Guided Study Program in System Dynamics

System Dynamics in Education Project
System Dynamics Group
MIT Sloan School of Management[1]

Assignment #23

Assigned on: Friday, April 16, 1999

Due by: Monday, April 26, 1999
12:00 PM (Noon)[2]
WE WILL REVIEW THE RESPONSES ON MONDAY AFTERNOONS, BOSTON TIME.
LATE SUBMISSIONS WILL NOT RECEIVE FULL ATTENTION.

Please email assignment solutions, questions, or comments to:

gsp@sysdyn.mit.edu

Save solutions with the filename XYZ-S23.doc
(where XYZ are your initials)

Reading Assignment:

Please read the following:

- *Industrial Dynamics*,[3] by Jay W. Forrester, Chapter 5
- *Principles of Systems*,[4] by Jay W. Forrester, Chapter 5

[2] The deadline is in United States Eastern Time, equivalent to Greenwich Mean Time minus 4 hours during US daylight savings time, and Greenwich Mean Time minus 5 hours for the rest of the year.
[3] Forrester, Jay W., 1961. *Industrial Dynamics.* Waltham, MA: Pegasus Communications. 464 pp.
[4] Forrester, Jay W., 1968. *Principles of Systems*, (2nd. ed.). Waltham, MA: Pegasus Communications. 391 pp.

Exercises:

1. Industrial Dynamics and Principles of Systems

Please read chapter 5 of *Industrial Dynamics* and chapter 5 of *Principles of Systems* carefully. The chapters cover some fundamental concepts to keep in mind when formulating system dynamics models.

The following two modeling exercises include a one-paragraph description of a characteristic behavior of a type of system. Each exercise then contains guidelines to help you conceptualize and formulate a model that demonstrates the dynamics of the system. You will be asked to simulate the model and analyze how the model responds to certain inputs. Finally, you will use some of the tests introduced in the paper by Ray Shreckengost, *Dynamic Simulation Models: How Valid are They?* (see assignment 15), to evaluate the validity of the model.

2. Modeling Exercise: An Ecological System

The following description of an ecological system is taken from "Concepts of Ecology"[5] by E. Kormondy:

> "...At a critical time in the life history of a given population, a physical factor such as light or a nutrient may be significant as a regulatory agent; at another time, parasitism, predation, or competition, or even some other physical factor may become the operative factor. As complex and as variable as the niche of any species is, it is unlikely that the regulation comes about by any single agency. However, there does appear to be considerable and mounting evidence, both empirical and theoretical, to suggest that populations are self-regulating through automatic feedback mechanisms. Various mechanisms and interactions appear to operate both in providing the information and in the manner of responding to it, and with the exceptional case of a catastrophe, the stimulus to do so appears to depend on the density of the population. The end effect is one of avoiding destruction of a population's own environment and thereby avoiding its own extinction."

You will be building, step by step, a first-order system dynamics model (that is, containing one stock) to study an ecological system in Alaska, initially inhabited by 100 otters. Otters do not reproduce as quickly as some animals lower on the food chain; they usually cannot reproduce until they are three years of age, and the young are born an entire year after conception. Although each pair of otters gives birth to one to three babies per year, few otters survive infancy. Assume that one baby otter survives infancy

[5] Kormondy, E. J. (1969) *Concepts of Ecology*, Englewood Cliffs: Prentice-Hall, p. 110.

each year for every 4 adult otters in this particular ecological system. The 200-acre area of the ecosystem keeps the population in check due to limited natural resources. Under uncrowded conditions (less than 50 otters in the system), an otter lives on average about 15 years. When the ecosystem is crowded (more than 200 otters in the system), the habitat can no longer support all otters and about two out of five otters die per year. Furthermore, we know that initially (in 1984), the system is in equilibrium.

A. Start building the model by representing a stock of your choice. Formulate the stock's flows. In your assignment solutions document, include the model diagram and documented equations.

B. Draw a reference mode for the behavior of the stock over 25 years. Simulate the model for 25 years starting in 1984. In your assignment solutions document, include a graph of model behavior. Explain the behavior. Is the system in equilibrium? Why or why not?

Otters are valued by man for their extremely dense and lustrous fur. Many Alaskan fishermen supplement their income by trapping otters for their fur. The county preservation agency has asked fishermen to trap no more than 10 otters per year from this particular ecosystem.

C. Modify the model to represent the removal of ten otters from the system each year. In your assignment solutions document, include the modified model diagram and documented equations.

D. Estimate the new equilibrium of the system. Simulate the model. In your assignment solutions document, include a graph of the model behavior. Explain the behavior. What is the new system equilibrium? Explain.

In 1989, a large oil tanker known as the "Exxon Valdez" drifted onto a reef and spilled some 10.1 million barrels of oil into Alaska's Prince William Sound. Because of the catastrophe, half the otter population of the ecosystem is killed.

E. Modify the model to represent this scenario (*hint: use the PULSE function*[6]). Set the outflow modeled in part C equal to zero for this scenario. That is, fishermen do not trap and kill any otters during this tragic time. In your assignment solutions document, include the modified model diagram and documented equations.

F. Simulate the model. In your assignment solutions document, include a graph of the model behavior. Explain the behavior. Is the system "self-regulating through automatic feedback" as described in the passage?

[6] Please refer to the general solutions to assignment 17, Exercise 1, part 1C, if you need help with formulating a PULSE function.

G. Evaluate the validity of the model. You may want to use the behavior sensitivity test, among others. Describe the test(s) that would be most indicative of validity and the results of these tests.

3. Modeling Exercise: A Predator/Prey System

The following description of a predator/prey system comes from "Fundamentals of Ecology"[7] by Eugene Odum:

> "...Interesting and only partly understood density variations are those which are not related to seasonal or obvious annual changes, but which involve regular oscillations or cycles of abundance with peaks and depressions every few years, often occurring with such regularity that population size may be predicted in advance. The best known cases concern mammals, birds, insects, fish and seed production in plants in northern environments. Among the mammals, the best-studied examples exhibit either a 9 to 10 year or a 3 to 4 year periodicity... Peaks of abundance often are followed by "crashes," or rapid declines."

Initially, a population of 1250 predators and 50000 prey coexist in an ecosystem encompassing 1000 acres of land. The prey reproduce much more rapidly than the predator (almost always the case with any predator/prey system), producing on average five offspring for every four prey each year. The predators, on the other hand, produce about one offspring for every four predators per year. Predators die either by natural causes (about ten per hundred predators each year), or by starvation, when prey is scarce. Prey die either by natural causes (about 50 per 100 prey each year) or are killed by predators.

A. The ecology text hypothesizes that predator/prey models will exhibit oscillatory behavior. Do you agree? Why or why not?

B. Start building the model by creating stocks of "Predator Population" and "Prey Population." Formulate the relevant inflows and outflows due to natural causes only. In your assignment solutions document, include the model diagram and documented equations.

The nature of the closed predator/prey system is such that predators depend on the prey for subsistence. When there are few prey in the system, the predators are unable to catch much food, and many predators die. In fact, when there are no prey at all, the predators die twice as quickly as they are born. On the other hand, when there are as many as 100,000 prey within the ecosystem, only about 1 out of 16 predators die annually.

---

[7] Odum, Eugene P. (1971) *Fundamentals of Ecology*, Philadelphia: W. B. Saunders Co. pp. 190-192.

C. Formulate the outflow from "Predator Population" due to starvation. In your assignment solutions document, include the modified model diagram, documented equations, and graphs of any lookup functions.

The only piece of the puzzle missing now is the outflow from "Prey Population" due to killings by predators. When there are no prey in the ecosystem, predators cannot catch any prey. When there are 100,000 prey in the system, each predator catches about 125 prey per year. When there are 200,000 prey in the system, each predator kills 350 prey per year. Predators are satiated at 500 prey per predator each year, attainable when there are at least 400,000 prey in the ecosystem.

D. Formulate the outflow from "Prey Population" due to killings by predators. In your assignment solutions document, include the modified model diagram, documented equations, and graphs of any lookup functions.

E. Simulate the model.[8] In your assignment solutions document, include graphs of model behavior. What type of behavior do you observe? Explain the behavior.

Assume for the rest of this exercise that the predator population represents insects and that the prey population represents crops (do not worry about changing the units here; just use the same model and observe the general behavior). Farmer Joe sees insects hovering over his crops and decides that they are keeping him from reaping a full harvest. Farmer Joe goes to town, buys several canisters of insecticide, and sprays it all over his crops. As a result, a year into a simulation, half of the insects are suddenly killed.

F. Simulate this policy change (*hint: use the PULSE function*). In your assignment solutions document, include graphs of model behavior. Explain the behavior. What are the short-term (during the first oscillations cycle following the policy change) and long-term (after several oscillations cycles) effects on the insect population and on the crops? Did the system react as Farmer Joe had expected?

G. Evaluate the validity of the model. In testing the model for validity and robustness, you may be interested in seeing whether the model is able to generate behavior that would not happen in real life (analogous behavior testing from the Shreckengost paper). Can you make one or both population stocks grow exponentially to infinity? Why would such a behavior happen? If such unrealistic behavior could result from the model, what does that say about the model? What is missing from the model that acts as a limiting factor in real life?

[8] Make sure to use a Time Step that is small enough to have no significant effect on the model behavior.