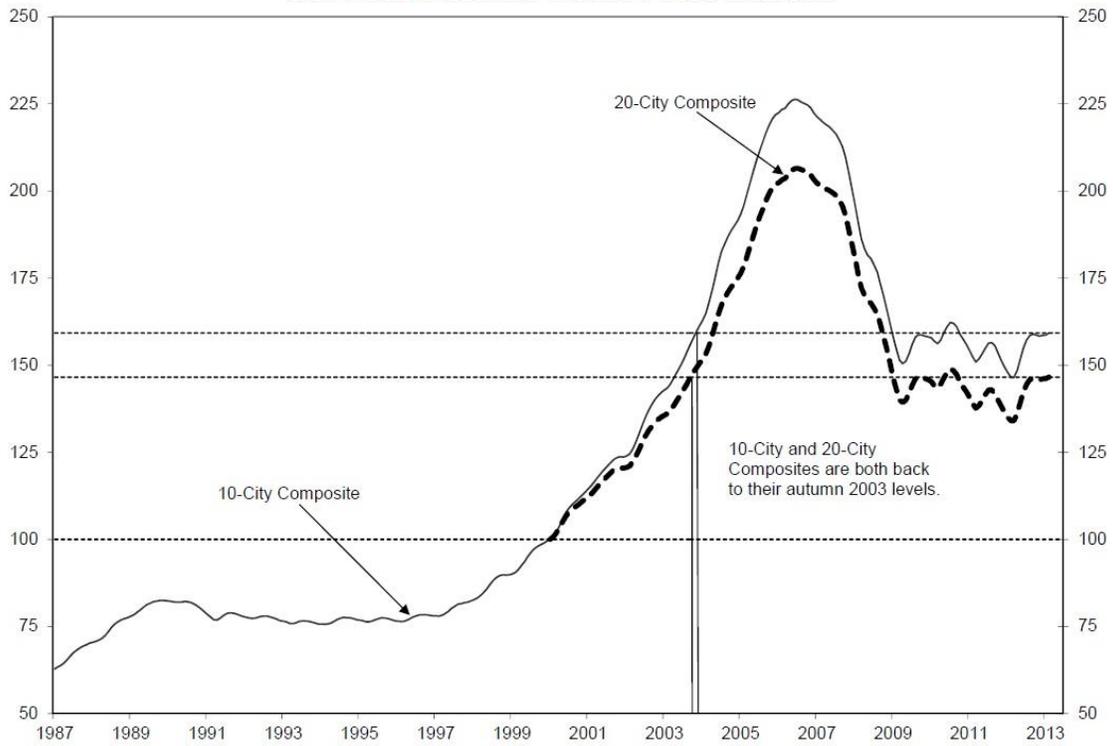
Read and do the challenge “Speculative Bubbles” on p. 173 of *Business Dynamics*. That challenge asks you to develop a reference mode (dynamic problem definition) for speculative bubbles in general, then expand the basic feedback structure for markets (p. 170) with the feedbacks contributing to speculative bubbles described by JS Mill. For this assignment, you should tailor your analysis to represent key features of the housing bubble. Specifically,

- B1. Make a list of the most important variables or concepts characterizing the housing bubble. Keep your list short (eight or fewer). Aggregate similar concepts where possible (e.g., do not represent different types of housing separately, or different types of mortgages: a broad boundary is more important than disaggregate detail).
- B2. Use the description above and your own knowledge to graph the behavior of the key variables you identified. First, identify the *time horizon* over which the dynamics unfold. Select a time horizon long enough to capture the dynamics of the critical variables throughout the bubble, including the past development and enough of the future for the dynamics to play out. Next, sketch a graph showing the behavior for each variable over the time horizon you identified. If two or more variables have the same units of measure, plot them on the same scale. For example, in a model of a business one would show revenue and cost on the same graph so that the difference between them (profit) can be easily seen. Qualitative patterns are more important than numerical precision in the early stages of problem definition. You do not need to go to the web or other sources to find data. Include your reference modes in your write-up.
- B3. Develop a causal diagram that captures the feedbacks you believe are responsible for the housing bubble. Your diagram should have, at its core, the basic feedback structure regulating demand and supply in markets (*Business Dynamics*, p. 170). Then add the most important feedbacks you believe are operating in the housing bubble.
- To get your causal diagram started it is useful to ask yourself “what is the rationale for the decisions of each actor in the system?” That is, what is the *intended rationality* or *intended outcome* of the decision to buy a home? To sell? To build? To Lend? For example, one motivation for buyers is to provide a roof over one’s head, but a house can also be viewed as an investment with the potential for capital gains. Similarly, what factors would motivate

developers to start new housing construction (see graph below of US residential construction).

- ☒ Be sure to show important time delays, including delays in physical processes, in the measurement and reporting of information, and in the change in perceptions and beliefs.
- ☒ Selecting an appropriate boundary is a critical skill in modeling. You need a boundary broad enough to include the key feedbacks but not so broad that your model becomes overwhelming. While the effects of the housing bubble and crash rippled out to affect world financial markets, economic output and employment, do not attempt to develop a global macroeconomic model. Keep your model focused on the core dynamics responsible for the housing bubble. Remember that while the specifics of the housing market may have differed in this episode compared to previous bubbles, the feedback structure underlying all speculative bubbles is the same.
- ☐ B4. Using your diagram, briefly explain the genesis of the bubble. What caused the bubble to burst? What policies might have prevented or moderated the bubble? What policies might have mitigated the harm it caused? What policies might prevent such a bubble from happening again?

### S&P/Case-Shiller Home Price Indices

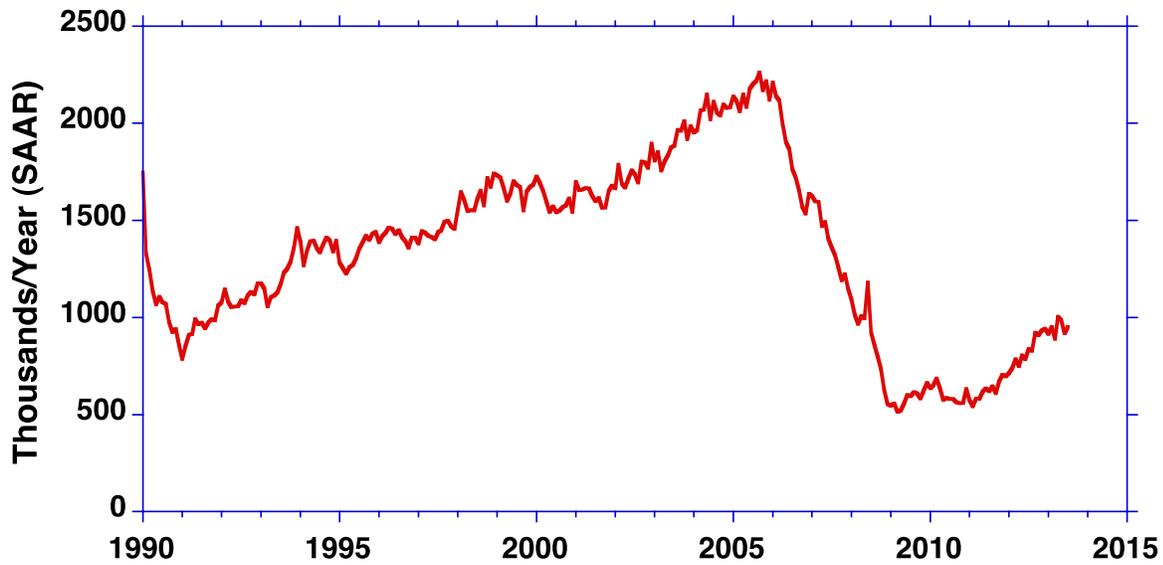


Source: S&P Dow Jones Indices and CoreLogic

### Case-Shiller home price index.

Source: <http://www.ritholtz.com/blog/2013/04/case-shiller-home-prices-rise-in-february-2013/>

### US Residential Construction



### US Residential Construction:

Source: US Census Bureau. SAAR (Seasonally Adjusted at Annual Rates)

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