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

### Solutions to Assignment #19
### Sunday, April 11, 1999

## *Reading Assignment:*

*Please read the following paper:*
- *Generic Structures:  Exponential Smoothing, by Kevin Stange (D-4782)*

*Please refer to Road Maps 5:  A Guide to Learning System Dynamics (D-4505-4) and read the following paper from Road Maps 5:*
- *Answers to Exercises for Chapter 17: Introduction to Delays from Introduction to Computer Simulation, by Kamil Msefer and Mark Choudhari (D-4415-4)*
  *and* Introduction to Computer Simulation,[2] *by Nancy Roberts et al., Chapter 17*

*Please refer to Road Maps 7:  A Guide to Learning System Dynamics (D-4507-1) and read the following paper from Road Maps 7:*
- *System Dynamics, Systems Thinking, and Soft OR, by Jay W. Forrester (D-4405-1)*

## *Exercises:*

*1.  Generic Structures:  Exponential Smoothing*

*A.  Describe a situation in which you have used information smoothing.*

One example of information smoothing is when a friendship that has evolved over many years changes into a different kind of relationship.  Initially, one is inclined to distrust evidence that a friend has different feelings (i.e., a romantic interest), but eventually the "change in perception" described in the reading assignment accumulates to the point where a new perspective can be embraced.
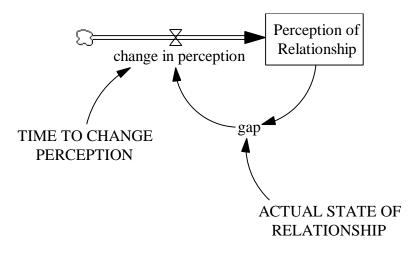
[2] Roberts, Nancy, David Andersen, Ralph Deal, Michael Garet, and William Shaffer, 1983.  *Introduction to Computer Simulation:  A System Dynamics Approach.*  Waltham, MA: Pegasus Communications.  562 pp.

*B. Using the generic structure presented in this paper, build a simple model based on the situation you described in part A. As the "ACTUAL STATE OF SMOOTHED VARIABLE," use any combination of step or pulse functions that you think are appropriate. In your assignment solutions document, include the model diagram and documented equations.*
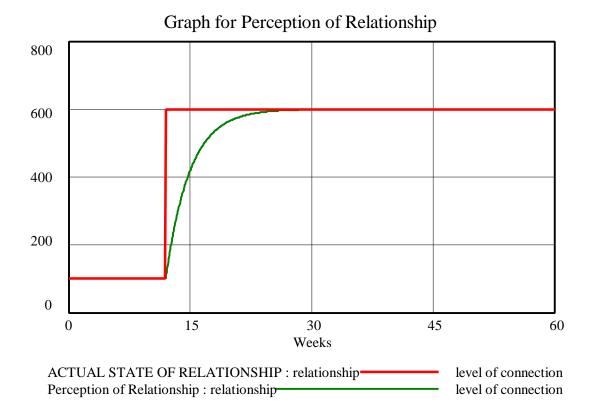
Model diagram:



Model equations:

ACTUAL STATE OF RELATIONSHIP = 100 + STEP(500,12)
      Units: level of connection
      The actual level of connectedness in the relationship.

change in perception = gap / TIME TO CHANGE PERCEPTION
      Units: level of connection/Week
      The rate at which the perception of a relationship changes.

gap = ACTUAL STATE OF RELATIONSHIP – Perception of Relationship
      Units: level of connection
      The difference between the actual state of the relationship and the perceived state of the relationship.

Perception of Relationship = INTEG (change in perception, ACTUAL STATE OF RELATIONSHIP)
      Units: level of connection
      The perceived state of a relationship.

TIME TO CHANGE PERCEPTION = 3
      Units: Week
      The time it takes to change one's perception of a relationship.

*C. Simulate the model and explain the behavior that you observe. In your assignment solutions document, include a graph of model behavior. Explain how the simulation output relates to the actual situation you described in part A.*

Model behavior:

## Graph for Perception of Relationship



| ACTUAL STATE OF RELATIONSHIP : relationship | ———————— | level of connection |
| Perception of Relationship : relationship | ———————— | level of connection |

As the graph illustrates, the "Perception of Relationship" does not immediately adjust to the new level of "600" in week twelve when the actual change occurs. Instead, it takes an additional fifteen weeks or so to recognize that the friendship has changed. In my personal example, a longtime friendship evolved into a romantic relationship but it was difficult in hindsight to figure out at what point I recognized how the other person's feelings had changed.

## 2. Answers to Exercises for Chapter 17: Introduction to Delays from *Introduction to Computer Simulation*

*Read the above paper and the sections from Chapter 17 of* Introduction to Computer Simulation *that the paper asks you to read, and work through all of the exercises. Starting from Exercise 2, you will need to use the PULSE function in Vensim PLE, which works differently from the PULSE function in DYNAMO.*

*The general form of the PULSE function is:*

*PULSE(start,duration)*

*Here are some hints for formulating the "dump rate" equation in the Nobug model:*

- *define a constant "AMOUNT DUMPED" and set it equal to 420 gallons*
- *include a shadow variable for the time step*
- *define the equation for "dump rate" as:*

*dump rate = AMOUNT DUMPED \* PULSE(1,TIME STEP) / TIME STEP[3]*

*To "simulate repeated batches," as in Exercise 3, add another PULSE formulation to the above "dump rate" equation, only with a different start time.*

*When you have finished working through all the exercises that are answered in the paper, please answer the following question:*

*What policy would you recommend to stabilize the oscillations produced by the apartment construction model in Exercise 7? Why? In your assignment solutions document, include the modified model diagram, documented equations, and behavior graphs of "Apartments in Construction" and "Apartments Completed," comparing the behavior of the two models. Explain how the policy that you proposed created the observed behavior.*
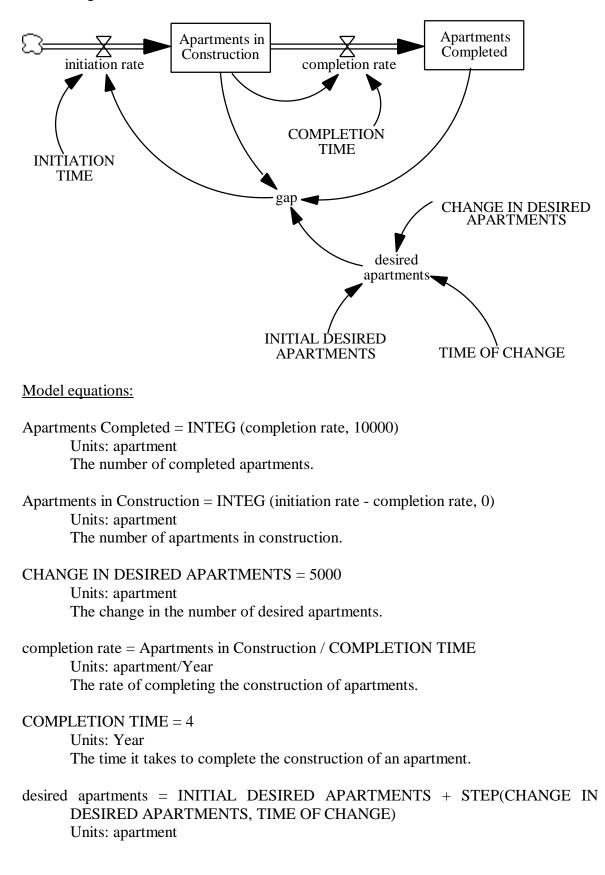
The original apartment construction model assumes that builders construct city apartments in response to the gap between the total number of apartments desired and the total number of apartments available. This formulation represents a system in which independent construction companies use the current demand for housing to decide whether to begin construction, without taking into account the buildings that are already in the process of being constructed but not yet ready to house people. Because construction companies do not take into account the work in progress, the total number of completed apartments eventually overshoots the number of desired apartments. Then, the number of apartments undershoots, also because of the delay involved in constructing apartments. The total number of completed apartments oscillates around the desired number of apartments with decreasing amplitude until finally the desired number is reached.

To stabilize the oscillations of the system, the construction companies would need to take into account all of the apartments in construction when deciding how many apartments to build. That is, builders construct apartments in response to the gap between the number of "desired apartments" and the sum of "Apartments in Construction" and "Apartments Completed."

---

[3] See the general solutions to assignment 17 for an explanation of this equation.

Model diagram:



Model equations:

Apartments Completed = INTEG (completion rate, 10000)
    Units: apartment
    The number of completed apartments.

Apartments in Construction = INTEG (initiation rate - completion rate, 0)
    Units: apartment
    The number of apartments in construction.

CHANGE IN DESIRED APARTMENTS = 5000
    Units: apartment
    The change in the number of desired apartments.

completion rate = Apartments in Construction / COMPLETION TIME
    Units: apartment/Year
    The rate of completing the construction of apartments.

COMPLETION TIME = 4
    Units: Year
    The time it takes to complete the construction of an apartment.

desired apartments = INITIAL DESIRED APARTMENTS + STEP(CHANGE IN DESIRED APARTMENTS, TIME OF CHANGE)
    Units: apartment

The number of apartments desired in the city after the step change.

gap = desired apartments - (Apartments Completed + Apartments in Construction)
	Units: apartment
	The gap between the number of apartments desired in the city and the sum of the
	completed apartments and apartments in construction.

INITIAL DESIRED APARTMENTS = 10000
	Units: apartment
	The initial number of apartments desired in the city.

initiation rate = gap / INITIATION TIME
	Units: apartment/Year
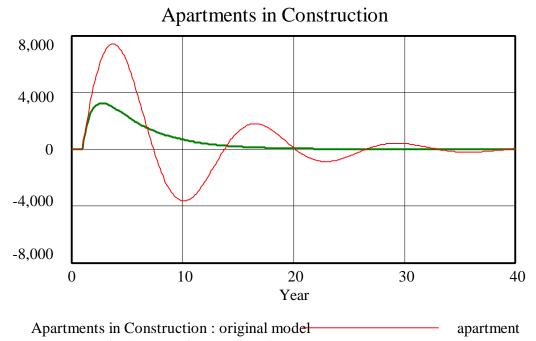	The rate at which construction of apartments is initiated.

INITIATION TIME = 1
	Units: Year
	The time required to initiate the construction of an apartment.
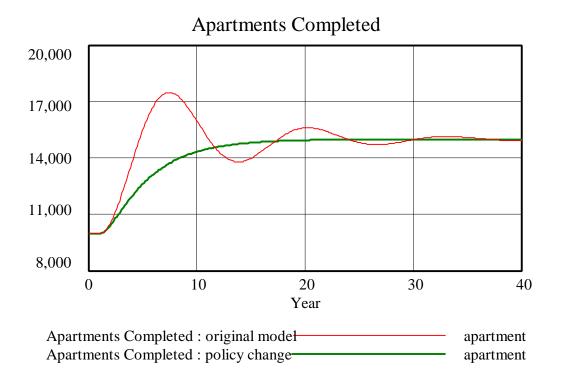
TIME OF CHANGE = 1
	Units: Year
	Time at which the desired number of apartments changes.

Model behavior:

## Apartments in Construction



Apartments in Construction : original model ——————— apartment
Apartments in Construction : policy change ——————— apartment

A negative apartment construction rate (corresponding to a negative number of apartments in construction) in the original model appears to be physical nonsense. It corresponds, however, to the destruction of apartment buildings or cancellation of contracts, which this model does not explicitly take into account. A more complete representation of the real-world system would account for these factors.

## Apartments Completed



Apartments Completed : original model ——————— apartment
Apartments Completed : policy change ——————— apartment

As seen in the above graphs, the behavior of both stocks, "Apartments in Construction" and "Apartments Completed," changes from damped oscillations to asymptotic behavior. By taking into account the "Apartments in Construction" when deciding on the "initiation rate," the system behaves as a simple goal-gap negative feedback loop, generating asymptotic behavior.

### *3.  System Dynamics, Systems Thinking, and Soft OR*

*Please read this paper carefully and answer the following questions:*

*A. On page 4, Professor Forrester answers the question of model validity in the following way:*

> *"One can achieve only a degree of confidence in a model that is a compromise between adequacy and the time and cost of further improvement. The proper basis of comparison lies between the simulation model and the model that would otherwise be used. That competitive*

*model is almost always the mental model in the heads of the people operating in the real system."*

*To what extent does this proposition agree or disagree with the propositions presented by Raymond Shreckengost in* Dynamic Simulation Models: How Valid Are They *(D-4463)?*

Shreckengost states in his paper that in "a strict sense... there are no fully valid models." Validity as described in this paper should be considered as a means to increase confidence in the model. This is in accordance with Prof. Forrester's statement on model validity. Models are thought to be valid when they can be used with confidence. Of course, comparison should not be done between a model and an "ideal" model but between the model and a competitive model that would be used in absence of the system dynamics model.
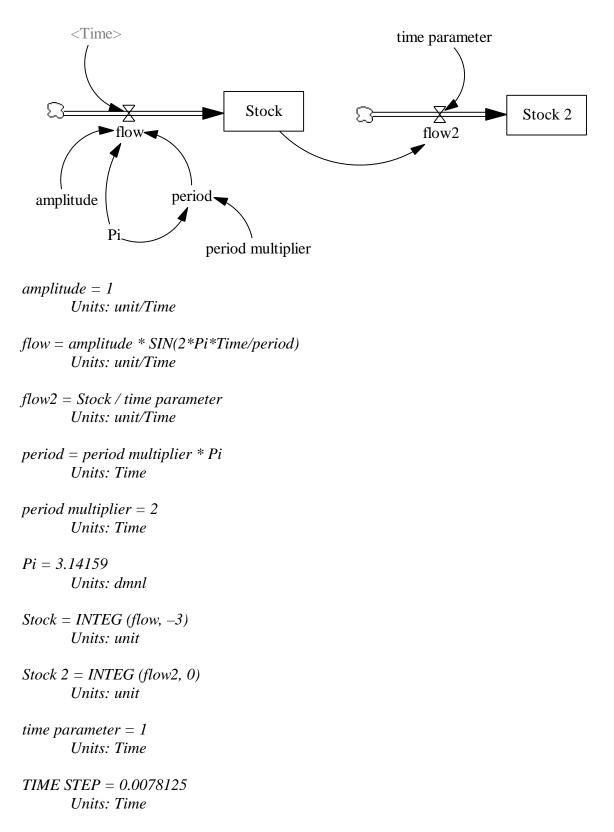
*B. On page 11, Professor Forrester lists three possible consequences of system thinking. From your experience or the experience of your colleagues, provide an example of systems thinking being used constructively and an example of systems thinking being used detrimentally.*

An example of systems thinking being used constructively is the growing awareness of the impact each country's actions have on the rest of the world, and the perception that we live in an interconnected world, at all levels (ecology, economy, politics, social development, etc.)
I witnessed an example of systems thinking being used detrimentally the first time I tried to explain to a group of colleagues the principles of systems thinking. When I explained that *everything is connected to everything else,* their first reaction was *so we are just a cog in a wheel, absolutely powerless.*
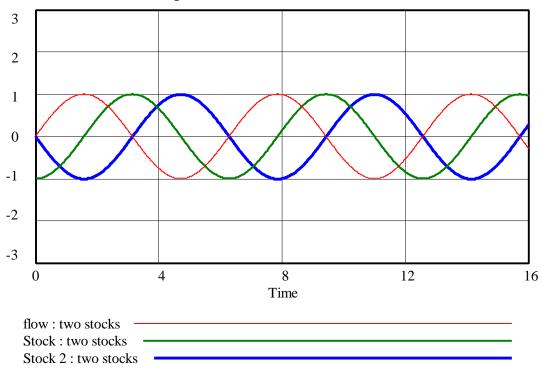
## 4. Understanding Oscillatory Systems

*This is the third in a series of exercises designed to help your understanding of oscillatory systems. Build the following model in Vensim PLE and then complete the exercises. Make sure that the time step is smaller than 0.0625 (or small enough that the value of DT no longer has a substantial effect on the result of the simulation). The time horizon over which you simulate the model should be at least 16 units of time.*

*amplitude = 1*
     *Units: unit/Time*

*flow = amplitude * SIN(2*Pi*Time/period)*
     *Units: unit/Time*

*flow2 = Stock / time parameter*
     *Units: unit/Time*

*period = period multiplier * Pi*
     *Units: Time*

*period multiplier = 2*
     *Units: Time*

*Pi = 3.14159*
     *Units: dmnl*

*Stock = INTEG (flow, –3)*
     *Units: unit*

*Stock 2 = INTEG (flow2, 0)*
     *Units: unit*

*time parameter = 1*
     *Units: Time*

*TIME STEP = 0.0078125*
     *Units: Time*

*Notice that "flow2" is not an outflow from "Stock"; only the information about the value of "Stock" is used as the input to "flow2."*

Please notice that we have modified the model slightly from the one presented in the assignment. As given in the assignment, the equations were not complete with units, and a "time parameter" was missing in the equation for "flow2." The modified model includes units of measure and is dimensionally consistent. The analysis of oscillatory behavior in the following exercises is not affected by the changes in the model.

*A. Simulate the model. In your assignment solutions document, include graphs of the behavior of the "flow," "Stock," and "Stock2." Describe the relationships between each pair of the three graphs.*
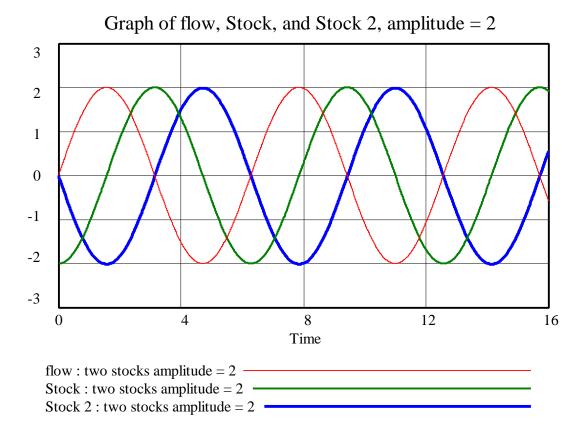
## Graph of Flow, Stock, and Stock 2



| | |
|---|---|
| flow : two stocks | |
| Stock : two stocks | |
| Stock 2 : two stocks | |

All three variables, "flow," "Stock," and "Stock 2," show oscillating behavior with the same period and amplitude. The "Stock" lags one quarter of a period behind the "flow," and "Stock 2" lags one quarter of a period behind the "Stock." Hence, "Stock 2" lags one half of a period behind the "flow," which means that at any time, the value of "Stock 2" is the negative of the value of the "flow."
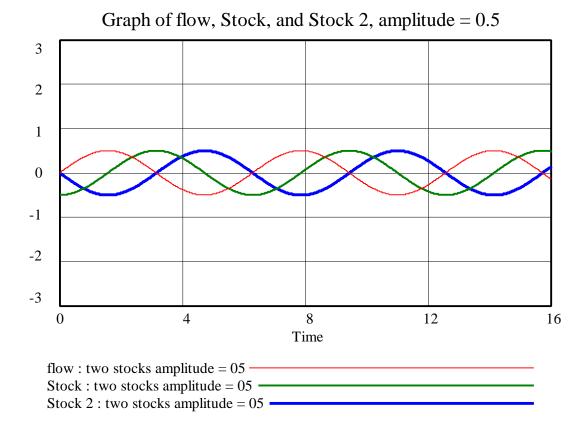
*B. Create a new dataset and simulate the model with "amplitude" equal to 2. In your assignment solutions document, include graphs of the behavior of the "flow," "Stock," and "Stock2" in this simulation. You may wish to change the initial value of the "Stock." Describe the relationship between each pair of the three graphs and compare the simulation to that from part A.*

## Graph of flow, Stock, and Stock 2, amplitude = 2



flow : two stocks amplitude = 2
Stock : two stocks amplitude = 2
Stock 2 : two stocks amplitude = 2

All three variables again show oscillating behavior with the same period and amplitude. The period of oscillation is the same as in part A, but the amplitude is twice the amplitude of the simulation in part A. The relationship between the graphs has not changed. "Stock" lags one quarter of a period behind the "flow," and "Stock 2" lags one quarter of a period behind the "Stock." "Stock 2" lags one half of a period behind "flow'"; hence at any time, the value of "Stock 2" is the negative of the value of "flow." Notice that we changed the initial value of "Stock" to –2 so that "Stock" oscillates around 0.

*C. Repeat part B with "amplitude" equal to 0.5.*

## Graph of flow, Stock, and Stock 2, amplitude = 0.5



flow : two stocks amplitude = 05
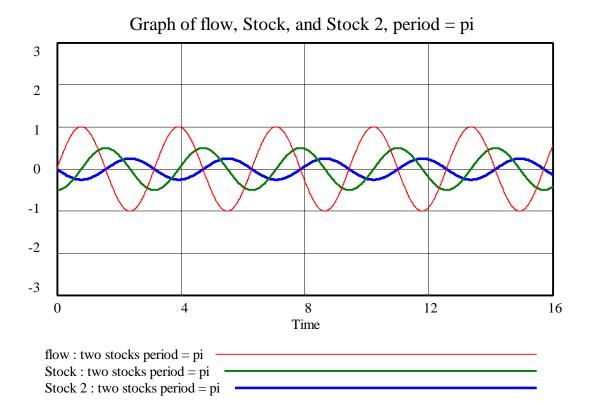Stock : two stocks amplitude = 05
Stock 2 : two stocks amplitude = 05

All three variables again show oscillating behavior with the same period and amplitude. The period of oscillation is the same as in part A, but the amplitude is half the amplitude of the simulation in part A. The relationship between the graphs has not changed. "Stock" lags one quarter of a period behind the "flow," and "Stock 2" lags one quarter of a period behind the "Stock." "Stock 2" lags one half of a period behind "flow'"; hence at any time, the value of "Stock 2" is the negative of the value of "flow." Notice that we changed the initial value of "Stock" to –0.5 so that "Stock" oscillates around 0.

*D. What conclusions can you make about the relationship between an oscillating "flow" and "Stock2" as the amplitude of the "flow" changes?*

As the amplitude of the "flow" changes, the amplitude of "Stock 2" changes to the same value. Also, no matter what the amplitude is, "Stock 2" always lags one half of a period behind the "flow," and hence the value of "Stock 2" at any time is the negative of the value of "flow."

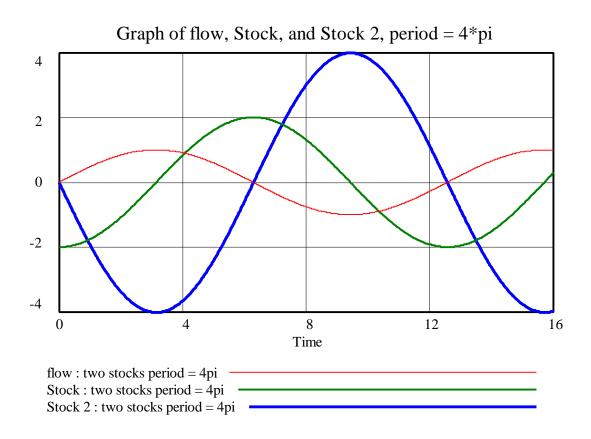*E. Repeat part B with "period" equal to Pi.*

## Graph of flow, Stock, and Stock 2, period = pi



flow : two stocks period = pi
Stock : two stocks period = pi
Stock 2 : two stocks period = pi

All three variables show oscillating behavior with the same period equal to Pi. The amplitude of the "flow" is still equal to 1 but the amplitude of "Stock" is reduced to 0.5, and the amplitude of "Stock 2" is reduced to 0.25. Because the period of the "flow" has been shortened, the "flow" is positive for a shorter amount of time and hence adds less to the value of "Stock." Therefore, "Stock" does not rise as high as "flow." Similarly, because the period of the "flow 2" has been shortened ("flow 2" is just equal to "Stock"), "flow 2" is positive for a shorter amount of time and hence adds less to the value of "Stock 2." Therefore, "Stock 2" does not rise as high as "Stock." Compared to part A, the period of "flow," "Stock," and "Stock 2" has halved, the amplitude of the "Stock" has halved, and the amplitude of "Stock 2" has quartered. The "Stock" still lags one quarter of a period behind "flow," and "Stock 2" lags one quarter of a period behind "Stock." "Stock 2" lags one half of a period behind "flow," which means that because of the decrease in amplitude, the value of "Stock 2" at any time is equal to negative one fourth of the value of "flow." Notice that we changed the initial value of the "Stock" to –0.5 to make the "Stock" oscillate around 0.

*F. Repeat part B with "period" equal to 4\*Pi.*

## Graph of flow, Stock, and Stock 2, period = 4*pi



flow : two stocks period = 4pi
Stock : two stocks period = 4pi
Stock 2 : two stocks period = 4pi

All three variables show oscillating behavior with the same period equal to 4*Pi. The amplitude of the "flow" is still equal to 1 but the amplitude of the "Stock" is increased to 2 and the amplitude of "Stock 2" is increased to 4. Because the period of the "flow" has become longer, the "flow" is positive for a longer amount of time and hence adds more to the value of "Stock." Therefore, the "Stock" rises higher than "flow." Similarly, because the period of "flow 2" has become longer, "flow 2" is positive for a longer amount of time and hence adds more to the value of "Stock 2." Therefore, "Stock 2" rises higher than "Stock." Compared to part A, the period of "flow," "Stock," and "Stock 2" has doubled, the amplitude of "Stock" has doubled, and the amplitude of "Stock 2" has quadrupled. The "Stock" still lags one quarter of a period behind "flow" and "Stock 2" lags one quarter of a period behind "Stock." "Stock 2" lags one half of a period behind "flow," which means that because of the increase in amplitude, the value of "Stock 2" at any time is equal to negative four times the value of "flow." Notice that we changed the initial value of the "Stock" to –2 to make the "Stock" oscillate around 0.

*G. What conclusions can you make about the relationship between an oscillating "flow" and "Stock2" as the period of the "flow" changes?*

As the period of the "flow" changes (is multiplied by a factor of A), the period of "Stock 2" changes to the same value. A change in the period of the "flow" has the additional effect of changing the amplitude of "Stock 2" by $A^2$, but it does not affect the amplitude of the "flow." Also, no matter what the period is, "Stock 2" always lags one half of a

period behind the "flow," and the value of "Stock 2" at any time is equal to negative $A^2$ of the value of the flow.