Mistakes and Misunderstandings:

Hidden Time Constants and

Growth Fractions

Prepared for the
MIT System Dynamics in Education Project
Under the Supervision of
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by
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1. THE SYSTEM

My history teacher had suggested that I learn something useful during my summer-long stay in Italy. Not wanting to disappoint him, I agreed wholeheartedly. Italy's rich history and culture provides an excellent basis for such a project. I had done my research on the region....the canals of Venice, Michelangelo's David, the Colosseum, Vatican City... 54 major historical sights in all. I thought that simply visiting all the sights and writing about the historical significance of each would suffice. Seeing as how I did not want to spend the entire vacation working on the project, I decided to visit all the sights in the very first week. I could then spend the remaining eleven weeks basking on the beaches of the Italian riviera.

By the first evening, I had painfully learned that eight cathedrals and piazzas in one day make even the most diligent historian whimper. Therefore, to avoid exhaustion, I granted myself an extra day to visit all the sights and promised myself that I would finish within the following week. Soon enough, my laziness took over and every morning I extended my deadline, swearing that I would finish within a week.

After finally taking in all there was to see (by about the 6^{th} week), I began to realize how incredibly boring it would be to write about every historical sight I had seen. Therefore, I searched for a new approach to completing my assignment. My sightseeing behavior, I noticed, seemed similar to behavior exhibited by simple goal-gap models that I had learned about in a weekend system dynamics course the previous summer. As a result, I decided that in lieu of the outrageous writing assignment I initially planned, I would attempt to build a model of my sightseeing decision-making to demonstrate why it took me so much longer than expected to see all the sights. I could then analyze the model for my teacher as proof that I had learned something while on vacation (though something more psychological than historical).

2. A FIRST ATTEMPT TO MODEL THE SYSTEM

I began by drawing the causal-loop diagram shown in Figure 1. I recalled that I saw more sights as the vacation progressed, leaving fewer sights not seen. As the number

of sights not seen decreased, however, laziness caused my rate of sightseeing (the number of sights I saw each week) to also decrease. The sightseeing rate slow-down caused me to approach my goal increasingly slower, the closer I got to completion.

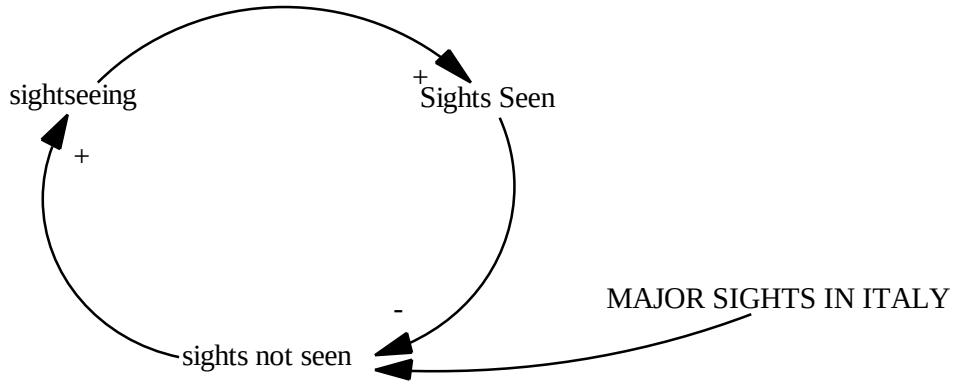

Figure 1: A causal-loop diagram of my sightseeing behavior

Satisfied that my causal-loop diagram accurately described the decisions I had made, I proceeded to translate the diagram into a stock-and-flow model, as shown in Figure 2. "Sights seen" is the stock of historical sights that I had already visited, while "sightseeing" is the inflow to that stock. "MAJOR SIGHTS IN ITALY" is the number of historical sights I planned on visiting, and "sights not seen" is the difference between "MAJOR SIGHTS IN ITALY" and "Sights Seen." "Sightseeing" (the number of sights I saw per week) was set equal to "sights not seen" because every day I told myself that I would see all remaining sights within a week.

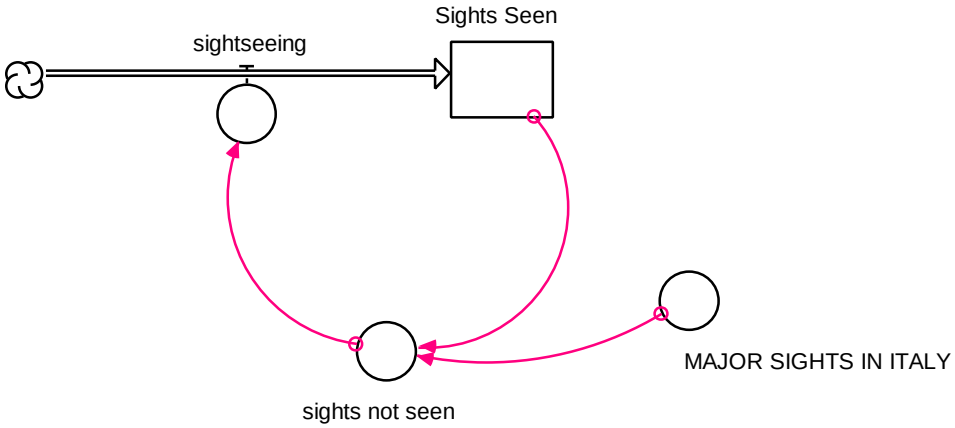

Figure 2: A stock-and-flow diagram of my sightseeing behavior

The finished model looked very similar to my causal loop diagram and produced behavior almost identical to what I had experienced, as displayed in Figure 3.

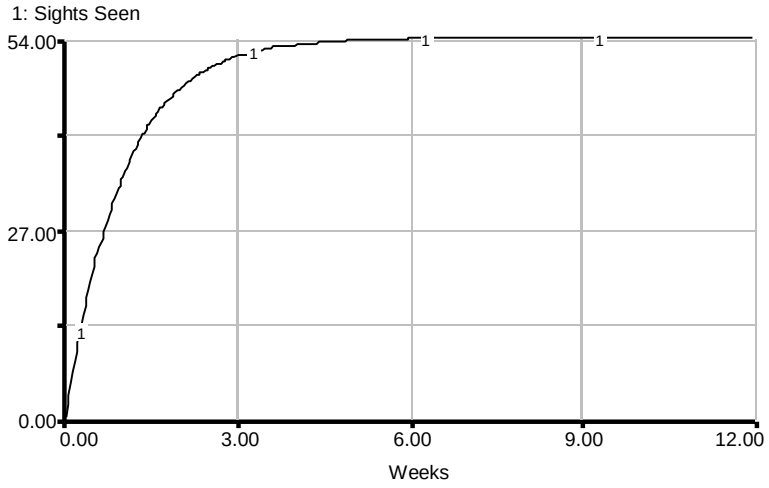

Figure 3: The sightseeing behavior produced by my model

3. MISTAKES AND MISUNDERSTANDINGS

Upon my return at summer's end, I approached my teacher in his office and enthusiastically presented my summer's work.

"This is probably not quite what you expected," I said as I handed him the paper.

After several minutes of silence, he looked up and said, "Although I am impressed with your creativity and your ability to capture the underlying feedback relationship in the system, you violated some of the most fundamental rules of system dynamics modeling. Your model is dimensionally inconsistent and contains hidden assumptions, making it nearly impossible to perform sensitivity analysis."

I asked him to explain.

"What are the units of 'sightseeing'?" he asked.

"That's easy," I replied. "Because the stock 'Sights Seen' has units of 'sights' and 'sightseeing' is the flow into it, 'sightseeing' must have units of 'sights/week.'"

"Very good. Now what are the units of 'sights not seen'?"

"That's another easy one: 'sights not seen' must have units of 'sights' because it is calculated as the difference between two things that both have units of 'sights.'"

"Correct. So why in your formulation of 'sightseeing' do you set something with units of 'sights/week' equal to something with units of 'sights'? Here your model is *dimensionally inconsistent*. Both sides of an equation must have the same units. After all, you can't add apples and oranges."

"In this formulation," he continued, "you have also hidden your assumption about how your sightseeing decision is made..."

"But I stated in my system description that every morning I awoke and promised myself I would finish all remaining sights within a week," I interrupted.

"Precisely, but I do not see an explicit statement of that decision and all the information used to make that decision, in your model. Now, suppose you were interested in seeing what would have happened if you had attempted to see only half, instead of all, the remaining sights in the upcoming week. How would you observe the effects of this change?"

"I suppose I could build another model that contained a different equation for 'sightseeing,' incorporating the new weekly sightseeing goal."

"Wouldn't it be much easier if you could just change a parameter in your current model, rerun the simulation, and observe the new behavior? The process of testing the response of the system to changes in parameters, initial conditions, or table functions is called *sensitivity analysis*."

Convinced of my mistake and eager to correct it, I pressed forth.

"So to fix this problem, I should add a constant called 'SIGHTSEEING FRACTION' to my model. This constant would be the fraction of sights not seen that I want to visit in the upcoming week. In my current model, 'SIGHTSEEING FRACTION' is equal to one. The fraction should have units of (sights/sights) per week, or simply '1/week.' I can then set 'sightseeing' equal to 'SIGHTSEEING FRACTION' times 'sights not seen.'"

"Excellent. You should also remember that explicitly stating time constants is equally as important as explicitly stating growth fractions," he said.

4. Overcoming Our Mistakes and Misunderstandings

I went straight home and quickly updated my model, as shown in Figure 4.

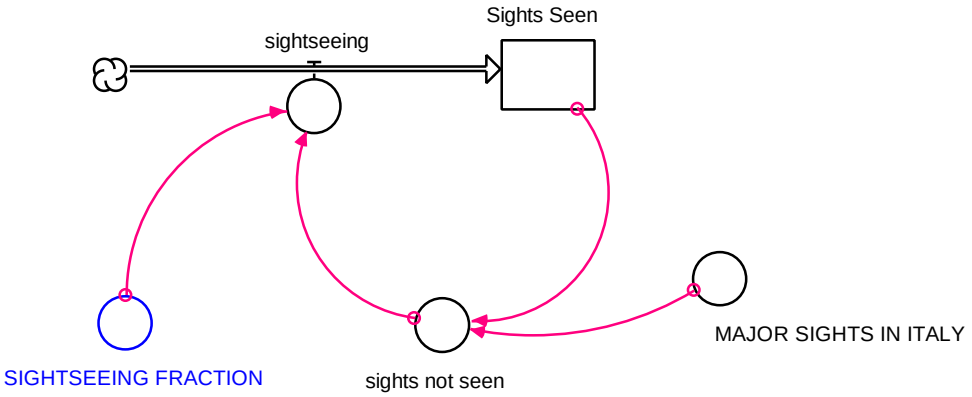

Figure 4: The corrected sightseeing model

My model is now dimensionally consistent and contains no hidden assumptions. That is, all formulations equate terms with equivalent units, and all decisions I made in the system are explicitly stated in my model. The new structure also allows me to vary the sightseeing fraction easily, showing what would have happened if my decision making process had been different.

5. Key Lessons

Working with my sightseeing model, I learned how important it is to explicitly state time constants and growth fractions in system dynamics models. Embedding constants in equations makes a model dimensionally inconsistent and can hide key assumptions. Embedding constants also makes it difficult to test the sensitivity of a model to changes in assumptions.

I also learned that embedding constants is a particularly easy mistake to make when converting a causal-loop diagram into a stock-and-flow structure because constants, especially when equal to one, are often not shown in causal-loop diagrams.

6. Appendix

Sights_Seen(t) = Sights_Seen(t - dt) + (sightseeing) * dt

INIT Sights_Seen = 0
DOCUMENT: Sights seen are the number of tourist sights that I have already seen.
UNITS: sights

sightseeing = sights_not_seen * SIGHTSEEING_FRACTION
DOCUMENT: The number of sights that I see each week.
UNITS: sights/week

MAJOR_SIGHTS_IN_ITALY = 54
DOCUMENT: The total number of historical sights in Italy that I want to visit during my trip.
UNITS: sights

sights_not_seen = MAJOR_SIGHTS_IN_ITALY - Sights_Seen
DOCUMENT: The number of historical sights that I still have not seen.
UNITS: sights

SIGHTSEEING_FRACTION = 1
DOCUMENT: SIGHTSEEING FRACTION is the fraction of the sights I have yet to visit that I will see in the next week.
UNITS: 1/week