

Guided Study Program in System Dynamics

System Dynamics in Education Project

System Dynamics Group

MIT Sloan School of Management¹

Solutions to Assignment #25

Tuesday, June 8, 1999

Reading Assignment:

Please refer to Road Maps 8: A Guide to Learning System Dynamics (D-4508-1) and read the following paper from Road Maps 8:

- *Oscillating Systems II: Sustained Oscillation by Kevin A. Agatstein (D-4602)*

Exercises:

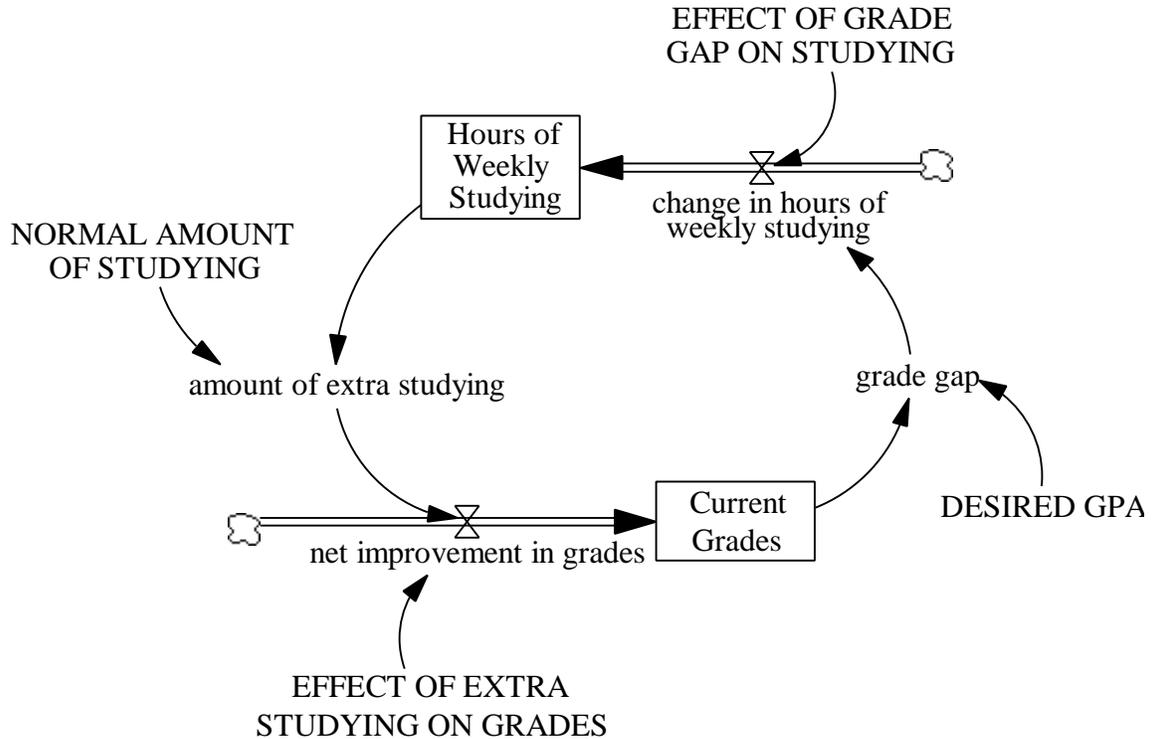
1. Oscillating Systems II: Sustained Oscillation

A. Please read the paper and build the academic performance model and the cleanliness of a dorm room model in Vensim. Simulate the models and explain the behavior that you observe. In your assignment solutions document, please include the model diagram, documented equations, and graphs of model behavior.

Academic performance model

Model diagram:

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Model equations:

amount of extra studying = Hours of Weekly Studying – NORMAL AMOUNT OF STUDYING

Units: hours/Week

The number of hours in a week Nan spends studying above her normal amount.

change in hours of weekly studying = EFFECT OF GRADE GAP ON STUDYING * grade gap

Units: (hours/Week)/Week

The number of hours by which Nan increases or decreases her amount of studying, based on her current academic performance.

Current Grades = INTEG (net improvement in grades, 2.5)

Units: GPA units

Nan's academic performance at any time, measured by her grade point average.

DESIRED GPA = 3.5

Units: GPA units

The GPA Nan wants.

EFFECT OF EXTRA STUDYING ON GRADES = 0.0285

Units: GPA units/hours

The amount of GPA improvement achieved when Nan studies one extra hour.

EFFECT OF GRADE GAP ON STUDYING = 2.45

Units: ((hours/Week)/Week)/GPA units

The amount by which Nan increases her weekly studying when she is below her desired GPA by 1.0 points.

grade gap = DESIRED GPA – Current Grades

Units: GPA units

The difference between Nan’s desired and actual GPA.

Hours of Weekly Studying = INTEG (change in hours of weekly studying, 21)

Units: hours/Week

The number of hours Nan spends per week studying. The initial value of 21 hours corresponds to 3 hours per night.

net improvement in grades = amount of extra studying * EFFECT OF EXTRA STUDYING ON GRADES

Units: GPA units/Week

The change in Nan’s grades as a result of studying more or less than her normal amount.

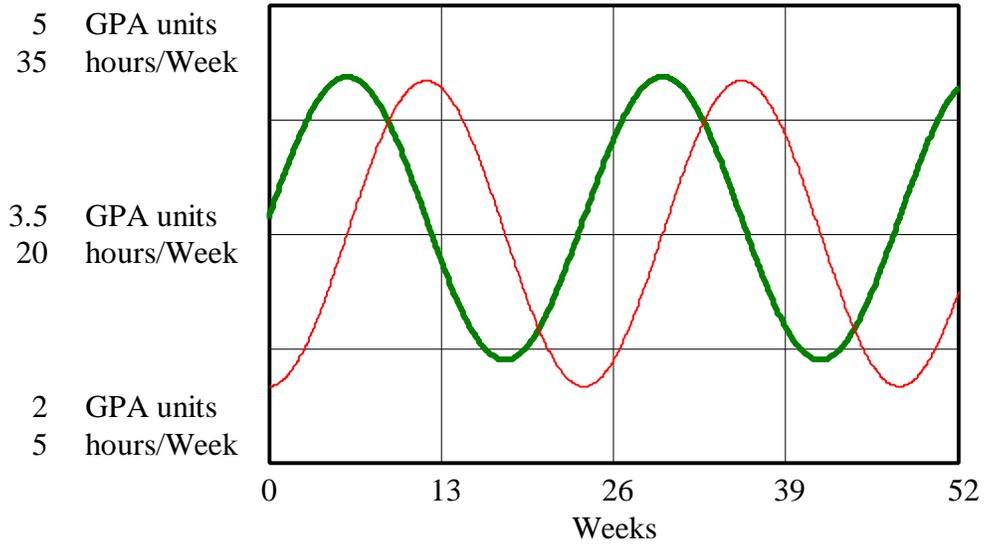
NORMAL AMOUNT OF STUDYING = 21

Units: hours/Week

The number of hours Nan would need to study consistently every week so that her “Current Grades” would approach her “DESIRED GPA.”

Model behavior:

Stocks -- base run

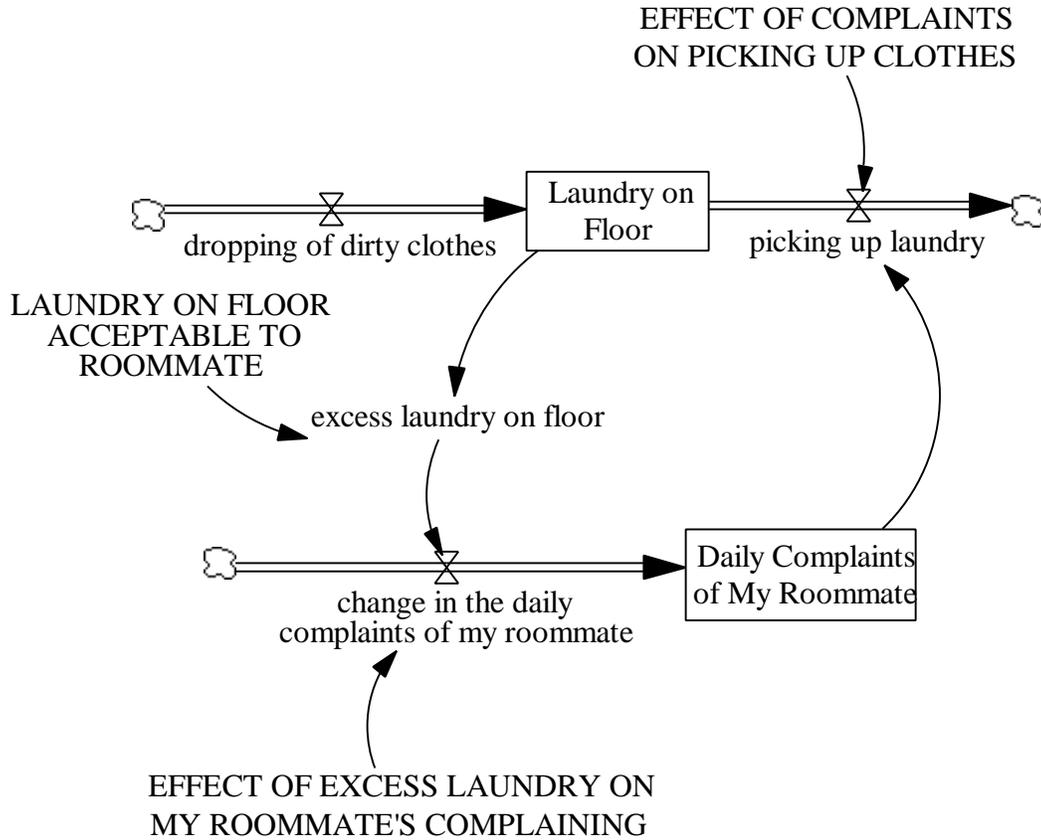


Current Grades : gpa — GPA units
 Hours of Weekly Studying : gpa — hours/Week

	Current Grades	Hours of Weekly Studying
Amplitude	0.5 GPA units	4.6 hours/week
Period	24 weeks	24 weeks
Mean	3.5 GPA units	21 hours/week

Cleanliness of a dorm room model

Model diagram:



Model equations:

change in the daily complaints of my roommate = EFFECT OF EXCESS LAUNDRY ON MY ROOMMATE'S COMPLAINING * excess laundry on floor

Units: complaints/(day * day)

This flow represents how my roommate's amount of complaining changes over time. It is a function of the amount of excess laundry on the floor.

Daily Complaints of My Roommate = INTEG (change in the daily complaints of my roommate, 3)

Units: complaints/day

The number of complaints my roommate registers with me each day about the cleanliness of the room.

dropping of dirty clothes = 5

Units: clothes/day

The number of dirty clothes I drop on my floor everyday. The model assumes that my roommate's complaining does not stop me from dropping all my clothes on the floor, it only changes how many I pick up.

EFFECT OF COMPLAINTS ON PICKING UP CLOTHES = 1

Units: clothes/complaints

This variable is the number of extra clothes I will pick up each day if my roommate increases his complaining by one complaint per day.

EFFECT OF EXCESS LAUNDRY ON MY ROOMMATE'S COMPLAINING = 1

Units: ((complaints/day)/day)/clothes

This constant reflects how my roommate increases his complaining based on the addition of one more article of clothing to the floor.

excess laundry on floor = Laundry on Floor – LAUNDRY ON FLOOR ACCEPTABLE TO ROOMMATE

Units: clothes

This variable is the difference between the number of articles of clothing on my floor and the number of articles acceptable to my roommate.

Laundry on Floor = INTEG (dropping of dirty clothes – picking up laundry, 3)

Units: clothes

The number of articles of clothing on my dorm room floor.

LAUNDRY ON FLOOR ACCEPTABLE TO ROOMMATE = 3

Units: clothes

This is the number of pieces of clothing on the floor that my roommate finds acceptable (because they don't spill over to his side of the room).

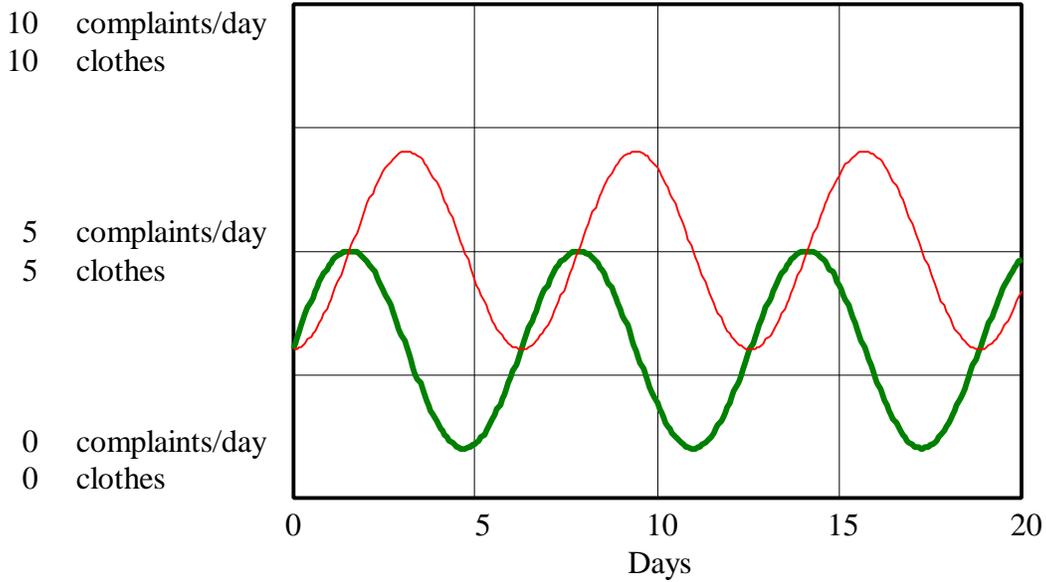
picking up laundry = EFFECT OF COMPLAINTS ON PICKING UP CLOTHES * Daily Complaints of My Roommate

Units: clothes/day

The number of clothes I pick up each day. It is a function of how many complaints my roommate registers with me.

Model behavior:

Stocks -- base run



Daily Complaints of My Roommate : laundry — complaints/day
 Laundry on Floor : laundry — clothes

	Daily Complaints of My Roommate	Laundry on Floor
Amplitude	2 complaints/day	2 clothes
Period	6.25 days	6.25 days
Mean	5 complaints/day	3 clothes

Both models generate sustained oscillations. The initial values in both models are such that there is an imbalance between the equilibrium values and the initial values, which causes the systems to correct the imbalance, and the oscillation is initiated.

B. What is the effect of the following changes on the amplitude, the period, and the mean value of the sustained oscillations? Make each of the following changes individually, and explain the effect of each change on the behavior of the model. Relate your explanations to previous exercises on oscillation.

In the academic performance model:

- Increase the “NORMAL AMOUNT OF STUDYING” from 21 hours to 25 hours.
- Decrease the “NORMAL AMOUNT OF STUDYING” from 21 hours to 15 hours.
- Decrease Nan’s “DESIRED GPA” from 3.5 GPA units to 3.0 GPA units.
- Decrease the initial value of “Current Grades” from 3.0 GPA units to 2.5 GPA units.

In the cleanliness of a dorm room model:

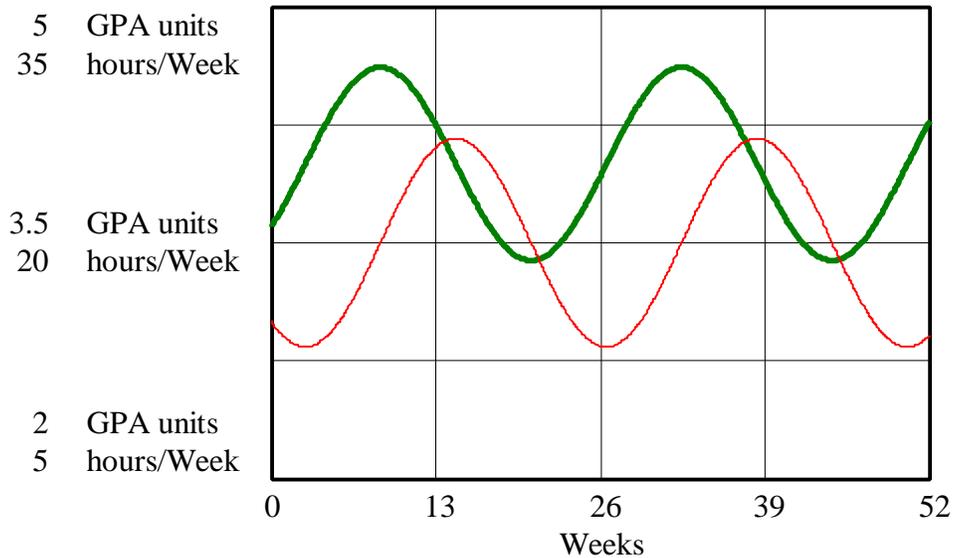
- Decrease the “dropping of dirty clothes” from 5 articles/day to 3 articles/day.

- Increase the “LAUNDRY ON FLOOR ACCEPTABLE TO ROOMMATE” from 3 to 5 articles of clothing.

Academic performance model

- Increase the “NORMAL AMOUNT OF STUDYING” from 21 hours per week to 25 hours per week.

NORMAL AMOUNT OF STUDYING 25 hours



Current Grades : NAS up — GPA units
 Hours of Weekly Studying : NAS up — hours/Week

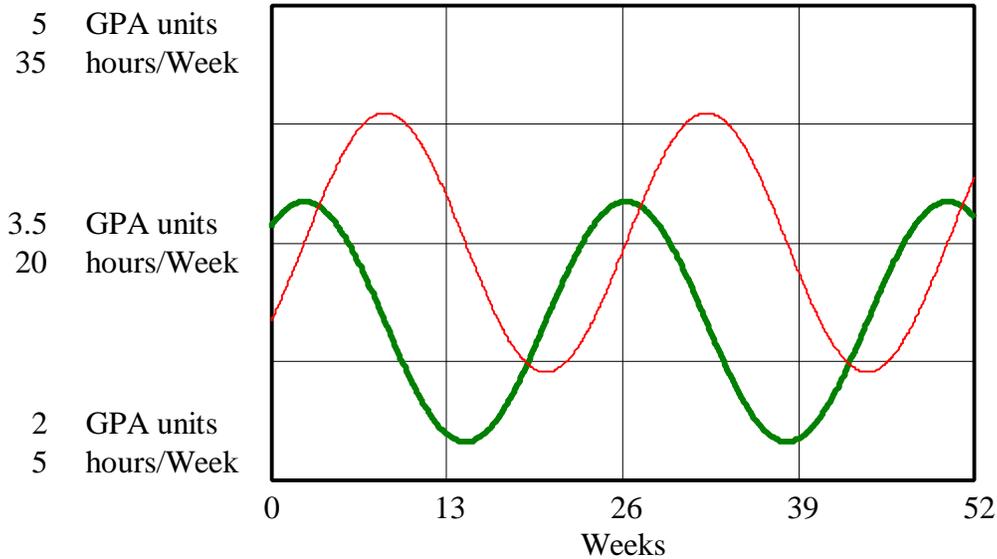
	Current Grades	Hours of Weekly Studying
Amplitude	increase to 0.66 GPA units	increase to 6.12 hours/week
Period	24 weeks	24 weeks
Mean	3.5 GPA units	increase to 25 hours/week

Because “Hours of Weekly Studying” is initially below its normal value, “Current Grades” decreases even further below 3.0 GPA points. As soon as “Hours of Weekly Studying” reaches 25 hours, “Current Grades” starts increasing, but because it is still below its desired value of 3.5 GPA units, “Hours of Weekly Studying” continues to increase well above the normal value of 25 hours per week, and above the peak value from the base run. When “Current Grades” reaches 3.5 GPA units, “Hours of Weekly Studying” stop rising and start declining, while “Current Grades” keeps rising because of the large accumulation of studying. When “Hours of Weekly Studying” fall down to 25 hours per week, “Current Grades” stops rising and start declining. Notice that with the parameter values used in this simulation, the peak value of “Current Grades” is higher than 4.0 GPA units, which is the maximum value of GPA at most schools. Because of

the high “Current Grades,” “Hours of Weekly Studying” will continue to fall, and the oscillation will repeat itself throughout the simulation.

- Decrease the “NORMAL AMOUNT OF STUDYING” from 21 hours per week to 15 hours per week.

NORMAL AMOUNT OF STUDYING 15 hours

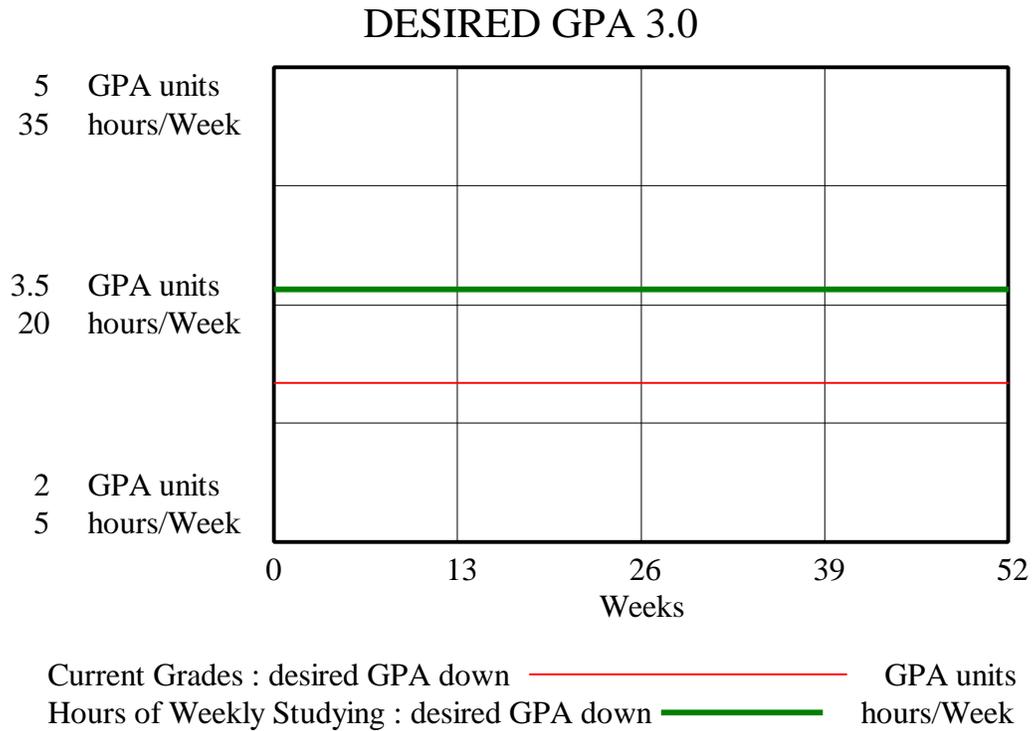


Current Grades : NAS down ——— GPA units
 Hours of Weekly Studying : NAS down ——— hours/Week

	Current Grades	Hours of Weekly Studying
Amplitude	increase to 0.82 GPA units	increase to 7.58 hours/week
Period	24 weeks	24 weeks
Mean	3.5 GPA units	decrease to 15 hours/week

Because “Hours of Weekly Studying” is initially above its normal value, “Current Grades” starts increasing, and when it reaches 3.5 GPA units, “Hours of Weekly Studying” starts falling. “Current Grades” continues to increase, however, because of the large accumulated amount of studying. When “Hours of Weekly Studying” falls to its normal value of 15 hours per week, “Current Grades” peaks (again above 4.0 GPA units) and starts declining. Because “Current Grades” is still higher than its desired value of 3.5 GPA units, “Hours of Weekly Studying” continues to decline, and starts rising again only when “Current Grades” falls down to 3.5 GPA units. Because “Hours of Weekly Studying” is now much lower than the normal value, “Current Grades” keeps falling until “Hours of Weekly Studying” reaches 15 hours per week again. The oscillation then repeats itself throughout the simulation.

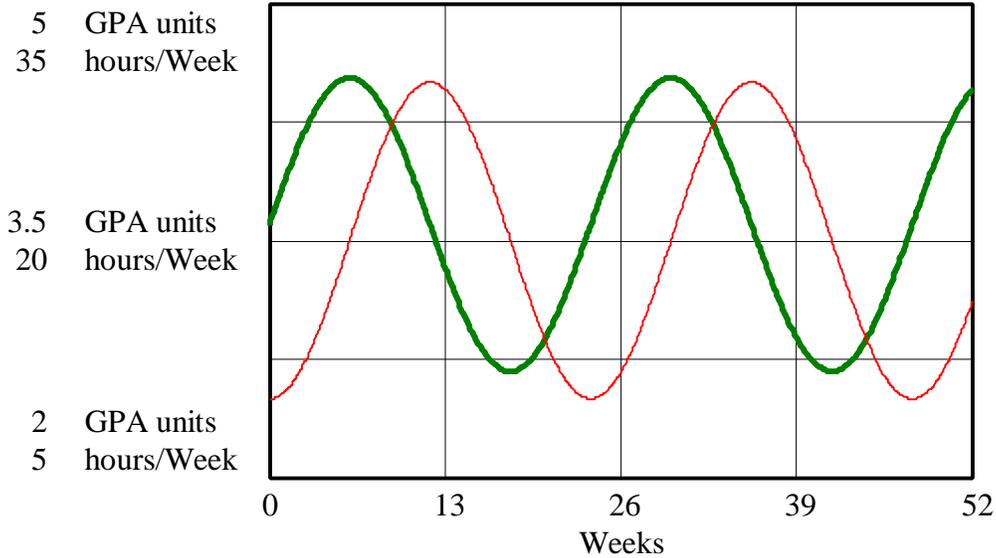
- Decrease Nan’s “DESIRED GPA” from 3.5 GPA units to 3.0 GPA units



The system starts and remains at equilibrium throughout the simulation because the initial value of each stock equals its normal or desired value.

- Decrease the initial value of “Current Grades” from 3.0 GPA units to 2.5 GPA units.

Initial Current Grades 2.5



Current Grades : initial Grades down — GPA units
 Hours of Weekly Studying : initial Grades down — hours/Week

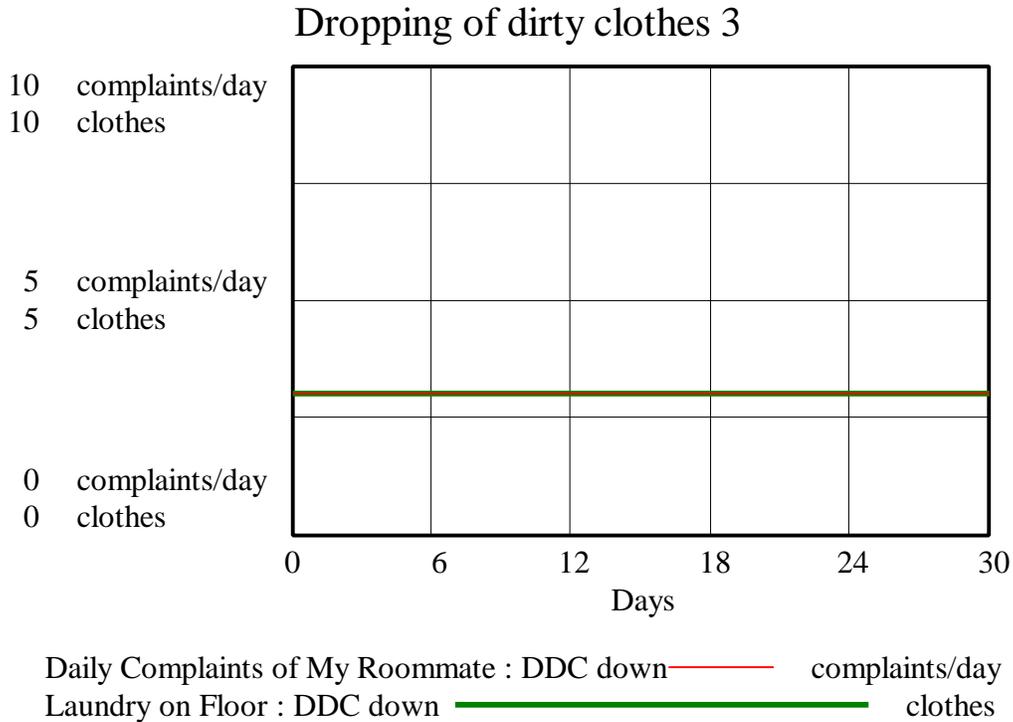
	Current Grades	Hours of Weekly Studying
Amplitude	increase to 1 GPA unit	increase to 9.27 hours/week
Period	24 weeks	24 weeks
Mean	3.5 GPA units	21 hours/week

Initially, “Current Grades” is substantially below the desired grades, so “Hours of Weekly Studying” starts rising fast. As the amount of studying increases, so do Nan’s grades. Because Nan is trying to close a much larger “grade gap” than in the base run, her “Hours of Weekly Studying” must rise to a higher peak value. When her “Current Grades” reaches 3.5 GPA units, she starts studying less and less, but because she is still studying more than her normal amount, her grades keep increasing. Nan’s “Current Grades” also peak at a higher value than in the base run because Nan has put in more time studying. When “Hours of Weekly Studying” fall back to the normal amount of 21 hours per week, “Current Grades” starts declining. Because Nan’s “Current Grades” is still higher than her desired grades, she keeps decreasing the number of hours that she studies, until “Current Grades” falls to 3.5 GPA units. Nan then starts to increase her “Hours of Weekly Studying,” but her “Current Grades” keeps falling down to 2.5 GPA units. The cycle then repeats itself throughout the simulation.

As these scenarios demonstrate, when one initializes a model to varying degrees from its “normal” or “desired” position, only the amplitude of oscillations is affected. Because none of the scenarios changed any of the time constants, the period always remained the same.

Cleanliness of a dorm room model

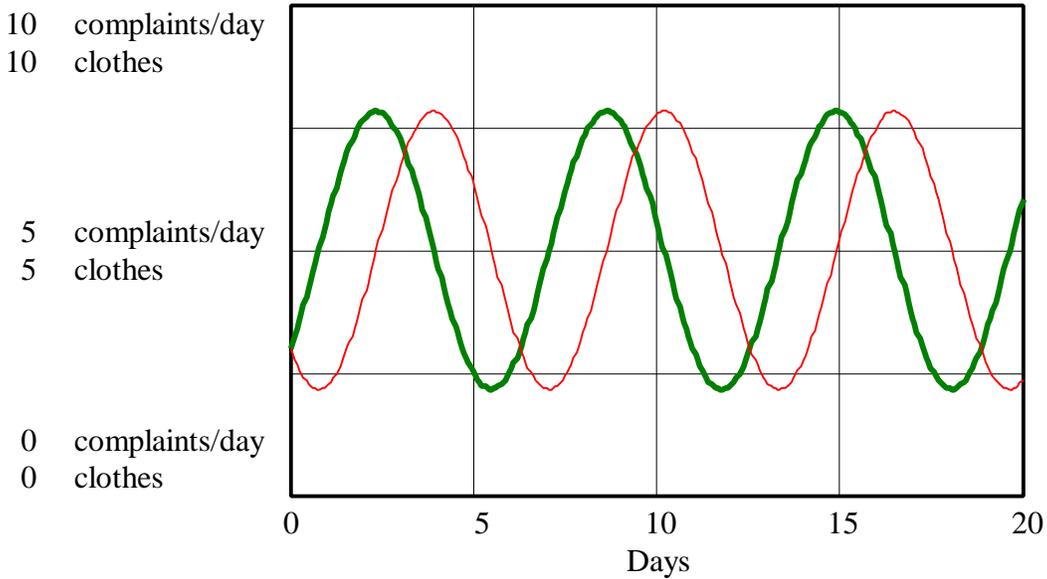
- Decrease the “dropping of dirty clothes” from 5 clothes/day to 3 clothes/day.



The system starts and remains at equilibrium throughout the simulation. If I only drop 3 articles of clothing every day, and my roommate initially complains 3 times a day, the number of articles of clothing on the floor stays at 3 because my roommate’s complaints drive me to pick up 3 clothes per day. Because the “Laundry on Floor” is 3 clothes, my roommate is not too unhappy and does not increase his amount of complaining.

- Increase the “LAUNDRY ON FLOOR ACCEPTABLE TO ROOMMATE” from 3 articles of clothing to 5 articles of clothing.

LAUNDRY ON FLOOR ACCEPTABLE TO ROOMMATE 5



Daily Complaints of My Roommate : LFAR up ——— complaints/day
 Laundry on Floor : LFAR up ————— clothes

	Daily Complaints of My Roommate	Laundry on Floor
Amplitude	increase to 2.83 complaints/day	increase to 2.83 clothes
Period	6.25 days	6.25 days
Mean	5 complaints/day	increase to 5 clothes

Initially, because “Laundry on Floor” is below the amount that my roommate considers acceptable, he is complaining little, and the number of “Daily Complaints of My Roommate” is decreasing. As soon as the number of articles of clothing on the floor reaches 5, however, the number of complaints by my roommate starts increasing, but is still not high enough for me to pick up enough laundry from the floor, so “Laundry on Floor” increases to a peak value that is higher than in the base run. When he complains 5 times a day, I start picking up more laundry than I drop, so “Laundry on Floor” starts falling. Now my roommate is so angry that he keeps complaining more and more every day, and he starts decreasing his daily number of complaints when “Laundry on Floor” falls back to 5 clothes. He is still complaining quite often, however, so I keep picking up more and more laundry, until my roommate stops complaining so much and complains only 5 times a day. Seeing that he is not so angry anymore, I become lazy again and don’t pick up as much laundry as I drop, so “Laundry on Floor” starts growing again. The oscillation repeats itself throughout the simulation.

C. The time lag between two oscillations is the time between a peak of one oscillation and the corresponding peak of the other. The phase shift between two oscillations is the time lag divided by the period.

In the academic performance model:

- *What is the phase shift between the “change in hours of weekly studying” and the “Hours of Weekly Studying” in the academic performance model?*
- *What is the phase shift between the “Hours of Weekly Studying” and the “net improvement in grades”?*
- *What is the phase shift between the “net improvement in grades” and “Current Grades”?*
- *What is the phase shift between “Current Grades” and “change in hours of weekly studying”?*

In the cleanliness of a dorm room model:

- *What is the phase shift between “picking up laundry” and “Laundry on Floor” in the cleanliness of a dorm room model?*
- *What is the phase shift between “change in the daily complaints of my roommate” and “Daily Complaints of My Roommate”*

The phase shift is given in terms of the number of degrees out of a total circle of 360 degrees, or as a fraction of the period of oscillation.

Academic performance model

- The phase shift between the “change in hours of weekly studying” and the “Hours of Weekly Studying” in the academic performance model is one quarter of a period, or 90 degrees, which corresponds to a time lag of 6 weeks.
- There is no phase shift or time lag between the “Hours of Weekly Studying” and the “net improvement in grades.”
- The phase shift between the “net improvement in grades” and “Current Grades” is one quarter of a period, or 90 degrees, which corresponds to a time lag of 6 weeks.
- The phase shift between “Current Grades” and “change in hours of weekly studying” is half of a period, or 180 degrees, which corresponds to a time lag of 12 weeks.

Cleanliness of a dorm room model

- The phase shift between “picking up laundry” and “Laundry on Floor:” in the cleanliness of a college dorm room model is three quarters of a period, or 27 degrees, which corresponds to a time lag of 4.6875 days. Notice that “picking up laundry” is an outflow from “Laundry on Floor,” so there is a phase shift of one quarter of a period between the negative of “picking up laundry” and “Laundry on Floor.”
- The phase shift between “change in the daily complaints of my roommate” and “Daily Complaints of My Roommate” is one quarter of a period, or 90 degrees, which corresponds to a time lag of 1.5625 days.

D. What is the sum of the phase shifts encountered by a signal traveling through the negative feedback loop of the academic performance model? What about for the

cleanliness of a dorm room model? Can you make any generalizations about the relationship in the phase shift between a stock and its flow?

In both models, the sum of the phase shifts encountered by a signal traveling through the negative feedback loop equals 1. In other words, the phase shift around the loop is 360 degrees. Correspondingly, the sum of the time lags equals the period of the oscillation. The phase shift between a flow and its stock is always equal to one quarter of the oscillation period, or 90 degrees

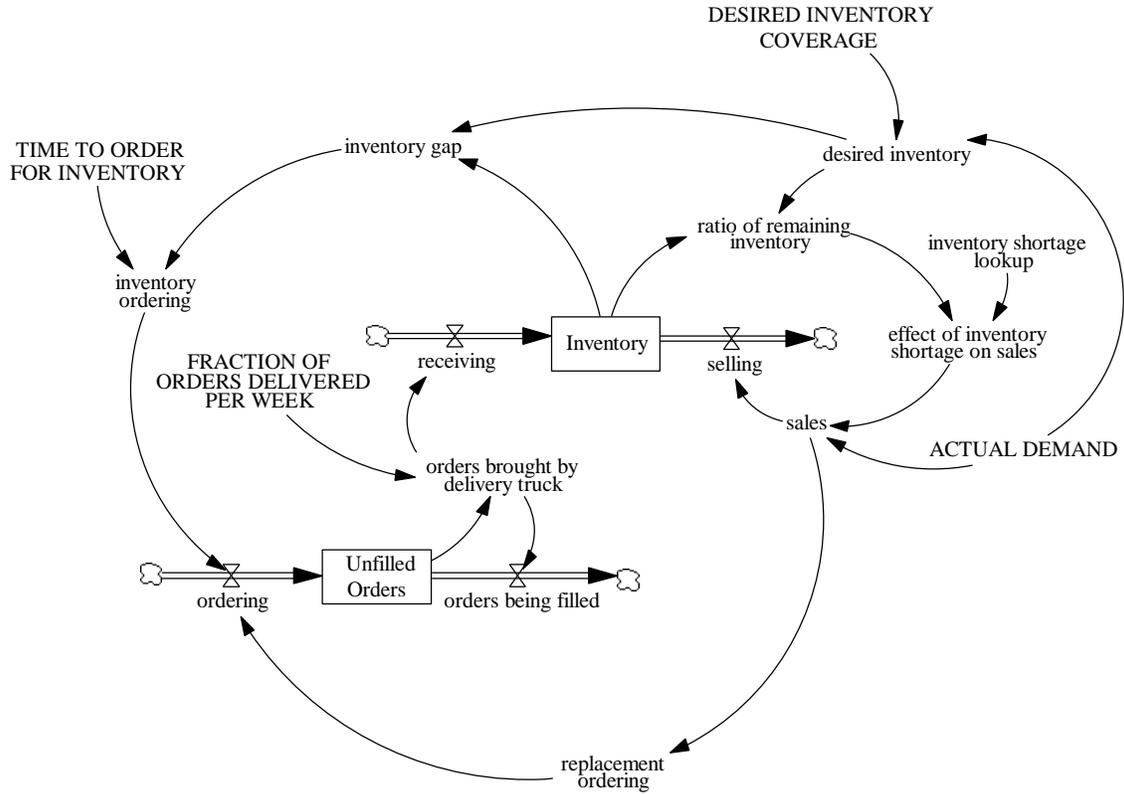
E. Can you think of another example of a system that exhibits sustained oscillations? What are the stocks in this system? Describe the negative feedback loop driving the oscillation.

A parent's anger with a child would provide such an example. The stocks in the system would be the extent of the child's misbehavior and the parent's anger. When the child exceeds the parent's threshold of tolerance, the parent will express his anger. In response the child will be on his good behavior for a time. The child's good behavior makes the parent soften until the parent's good mood makes the child feel that it is safe to misbehave again, ultimately making the parent angry again.

2. Modeling Exercise

We are now returning to the Tea Pot, the well-loved Heavenly Seasonings Tea, and the new sensation: Strawberry-Kiwi Delight Tea.

Here is the model from assignment 21 in its final state:



The equations are:

$$\text{Inventory} = \text{INTEG}(\text{receiving} - \text{selling}, 12)$$

Units: crates

The number of crates of Heavenly Seasonings Tea in Richard's supply room.

$$\text{receiving} = \text{ORDERS BROUGHT BY DELIVERY TRUCK}$$

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard receives from his supplier every week.

$$\text{selling} = \text{sales}$$

Units: crates/Week

The number of crates of Heavenly Seasonings tea that The Tea Pot sells to students every week.

$$\text{sales} = \text{ACTUAL DEMAND} * \text{effect of inventory shortage on sales}$$

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard is able to sell.

$$\text{ACTUAL DEMAND} = 4$$

Units: crates/Week

The actual number of crates of Heavenly Seasonings tea that students want to buy.

effect of inventory shortage on sales = inventory shortage lookup (ratio of remaining inventory)

Units: dmnl

The effect of inventory shortage on sales is a function of the ratio of remaining inventory.

inventory shortage lookup ([(0,0) - (1,2)], (0,0), (0.05,0.3), (0.1,0.55), (0.15,0.75), (0.2,0.9), (0.25,0.97),(0.3,1),(1,1))

Units: dmnl

The inventory shortage lookup function reflects the fact that as the ratio of remaining inventory decreases, Richard sells less tea.

ratio of remaining inventory = Inventory / desired inventory

Units: dmnl

The ratio of the current inventory to the desired inventory.

*desired inventory = ACTUAL DEMAND * DESIRED INVENTORY COVERAGE*

Units: crates

The number of crates of Heavenly Seasonings tea that Richard would like to keep in his supply room.

DESIRED INVENTORY COVERAGE = 3

Units: Week

The number of weeks worth of demand for Heavenly Seasonings tea that Richard wants to keep in his supply room.

inventory gap = desired inventory – Inventory

Units: crates

The difference between Richard's desired inventory and the current inventory.

inventory ordering = inventory gap / TIME TO ORDER FOR INVENTORY

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard orders every week to correct for an inventory gap.

TIME TO ORDER FOR INVENTORY = 2

Units: Week

The time it takes Richard to order tea to correct for an inventory gap.

Unfilled Orders = INTEG (ordering - orders being filled, 16)

Units: crates

The number of orders that Richard has placed with his supplier but has not yet received.

ordering = replacement ordering + inventory ordering

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard orders from his supplier every week.

replacement ordering = sales

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard has to order from his supplier every week to replace those that are sold to customers.

orders being filled = ORDERS BROUGHT BY DELIVERY TRUCK

Units: crates/Week

The number of orders that Richard has placed that are filled every week.

*orders brought by delivery truck = Unfilled Orders * FRACTION OF ORDERS DELIVERED PER WEEK*

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard's supplier delivers to The Tea Pot every week.

FRACTION OF ORDERS DELIVERED PER WEEK = 0.25

Units: 1/Week

The fraction of unfilled orders that The Tea Pot receives every week.

Build the model as shown above and study any possible difference between this model and the model you built in assignment 21.

Step 1: Expected Demand

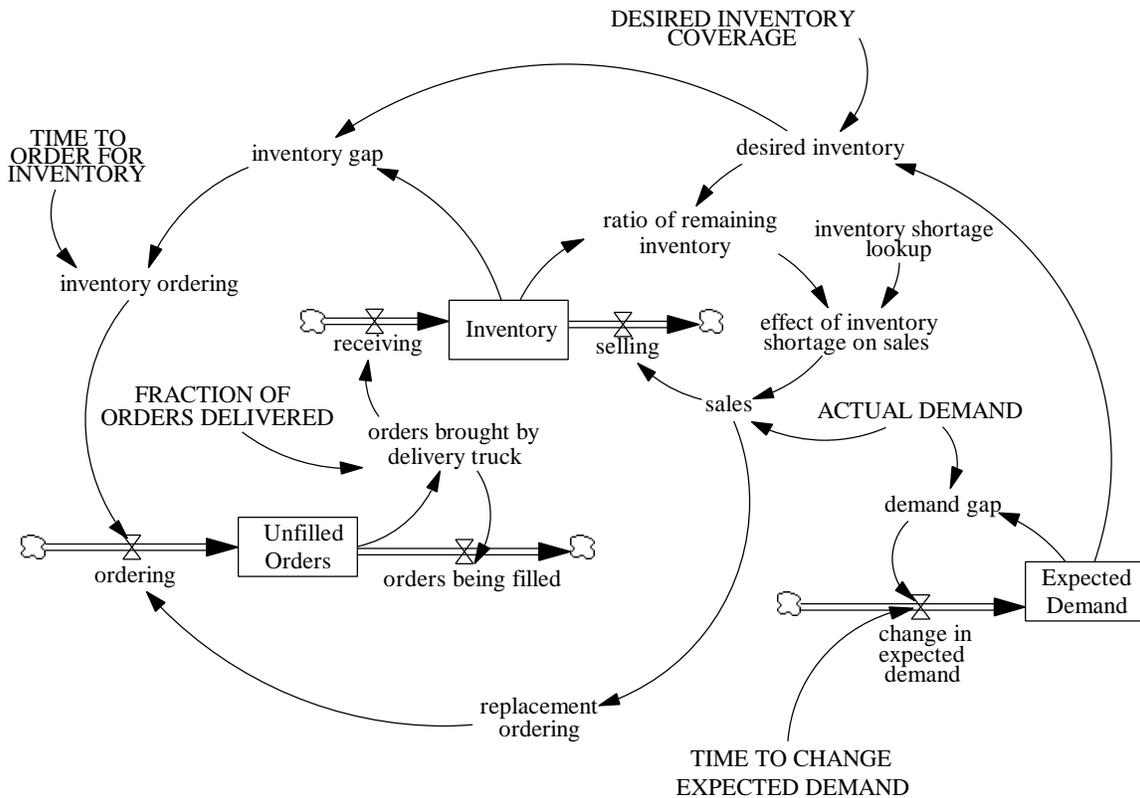
Right now, both unfilled orders and inventory undergo damped oscillations whenever actual demand changes slightly. The system oscillates because when Richard places his orders, he does not take into account the number of orders that he has placed but not yet received (the stock of "Unfilled Orders"). In effect, Richard is ignoring the long delay in the system between the time he places an order and the time he receives it. The long delay is due to the time for his supplier to receive his order and pass the order on to the manufacturer, the time for the manufacturer to change the production of tea, the time for the manufacturer to deliver the tea to Richard's supplier and the time for Richard's supplier to bring him the crates of tea. The number of orders that Richard has placed but not yet received is the amount of tea that is in the pipeline.

To compensate for the delay, Richard needs to plan ahead. He needs to try to predict his future demand so that he can place orders now for the sales four weeks from now, when the tea that he orders today arrives. How does Richard try to predict his future sales? Actual demand may fluctuate from day to day, but expected demand should not. Richard

projects expected demand by smoothing actual demand over a period of four weeks. Then, instead of basing the desired level of inventory on the actual current demand, Richard determines his desired inventory based on the demand he expects.

A. Create a stock representing “Expected Demand.” Formulate an equation for the change in expected demand. Do NOT use the SMOOTH function provided by Vensim. In your assignment solutions document, include the new model diagram and documented equations that you added or modified as a result of this revised formulation.

Model diagram:



Modified model equations:

$$\text{change in expected demand} = \text{demand gap} / \text{TIME TO CHANGE EXPECTED DEMAND}$$

Units: crates/Week/Week

The change in Richard’s expected demand.

$$\text{demand gap} = \text{ACTUAL DEMAND} - \text{Expected Demand}$$

Units: crates/Week

The difference between actual demand and the demand that Richard expects.

$$\text{desired inventory} = \text{Expected Demand} * \text{DESIRED INVENTORY COVERAGE}$$

Units: crates

The number of crates of Heavenly Seasonings tea that Richard would like to keep in his supply room.

Expected Demand = INTEG (change in expected demand, ACTUAL DEMAND)

Units: crates/Week

The demand for tea that Richard expects.

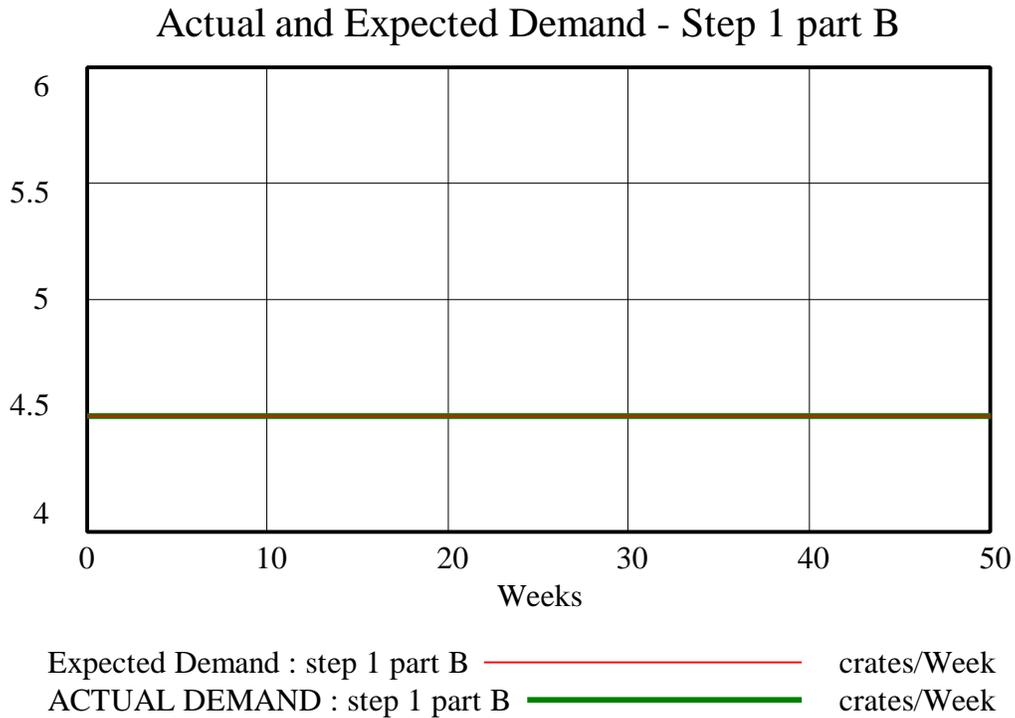
TIME TO CHANGE EXPECTED DEMAND = 4

Units: Week

The time over which Richard smoothes actual demand to project expected demand.

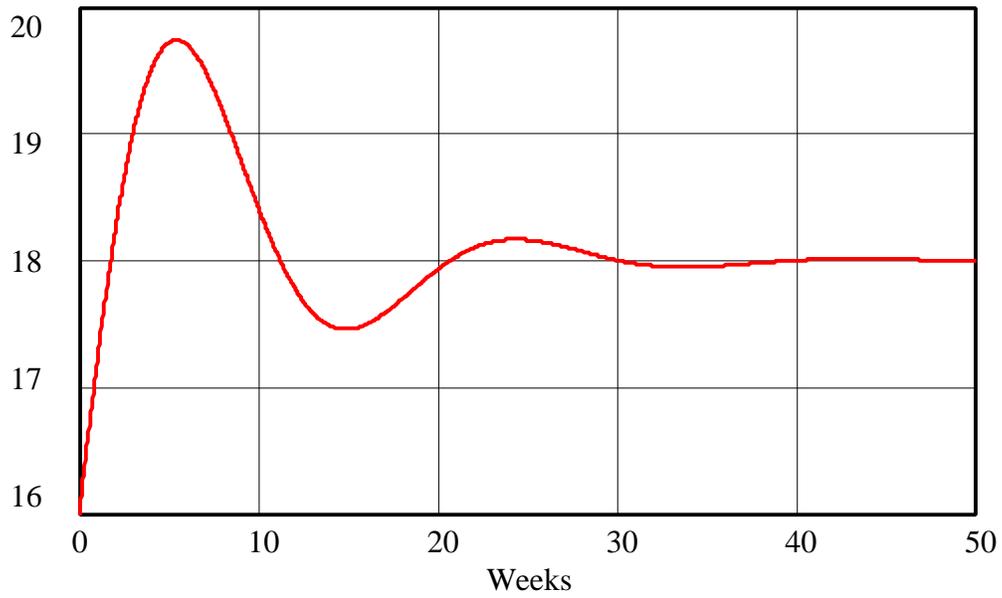
B. Consider the Strawberry Kiwi Delight scenario, in which actual demand is constant at 4.5 crates a week. Draw reference modes for the behavior of all stocks. Simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

When demand is constant at 4.5 crates a week, the following behavior is observed:



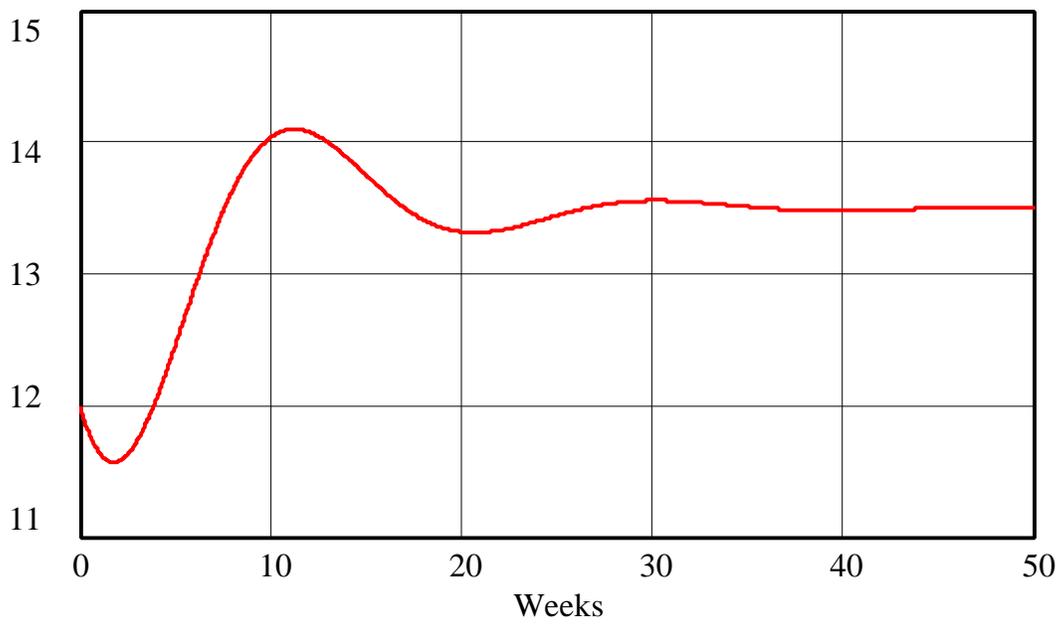
Both “ACTUAL DEMAND” and “Expected Demand” are constant at 4.5 crates a week.

Unfilled Orders - Step 1 part B



Unfilled Orders : step 1 part B ————— crates

Inventory - Step 1 part B



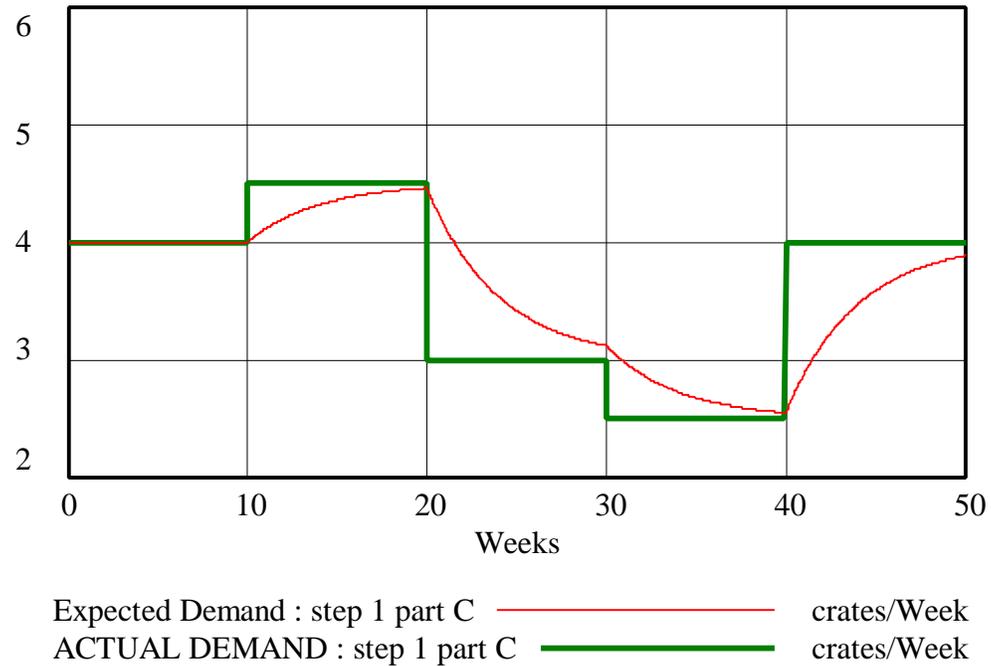
Inventory : step 1 part B ————— crates

The behavior is the same as that observed in Step 4 part C of the modeling exercise in assignment 21.

C. Imagine a scenario in which the college students suddenly become antsy. They experiment with many different things, including a wide variety of herbal teas. Actual demand is four crates a week for ten weeks, then four and a half crates a week for ten weeks, then three crates for ten weeks, then two and a half crates for ten weeks, then four crates again for ten weeks. What is Richard’s expected demand as actual demand fluctuates? Draw a reference mode and then simulate the model. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

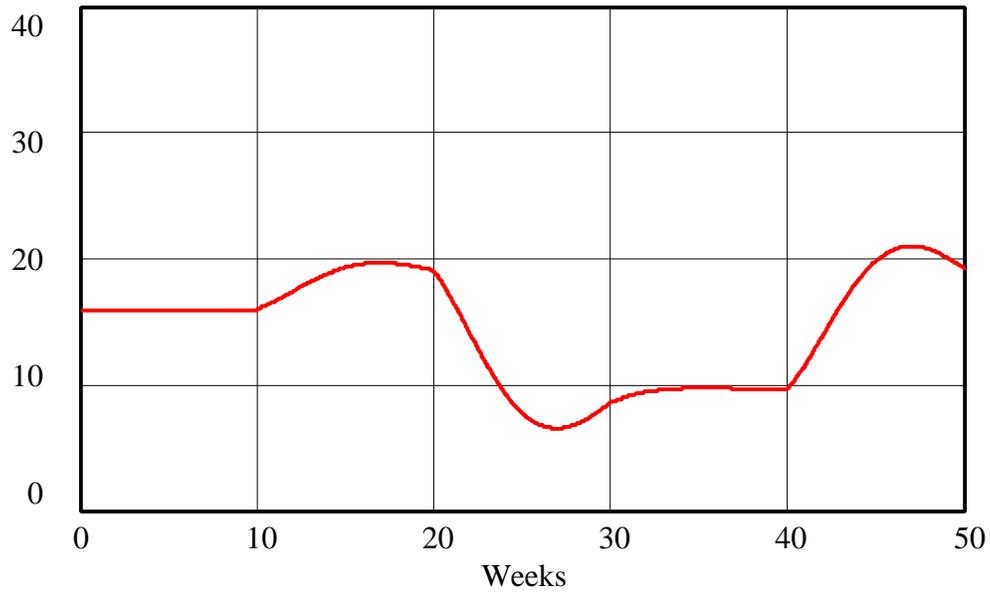
When demand changes according to the pattern described, the following behavior is observed:

Actual and Expected Demand - Step 1 part C



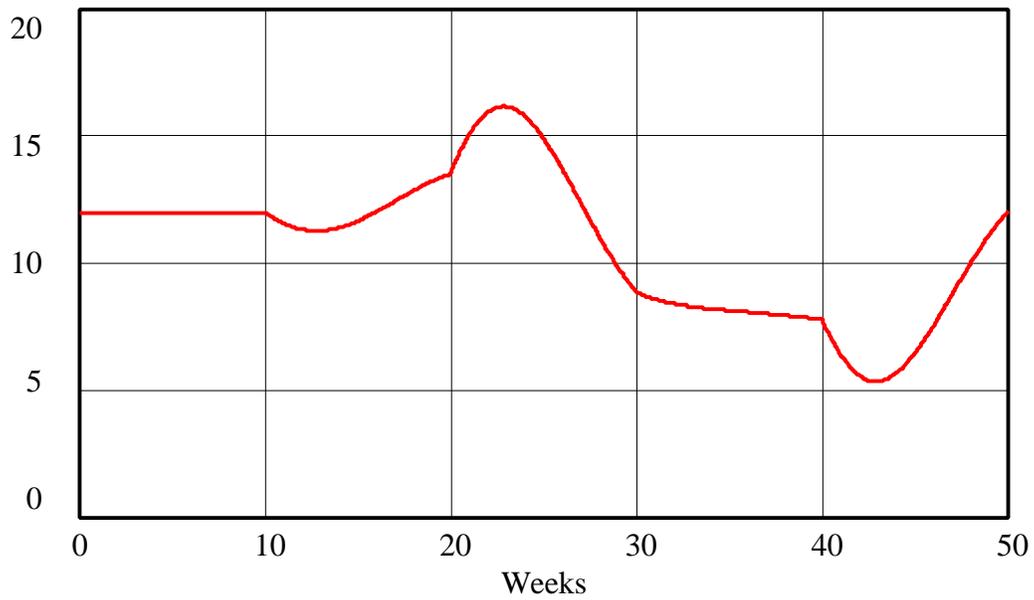
“Expected Demand” is simply an exponential smooth of the step functions of “ACTUAL DEMAND.”

Unfilled Orders - Step 1 part C



Unfilled Orders : step 1 part C — crates

Inventory - Step 1 part C



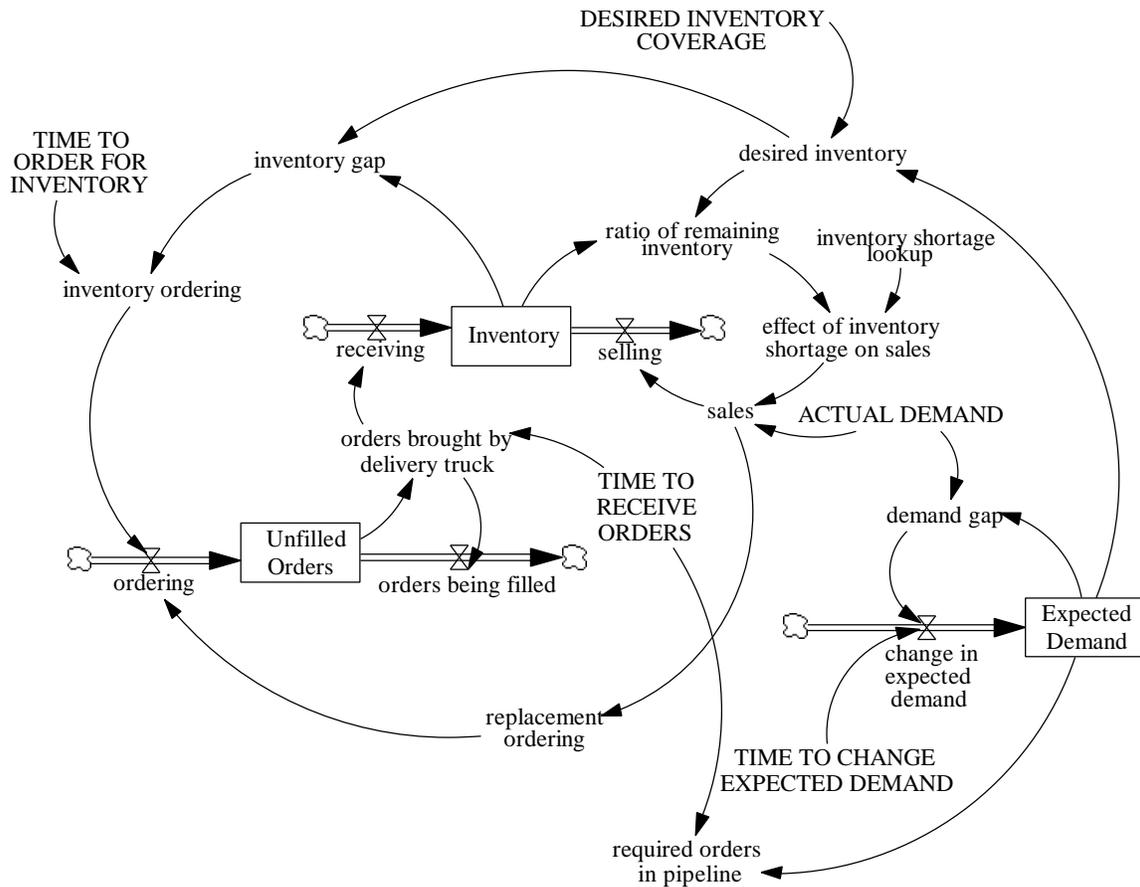
Inventory : step 1 part C — crates

Step 2: Pipeline Ordering

Richard only receives orders four weeks after he places them (each week, he receives 25% of the orders he places). In order to be ready to sell tea four weeks from now, Richard needs to have enough tea in the pipeline to cover his “Expected Demand” for the next four weeks.

A. Formulate an equation for the number of required orders in the pipeline. Convert the “FRACTION OF ORDERS DELIVERED PER WEEK” to “TIME TO RECEIVE ORDERS” and then use the parameter in two different places in the model. You may need to modify existing equations. Be sure to check for units errors before running the model. In your assignment solutions document, include the new model diagram and documented equations that you added or modified.

Model diagram:



Modified model equations:

orders brought by delivery truck = Unfilled Orders / TIME TO RECEIVE ORDERS
 Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard's supplier delivers to The Tea Pot every week.

required orders in pipeline = Expected Demand * TIME TO RECEIVE ORDERS

Units: crates

The number of crates of Heavenly Seasonings tea that Richard needs to have in the pipeline to cover his expected demand for the next four weeks.

TIME TO RECEIVE ORDERS = 4

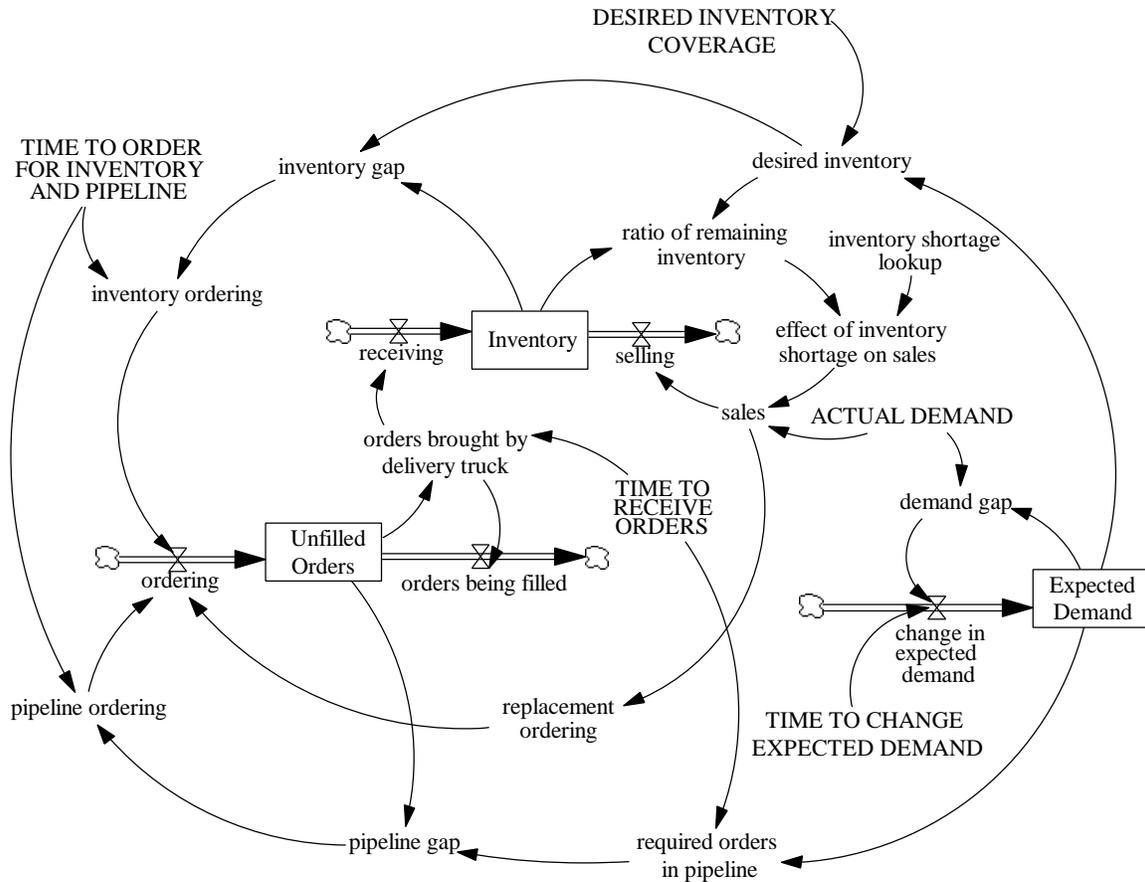
Units: Week

Richard receives tea four weeks after he orders it.

Richard now orders not only to replace the tea that he sells and maintain his desired inventory, but also to fill the pipeline with orders that he expects to need in the future. It takes him the same length of time to order for inventory as to order for pipeline correction. The pipeline gap is the difference between the current number of orders in the pipeline and the number of orders that need to be in the pipeline if Richard wants to be able to provide for his expected demand.

B. Add pipeline ordering to the model. In your assignment solutions document, include the new model diagram and documented equations that you added or modified.

Model diagram:



Modified model equations:

pipeline gap = required orders in pipeline - Unfilled Orders

Units: crates

The difference between the number of crates of Heavenly Seasonings tea that Richard wants to have in the pipeline and the number of crates that he has ordered but not yet received.

pipeline ordering = pipeline gap / TIME TO ORDER FOR INVENTORY AND PIPELINE

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard orders every week to fill the pipeline.

ordering = replacement ordering + inventory ordering + pipeline ordering

Units: crates/Week

The number of crates of Heavenly Seasonings tea that Richard orders from his supplier every week.

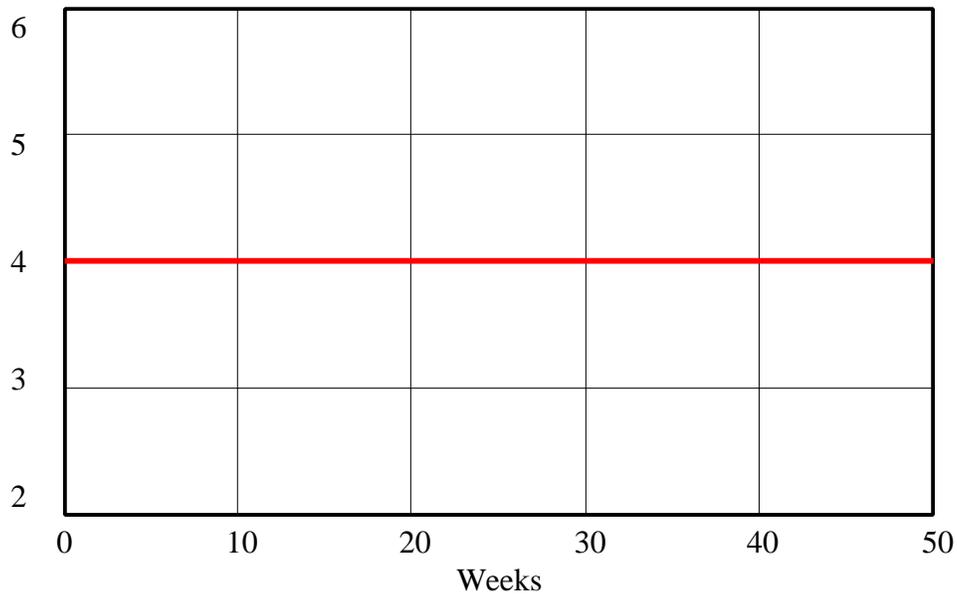
TIME TO ORDER FOR INVENTORY AND PIPELINE = 2

Units: Week

The time it takes Richard to order tea to correct for an inventory gap.

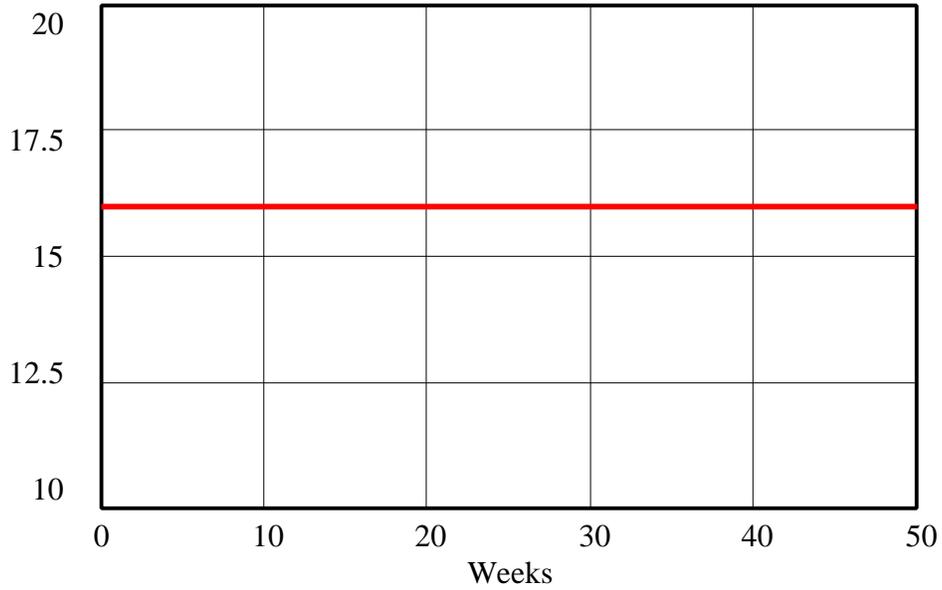
C. Consider the base scenario, in which actual demand is constant at 4 crates a week. Draw reference modes for the behavior of all stocks. Simulate the model under the base scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

Expected Demand - Step 2 part C



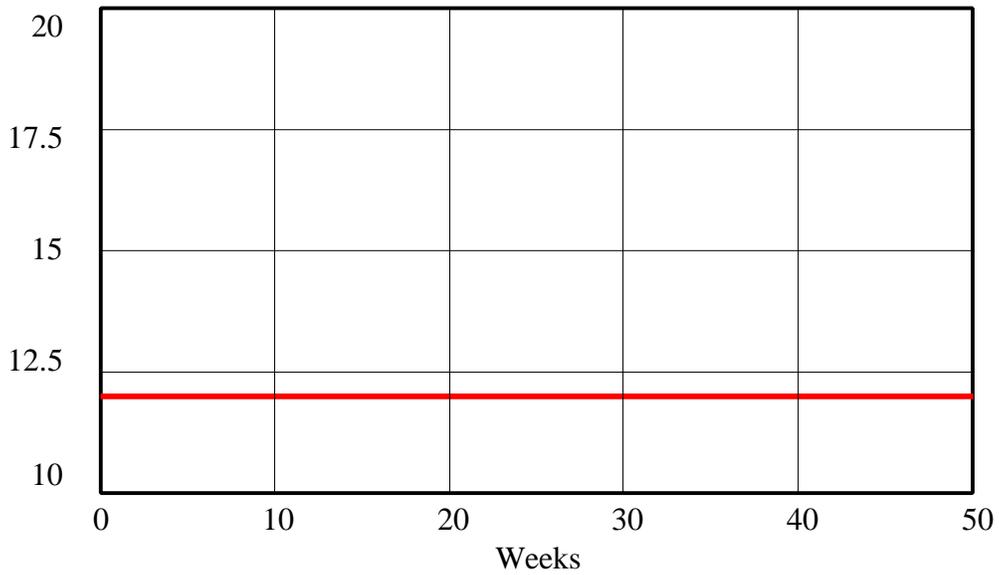
Expected Demand : Step 2 part C ——— crates/Week

Unfilled Orders - Step 2 part C



Unfilled Orders : Step 2 part C ————— crates

Inventory - Step 2 part C

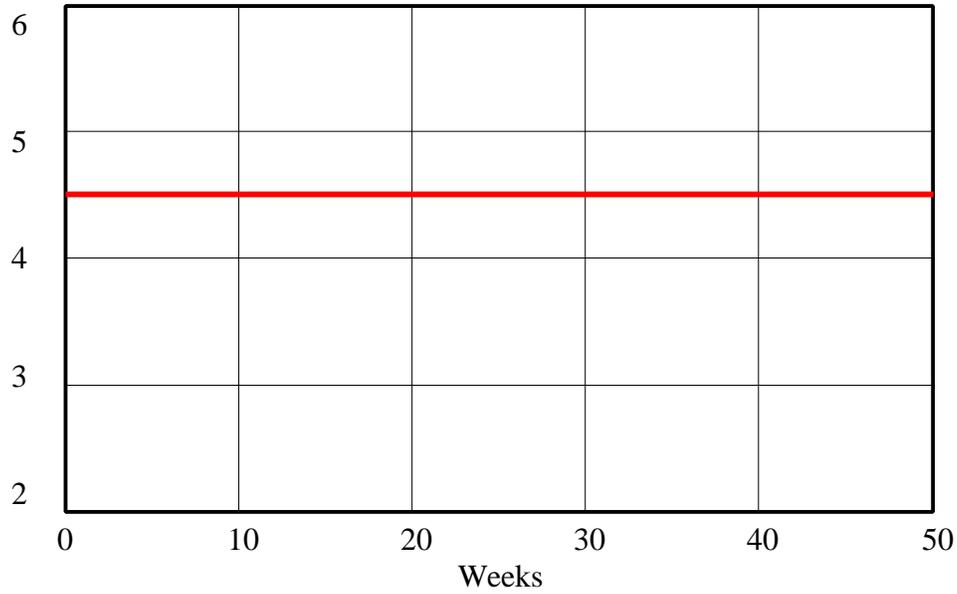


Inventory : Step 2 part C ————— crates

In the base scenario where actual demand is constant at 4 crates a week, the system starts and remains in equilibrium.

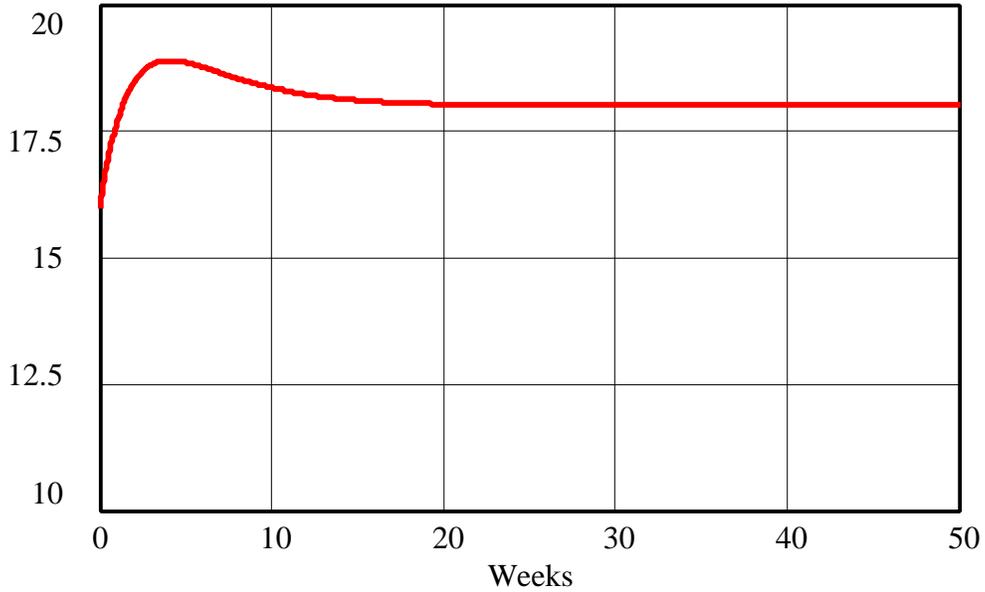
D. Consider the Strawberry Kiwi Delight scenario, in which actual demand is constant at 4.5 crates a week. Draw reference modes for the behavior of all stocks. Simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

Expected Demand - Step 2 part D



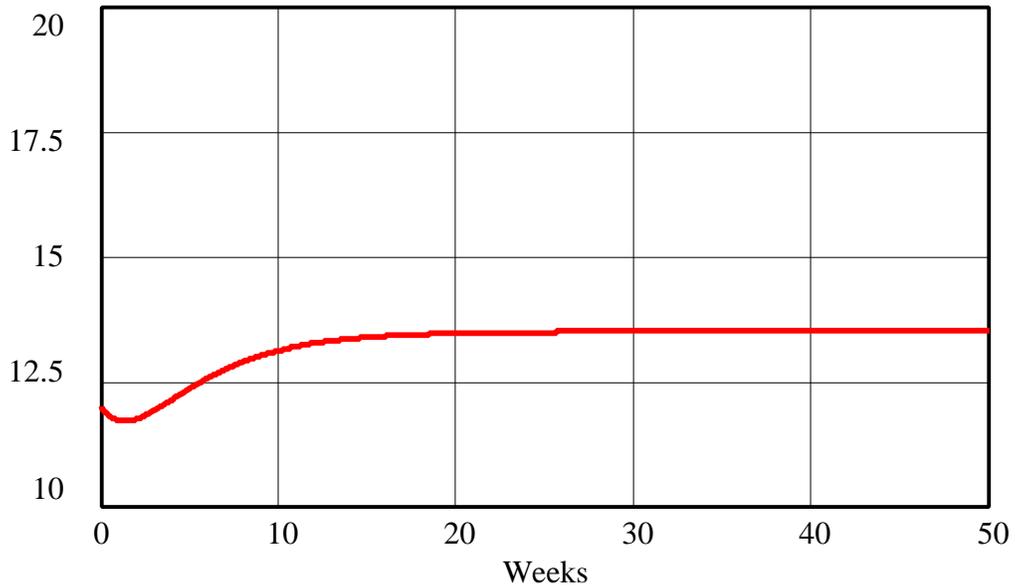
Expected Demand : Step 2 part D ——— crates/Week

Unfilled Orders - Step 2 part D



Unfilled Orders : Step 2 part D — crates

Inventory - Step 2 part D



Inventory : Step 2 part D — crates

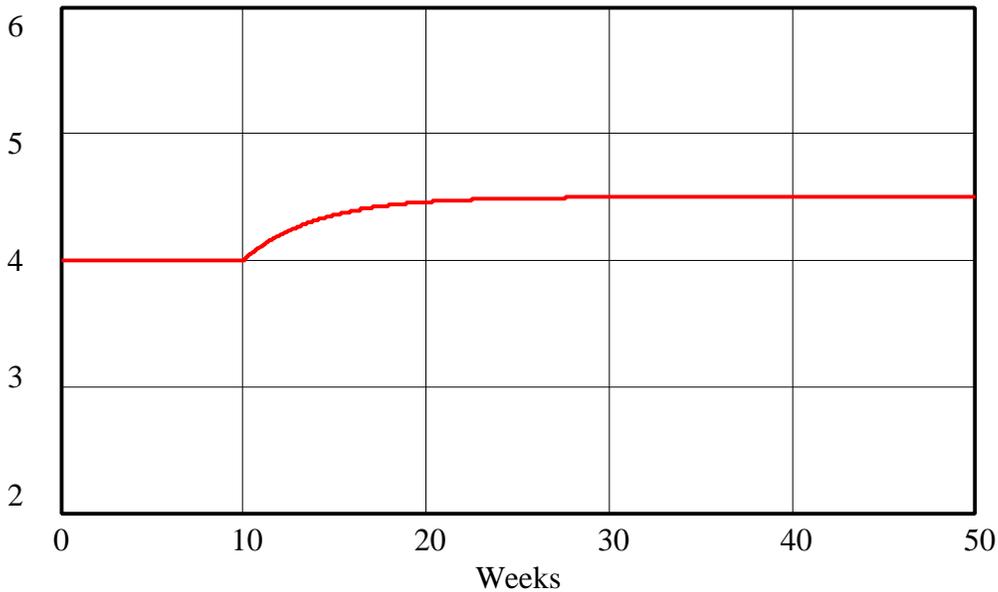
In the Strawberry Kiwi Delight scenario, “Expected Demand” is constant at 4.5 crates a week. The new structure that recognizes the pipeline reduces the oscillating behavior of

the model, and “Unfilled Orders” and “Inventory” reach their equilibrium values more smoothly.

E. Consider the base scenario for the first ten weeks and then introduce the Strawberry Kiwi Delight flavor on the 10th week. Draw reference modes for the behavior of all stocks. Simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

For the first 10 weeks, when demand is 4 crates a week, “Expected Demand” is constant also at 4 crates a week. When “ACTUAL DEMAND” steps up to 4.5 crates a week at week 10, “Expected Demand” starts increasing asymptotically to approach its equilibrium value.

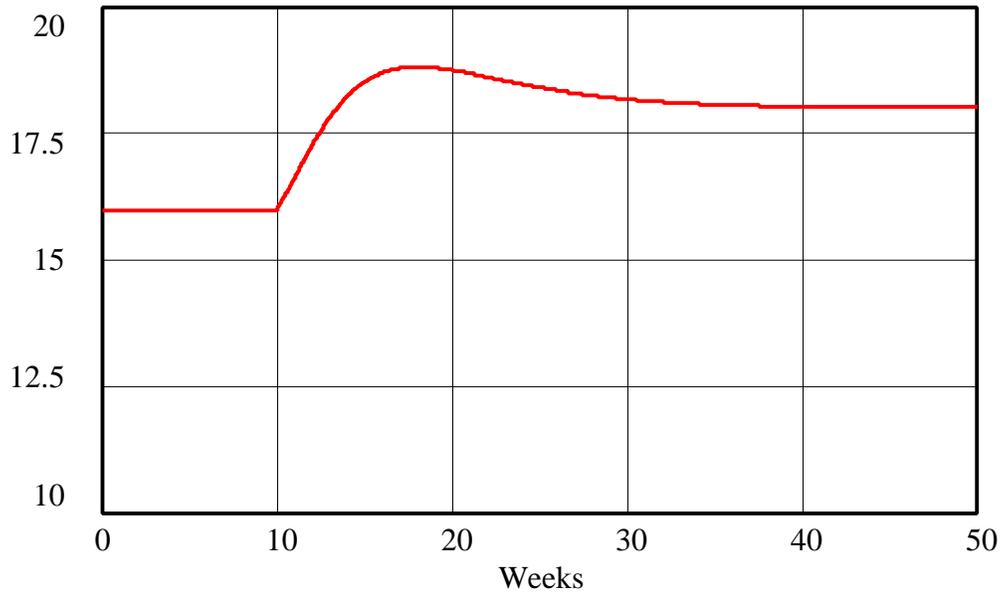
Expected Demand - Step 2 part E



Expected Demand : Step 2 part E ————— crates/Week

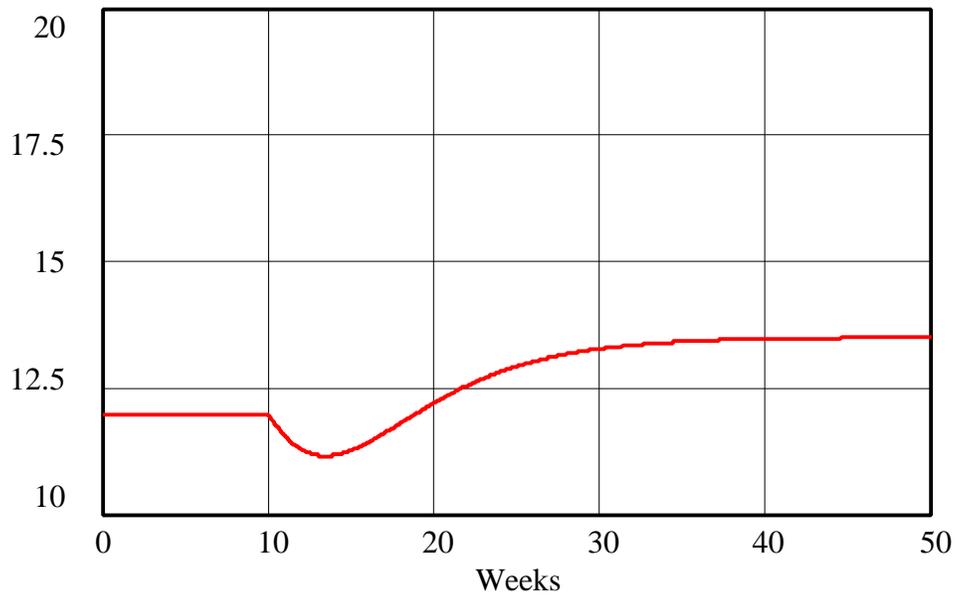
As in the previous scenario, the oscillations of “Unfilled Orders” and “Inventory” are strongly reduced. Notice that compared to part D, both stocks take longer to approach equilibrium. After week 0, “Expected Demand” is smoothed over a four-week period and therefore does not start at 4.5 crates per week, as in the scenario from part D. Because it takes time for “Expected Demand” to build up to its equilibrium value, the behavior of the rest of the model will also be modified.

Unfilled Orders - Step 2 part E



Unfilled Orders : Step 2 part E — crates

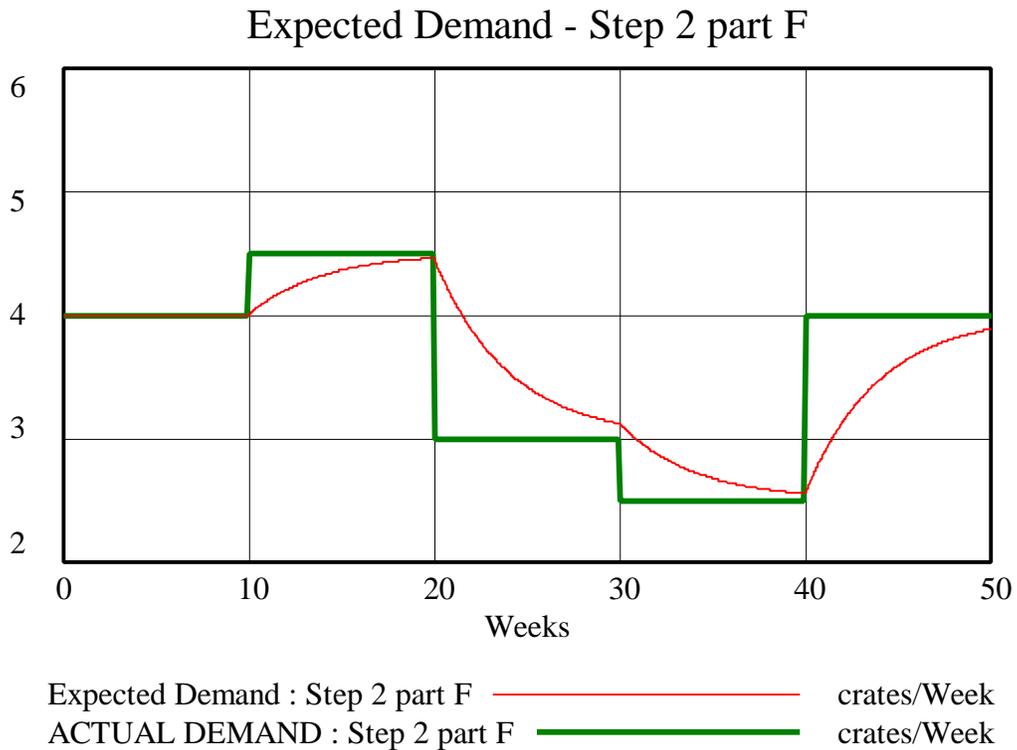
Inventory - Step 2 part E



Inventory : Step 2 part E — crates

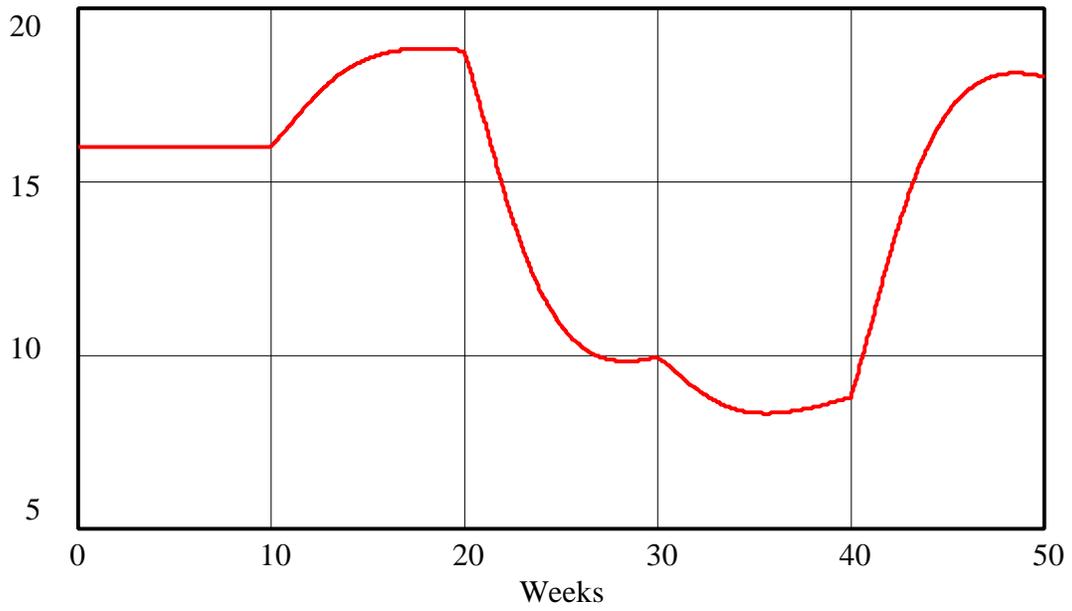
F. Consider the scenario of the antsy college students. Actual demand is four crates a week for ten weeks, then four and a half crates a week for ten weeks, then three crates for ten weeks, then two and a half crates for ten weeks, then four crates again for ten weeks. Draw reference modes for the behavior of all stocks. Simulate the model under the base scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Did you observe the behavior that you predicted? Why or why not?

In this scenario, “Expected Demand” asymptotically approaches the value of “ACTUAL DEMAND” in each 10-week interval.



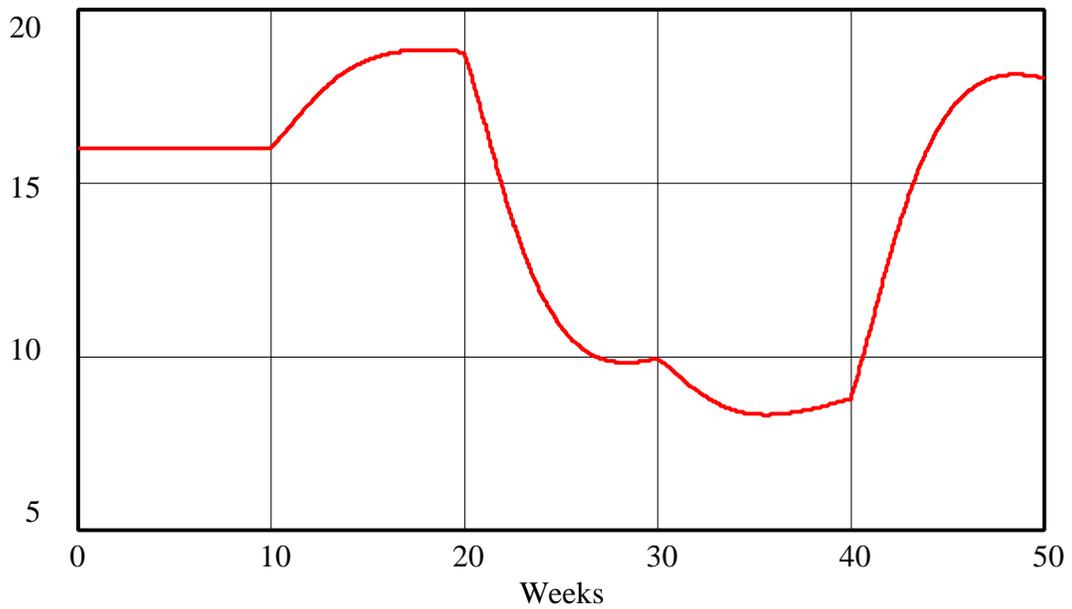
The oscillations in the behavior of “Unfilled Orders” and “Inventory” are again reduced compared to the previous version of the model where “Expected Demand” and “required orders in pipeline” were not considered.

Unfilled Orders - Step 2 part F



Unfilled Orders : Step 2 part F — crates

Unfilled Orders - Step 2 part F



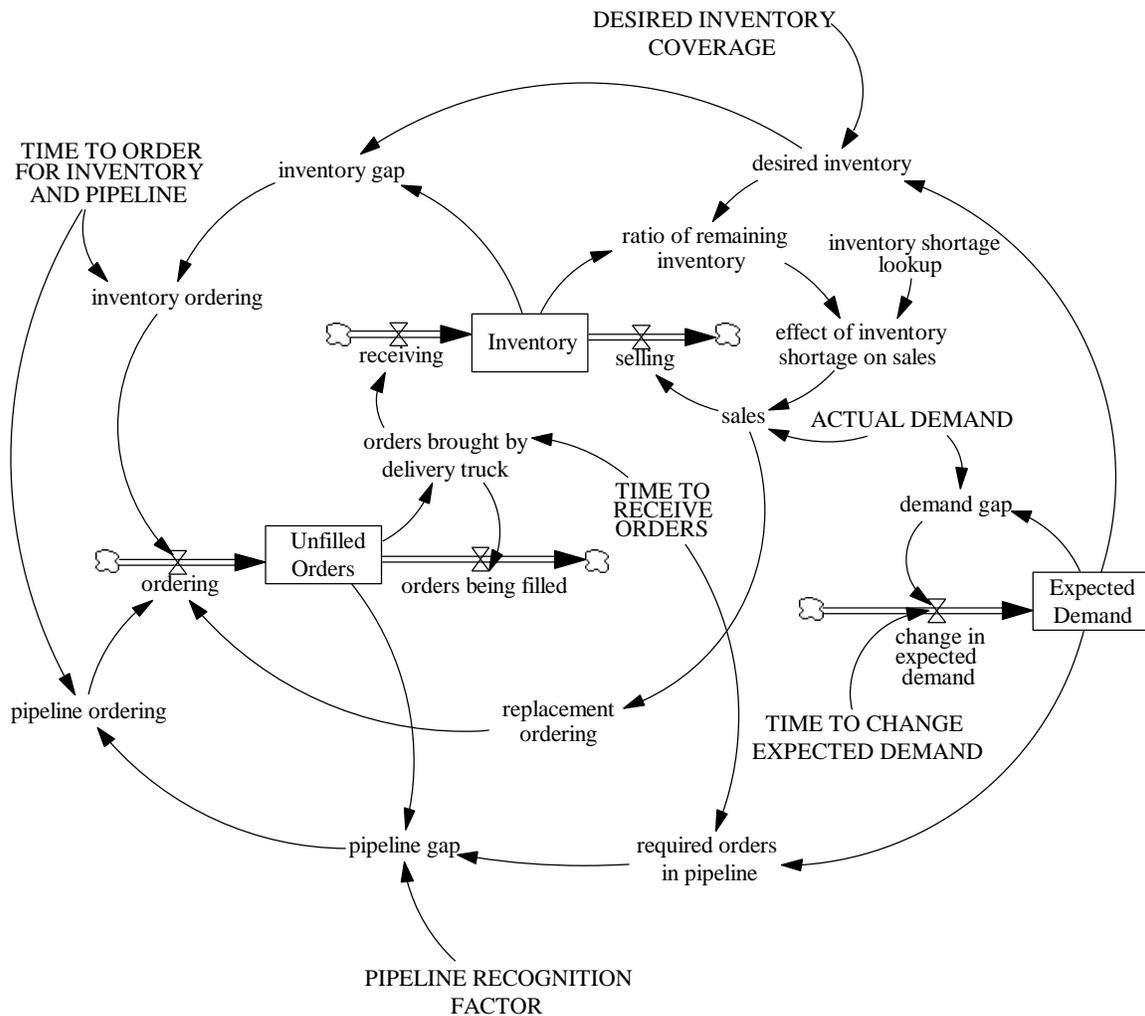
Unfilled Orders : Step 2 part F — crates

Step 3: Pipeline Recognition

Richard keeps good records of the orders he makes, and thus knows exactly how many orders are in the pipeline. Jim, who owns a competing tea shop, The Other Tea Pot, is not so organized. Thus, he tends to underestimate the number of orders in the pipeline. Jim’s estimation error can be modeled using a pipeline recognition factor, which is a fraction between 0 and 1. For instance, if Jim thinks there are orders for 50 tea in the pipeline when in reality, 100 orders of tea are in the pipeline, his pipeline recognition factor would be 0.5.

A. Add the “PIPELINE RECOGNITION FACTOR” to the model, and reformulate the equation for pipeline gap to account for the “PIPELINE RECOGNITION FACTOR.” In your assignment solutions document, include the new model diagram and documented equations that you added or modified.

Model diagram:



Modified model equations:

pipeline gap = (required orders in pipeline – Unfilled Orders) * PIPELINE RECOGNITION FACTOR

Units: crates

The difference between the number of crates of Heavenly Seasonings tea that Richard wants to have in the pipeline and the number of crates that he has ordered but not yet received.

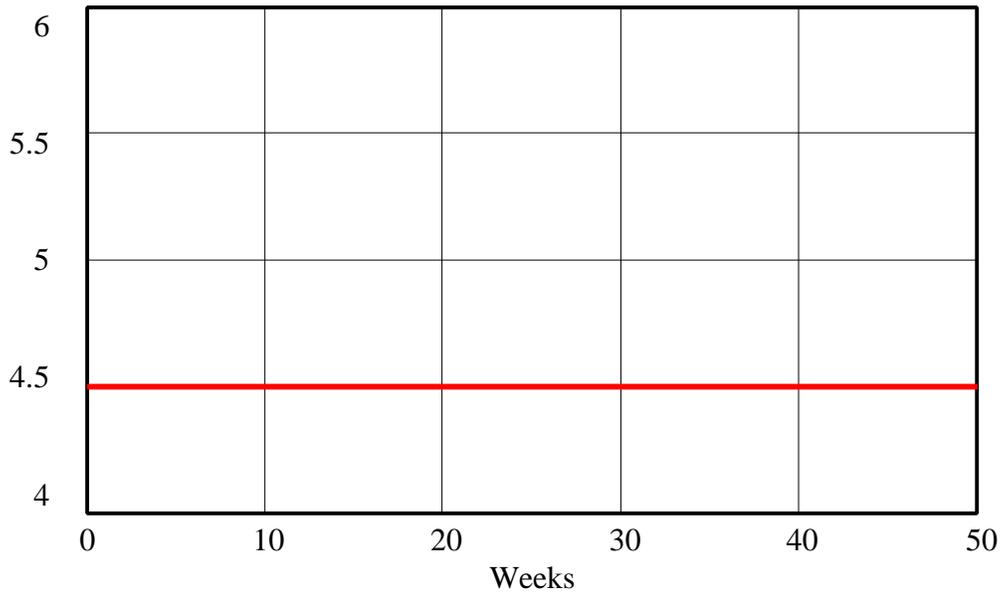
PIPELINE RECOGNITION FACTOR = 1

Units: dmnl

The fraction of the orders in the pipeline that Richard takes into account when making orders.

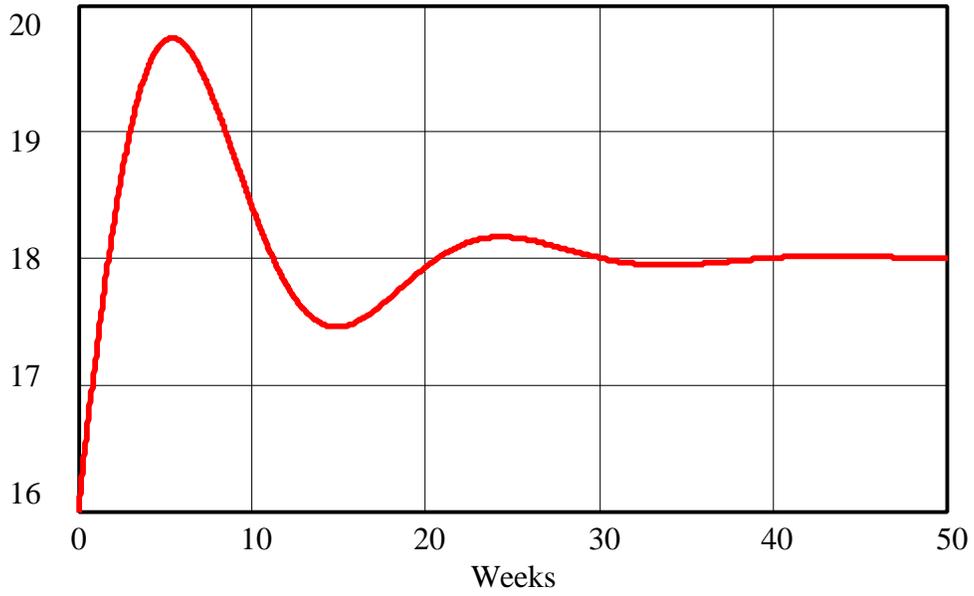
B. Consider the Strawberry Kiwi Delight scenario. Set the “PIPELINE RECOGNITION FACTOR” to 0, and simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Explain the behavior you observe. Which earlier-discussed scenario does this scenario mimic? What does a “PIPELINE RECOGNITION FACTOR” of 0 mean?

Expected Demand - Step 3 part B



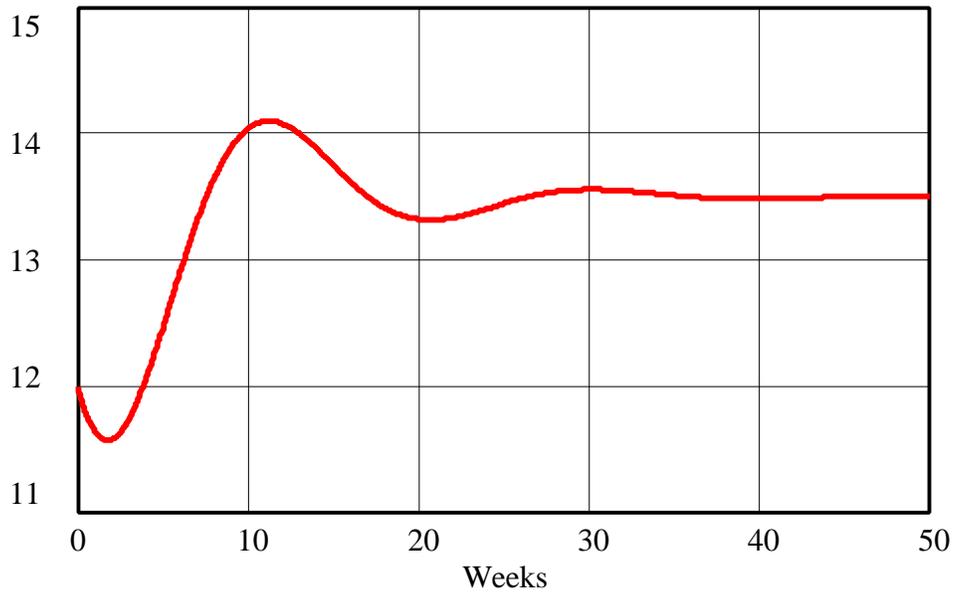
Expected Demand : Step 3 part B ————— crates/Week

Unfilled Orders - Step 3 part B



Unfilled Orders : Step 3 part B ——— crates

Inventory - Step 3 part B

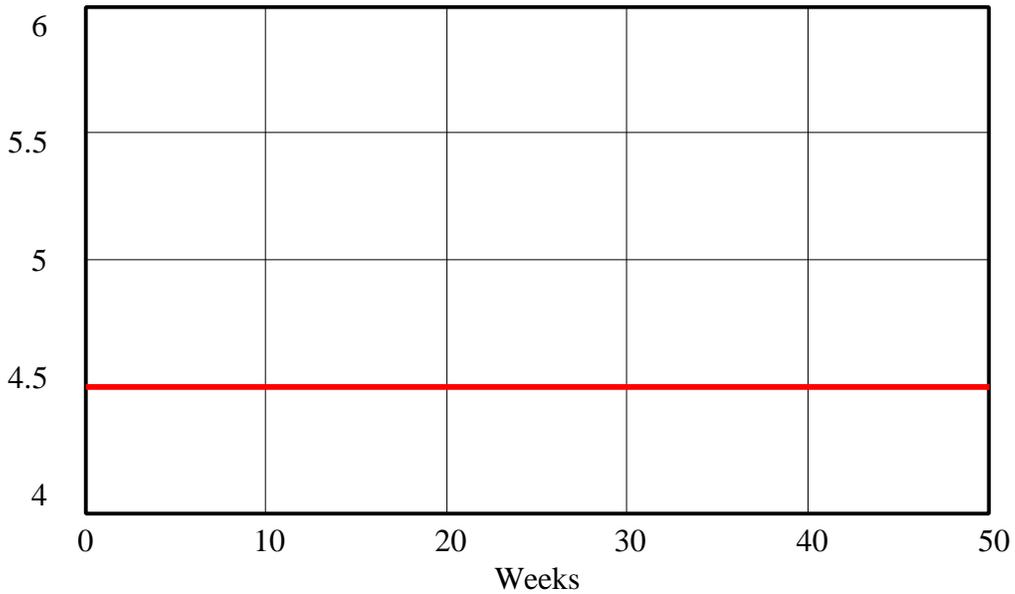


Inventory : Step 3 part B ——— crates

This scenario mimics the scenario from Step 1 part B, before pipeline ordering was added to the model. A “PIPELINE RECOGNITION FACTOR” of 0 means that Jim does not take into account any of the orders that are in the pipeline when he is making new orders.

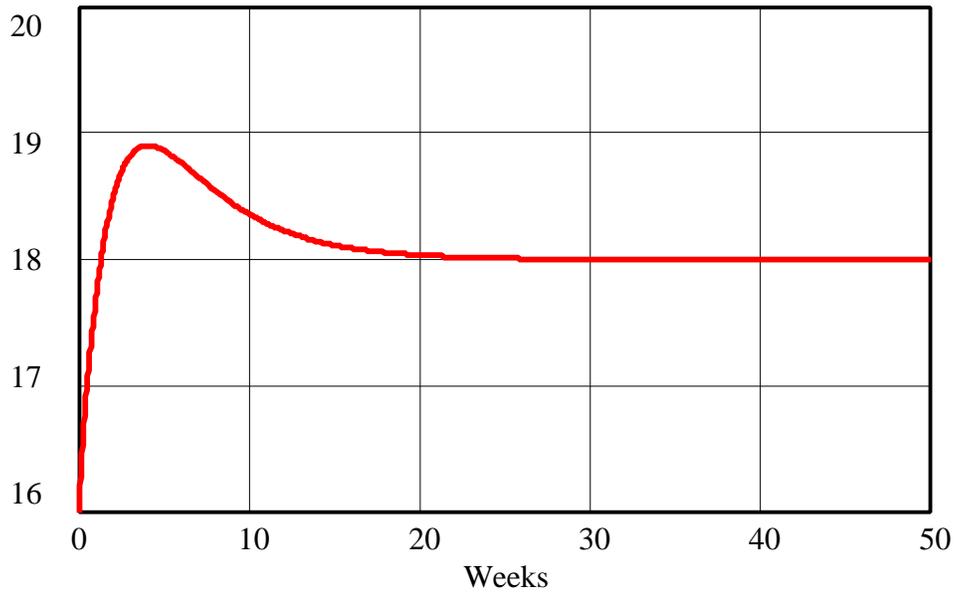
C. Again, consider the Strawberry Kiwi Delight scenario. Set the “PIPELINE RECOGNITION FACTOR” to 1, and simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Explain the behavior you observe. Which earlier-discussed scenario does this scenario mimic? What does a “PIPELINE RECOGNITION FACTOR” of 1 mean?

Expected Demand - Step 3 part C



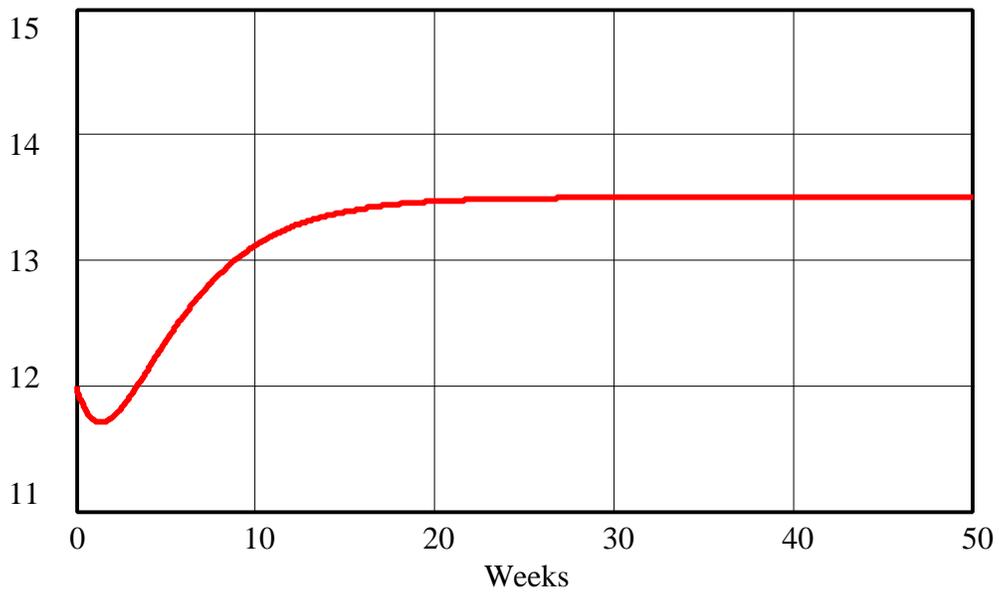
Expected Demand : Step 3 part C ——— crates/Week

Unfilled Orders - Step 3 part C



Unfilled Orders : Step 3 part C — crates

Inventory - Step 3 part C

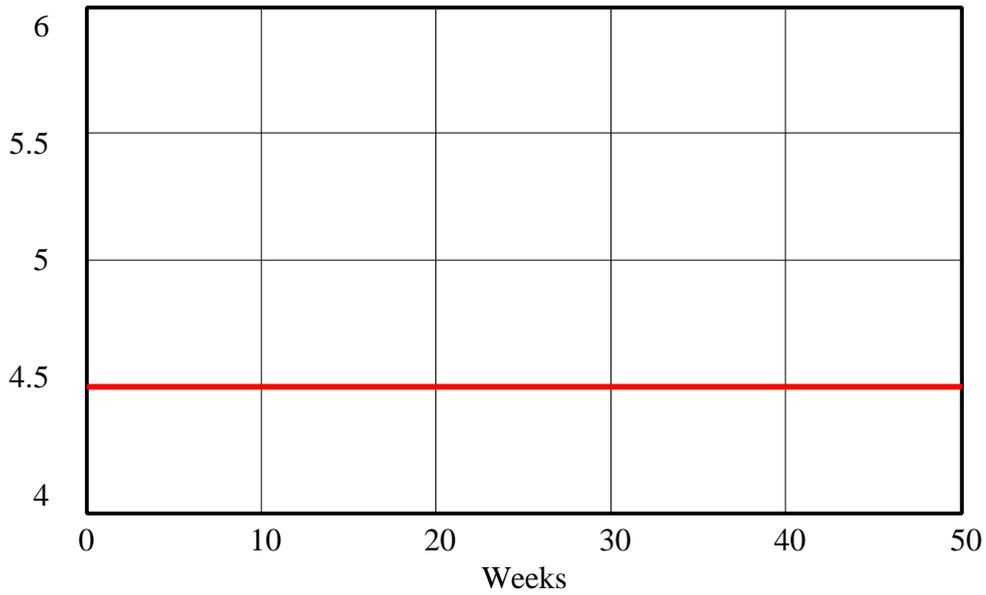


Inventory : Step 3 part C — crates

This scenario mimics the scenario from Step 2 part D, after pipeline ordering was added to the model. A “PIPELINE RECOGNITION FACTOR” of 1 means that Jim takes into account all of the orders that are in the pipeline when he is making new orders.

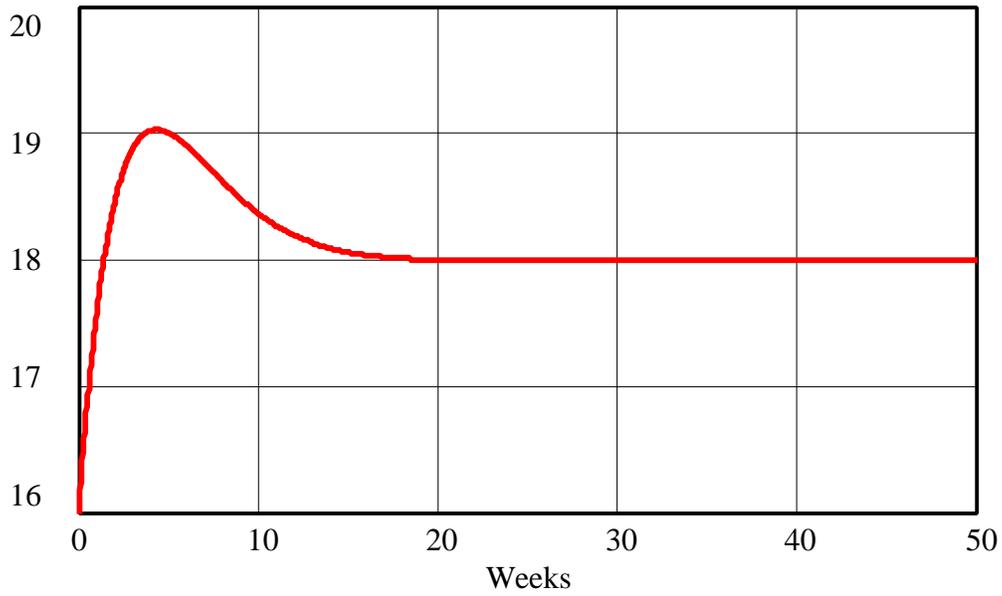
D. Again, consider the Strawberry Kiwi Delight scenario. Set the “PIPELINE RECOGNITION FACTOR” to 0.75, and simulate the model under this scenario over a period of 50 weeks. In your assignment solutions document, include behavior graphs for all stocks. Explain the behavior you observe.

Expected Demand - Step 3 part D



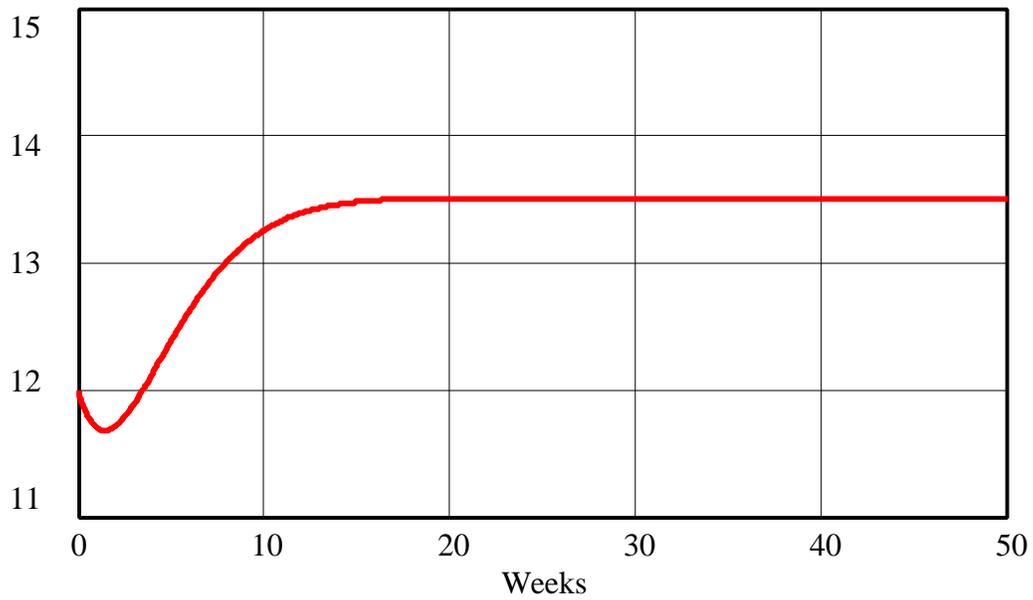
Expected Demand : Step 3 part D ——— crates/Week

Unfiled Orders - Step 3 part D



Unfiled Orders : Step 3 part D — crates

Inventory - Step 3 part D



Inventory : Step 3 part D — crates

Even though in this scenario Jim recognizes only 75% of the orders in the pipeline, the behavior is almost as stable as if he took into account the entire pipeline. The higher the “PIPELINE RECOGNITION FACTOR,” the more stable the system behavior.

The “PIPELINE RECOGNITION FACTOR” is often lower than expected in the real world because different people control different parts of the company, and communication is not always perfect. Furthermore, when one considers enormously complex supply chains, the “PIPELINE RECOGNITION FACTOR” often is close to zero. Hence, huge oscillations are seen in industry because everyone looks at only their company, or their part of the supply chain, without considering what is happening upstream and downstream from them.