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

Assignment #21

Assigned on: Friday, March 26, 1999

Due by: Monday, April 5, 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-S21.doc
(where XYZ are your initials)

Reading Assignment:

- *Industrial Dynamics*,[3] by Jay W. Forrester, Chapter 2: An Industrial System

---

[1] Copyright © 1999 by the Massachusetts Institute of Technology. Permission granted to distribute for non-commercial educational purposes.

[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.

Exercises:

1. Industrial Dynamics

Please read chapter 2 of *Industrial Dynamics*. The chapter shows and explains the behavior of a simple model of a distribution system, similar to the system simulated in the "Beer Game." Please let us know if you have any questions. You do not need to submit anything for this reading assignment.

2. Modeling Exercise

In this exercise, you are going to build a simple model of inventory ordering. We will continue to expand on this model in later assignments to eventually build a full model of the "Beer Game."

In New England, USA, a certain town is home to many prestigious colleges. The rowdy students in these centers for higher learning spend their evenings nestled in front of their computers with mugs of herbal tea. All of the students go to a local shop, The Tea Pot, to buy many varieties of tea, among them the well-loved Heavenly Seasonings brand, a caffeine-free, 100% natural herbal tea. Richard, the manager at The Tea Pot, displays some boxes of tea on his shelves, but keeps most of his tea in large crates in his supply room. These crates constitute his inventory of tea. Richard has hired you as a consultant to help him study the fluctuations of his inventory of Heavenly Seasonings tea.

Step 1: Inventory

Every week, The Tea Pot sells the contents of four crates of Heavenly Seasonings tea to the college students in the area. Today, Richard counted exactly twelve crates of Heavenly Seasonings tea in his supply room. In order to always have plenty of herbal tea on hand, Richard receives four crates of Heavenly Seasonings tea from his supplier every week.

A. Start building a model by representing the stock of the inventory of Heavenly Seasonings tea that Richard has in his supply room, along with the inflow and outflow to the stock. In your assignment solutions document, include the model diagram and documented equations.

B. Draw a reference mode for the behavior of the stock over a period of fifty weeks. Simulate the model. In your assignment solutions document, include a graph of the model behavior. What happens to the inventory of herbal tea? Why?

C. Consider the scenario in which demand for Heavenly Seasonings tea is higher due to the introduction of a new flavor: Strawberry Kiwi Delight. Now college students are buying four and a half crates worth of Heavenly Seasonings tea a week. Richard is not

sure that the new craze will last, so he continues receiving only four crates a week. Draw a reference mode for the behavior of The Tea Pot's inventory over the next fifty weeks. Then simulate the model. In your assignment solutions document, include a graph of model behavior in this scenario. What happens to the stock of inventory? Why?

We need to improve the model to take into account the fact that Richard may not always be able to satisfy the demand for Heavenly Seasonings tea. He can only sell tea if he has it on hand, in his supply room. As long as the inventory is above a certain fraction of the inventory that Richard desires to keep, sales will equal demand. As students deplete his inventory of tea, however, Richard starts to ration the tea. Richard would most likely not sell all of his Heavenly Seasonings tea to the first people who came into his store; he would probably keep a few boxes aside for employees or for his favorite customers. Hence, as The Tea Pot's inventory declines further, the inventory shortage will start having an effect on sales, and sales will fall below demand. When the ratio of the remaining to desired inventory drops to zero, the effect of inventory shortage will prevent any sales from taking place.

D. From the above description, improve the model to reflect Richard's inability to sell tea that he does not have. In your assignment solutions document, include the modified model diagram and documented equations.
Hint: You will need to use a lookup function. You will also want to create a variable, sales, and set the outflow of the stock of inventory equal to those sales.

E. Draw a new reference mode for the behavior of the stock of inventory in the Strawberry Kiwi Delight scenario. Simulate the model over a period of fifty weeks. In your assignment solutions document, include a graph of model behavior. What happens now to the stock of inventory? Why?

Step 2: Unfilled Orders

If Richard receives four crates of Heavenly Seasonings tea every week, it is because he placed orders for that tea with his supplier several weeks earlier. Now, Richard orders tea to replace the tea that he sells every week. In a notebook, Richard keeps a log of all of his transactions. He keeps track of how many orders he places every week and how many orders are filled every week when the delivery truck arrives. Today, Richard has unfilled orders for 16 cases of herbal tea.

A. Create a stock of "Unfilled Orders." What are the inflows and outflows to the stock? From the above description, formulate the equations driving the flows to the stock. In your assignment solutions document, include the new model diagram and documented equations.
Hint 1: The two stocks, "Inventory" and "Unfilled Orders" represent two different concepts and hence there cannot be a flow from one to the other.
Hint 2: Do not connect any flows to each other. Instead, formulate identical equations for the two flows if you wish them to have the same values.

B. Draw reference modes for the two stocks under the original scenario (college students demand four crates worth of herbal tea a week) and then simulate the model over a period of fifty weeks. In your assignment solutions document, include graphs of the behavior of both stocks. What are the equilibrium values of the two stocks? Why?

C. Draw reference modes for the two stocks under the Strawberry Kiwi Delight scenario. Simulate the model under this scenario over a period of fifty weeks. In your assignment solutions document, include graphs of the behavior of both stocks. What happens to the two stocks? Why?

The model is still unrealistic. If Richard is selling more than 4 crates of Heavenly Seasonings tea, and ordering more than 4 crates of tea, he must eventually begin to receive the extra tea that he ordered. To improve the model, we need to improve the formulation of the rate at which Richard receives inventory. For now, let us assume that every week The Tea Pot receives one fourth of its unfilled orders, which implies an average delivery time of four weeks.

D. Improve the model by reformulating the inflow to the stock of inventory. Draw reference modes for the two stocks and then simulate the model for the Strawberry Kiwi Delight scenario over a period of 50 weeks. In your assignment solutions document, include graphs of the behavior of both stocks. What happens to the stocks? Why? What are the new equilibrium values of the two stocks?

Step 3: Desired Inventory

When demand changes, the level of inventory in the supply room of The Tea Pot changes. If Richard wants to keep his inventory constant, he will need to order more tea, above and beyond his replacement order. Consider the Strawberry Kiwi Delight scenario. Richard has a desired inventory of twelve crates of Heavenly Seasonings tea. As his inventory is depleted, he needs to add extra crates of inventory correction ordering to his weekly replacement order. It takes two weeks to place an order to correct the inventory gap.

A. Add the new elements to the model. In your assignment solutions document, include the new model diagram and documented equations.

B. Draw reference modes for the behavior of the two stocks in the Strawberry Kiwi Delight scenario. Simulate the model for this scenario over a period of fifty weeks. In your assignment solutions document, include graphs of the behavior of both stocks and any other variables that might help you explain the behavior. Explain in detail the dynamics of the behavior that you observe.

C. Consider again the original scenario in which college students buy only four crates worth of Heavenly Seasonings tea. Draw reference modes for the behavior of the two

stocks. Simulate the model over a period of fifty weeks. In your assignment solutions document, include graphs of the behavior of both stocks. What behavior do you observe? Why?

D. Consider again the original scenario. Richard decides to increase his inventory of Heavenly Seasonings tea from twelve crates to sixteen crates. Draw reference modes for the behavior of the two stocks over the next fifty weeks. Simulate the model. In your assignment solutions document, include graphs of the behavior of both stocks. What behavior do you observe? Why?

Step 4: Desired Inventory Coverage

The model is still not very realistic. In the real world, managers do not desire a certain level of inventory but a certain level of inventory coverage. Desired inventory coverage, measured in days, weeks, or months, is simply the ratio of desired inventory to demand per unit time. If actual demand is four crates of tea a week, then a desired inventory of 12 crates represents an inventory coverage equal to three weeks. If Richard wants an inventory coverage of four weeks, then his desired inventory would be 16 crates.

A. Add the new elements to the model. In your assignment solutions document, include the new model diagram and documented equations.

B. First consider the original scenario with demand of four crates a week, in which Richard's desired inventory coverage is three weeks. Draw reference modes for the behavior of the two stocks over the next fifty weeks. Simulate the model. In your assignment solutions document, include graphs of the behavior of both stocks. What behavior do you observe? Why?

C. Consider now the Strawberry Kiwi Delight scenario with demand of four and a half crates a week. Assume that Richard's desired inventory coverage is still three weeks. Draw reference modes for the behavior of the two stocks over the next fifty weeks. Simulate the model. In your assignment solutions document, include graphs of the behavior of both stocks. What behavior do you observe? Why?

D. Finally consider the scenario in which demand is back to four crates a week, but Richard now desires an inventory coverage of four weeks. Draw reference modes for the behavior of the two stocks over the next fifty weeks. Simulate the model. In your assignment solutions document, include graphs of the behavior of both stocks. What behavior do you observe? Why?