

Generic Structures: First-Order Negative Feedback

Produced for the
System Dynamics in Education Project
MIT System Dynamics Group

Under the Supervision of
Dr. Jay W. Forrester
Sloan School of Management
Massachusetts Institute of Technology

by
Stephanie Albin
September 5, 1996
Vensim Examples added October 2001

Copyright © 2001 by the Massachusetts Institute of Technology

Permission granted to copy for non-commercial educational purposes

Table of Contents

1. INTRODUCTION	7
2. EXPONENTIAL DECAY	8
2.1 EXAMPLE 1: RADIOACTIVE DECAY	9
2.2 EXAMPLE 2: POPULATION-DEATH SYSTEM	10
2.3 EXAMPLE 3: COMPANY DOWNSIZING SYSTEM	10
3. THE GENERIC STRUCTURE	12
3.1 MODEL DIAGRAM	12
3.2 MODEL EQUATIONS	12
3.3 MODEL BEHAVIOR	15
4. BEHAVIORS PRODUCED BY THE GENERIC STRUCTURE	15
4.1 CHANGING THE INITIAL VALUE OF THE STOCK	15
4.2 CHANGING THE VALUE OF THE DRAINING FRACTION	16
4.3 CHANGING THE VALUE OF THE GOAL	18
5. SUMMARY OF IMPORTANT CHARACTERISTICS	19
6. USING INSIGHTS GAINED FROM THE GENERIC STRUCTURE	21
6.1 EXERCISE 1: RADIOACTIVE DECAY	21
6.2 EXERCISE 2: PACKAGE DELIVERIES	21
6.3 EXERCISE 3: COMPANY DOWNSIZING	22
7 SOLUTIONS TO EXERCISES	23
7.1 SOLUTION TO 6.1: RADIOACTIVE DECAY	23
7.2 SOLUTION TO 6.2: PACKAGE DELIVERIES SOLUTION	24
7.3 SOLUTION TO 6.3: COMPANY DOWNSIZING	24
8 APPENDIX	24
SECTION 2.1: RADIOACTIVE DECAY MODEL DOCUMENTATION	24
SECTION 2.2: POPULATION - DEATH SYSTEM MODEL DOCUMENTATION	25
SECTION 2.3: COMPANY DOWNSIZING MODEL DOCUMENTATION	26

1. Introduction

Generic structures are relatively simple structures that recur in many diverse situations. In this paper, for example, the models of radioactive decay and a population death system are shown to share the same basic structure! The transferability of structure between systems gives the study of generic structures its importance in system dynamics.

Road Maps contains a series of papers on generic structures. These papers use generic structures to develop an understanding of the relationship between the structure and behavior of a system. Such an understanding should help refine intuition about the systems that surround us and facilitate improvement of our ability to model behaviors exhibited by systems.

The knowledge about a generic structure in one system is transferable to understand the behavior of other systems that contain the same structure. Knowledge of generic structures and the behaviors they produce is transferable to systems never studied before!

Behavior of a system is often more obvious than its underlying structure. It is common practice to refer to systems by the behaviors they produce. However, it is incorrect to assume such systems are capable of exhibiting only their most popular behaviors, and a need for a closer look at the other possible behaviors is present. A study of generic structures examines the range of behaviors possible from particular structures. In each case, one seeks to understand what in the structure causes the behavior produced.

This paper introduces a simple generic structure of first-order linear negative feedback. Many examples of systems containing the basic generic structure illustrate this study. Soon the structure will become recognizable in many new and different models. The exercises at the end of the paper provide an opportunity to transfer your knowledge between different systems.

2. Exponential Decay

Exponential decay is one of the behaviors commonly exhibited by a negative feedback loop. Figure 1 contains a typical exponential decay curve. An important characteristic of exponential decay is its asymptotic behavior.¹ The asymptote that the level approaches is the “goal” of the level. The goal is equal to zero in Figure 1. Another important characteristic of exponential decay is the curve’s constant halving time. The halving time is the time it takes for the stock to reduce by one-half. The following simple formula approximates the halving time of a level using the time constant.

The halving time = $0.7 * \text{time constant}$.

Remember, the time constant is the time in which the initial slope reaches the goal. Figure 1 illustrates this concept. The time constant is 3 because the line tangent to the initial stock value crosses the time axis at 3 time units.

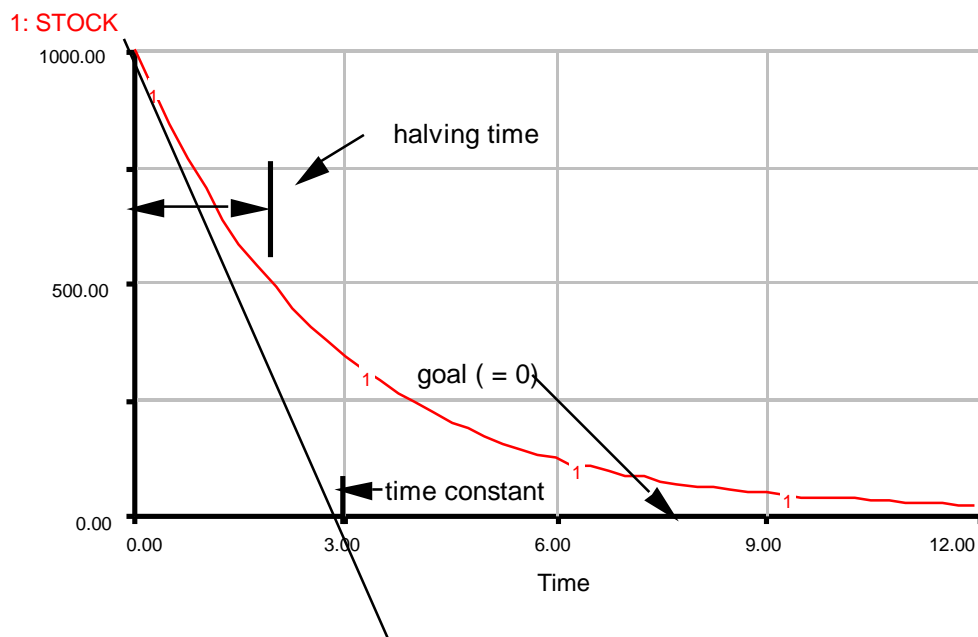


Figure 1. Exponential Decay Curve

¹ A curve exhibiting asymptotic behavior gradually approaches a specific value (the asymptote) over time. The slope of the curve gets closer and closer to the slope of the line.

A simple negative feedback loop consists of a stock, an outflow from the stock, and a goal. The outflow is proportional to the difference between the stock and the goal. One can also refer to negative feedback loops as self-correcting or goal-seeking loops.

For example, a radioactive element possesses a negative feedback structure and the resulting exponential decay. Another system with exponential decay arises from a population with no births or other inflows, and a death rate proportional to the population. Both of these systems share a common structure and exhibit similar behaviors. An additional system that exhibits exponential decay is a company that is downsizing its work-force to reach an explicit goal. These three systems share the basic negative feedback structure with a goal (in some cases the goal is zero), and exhibit the characteristic behavior of exponential decay.

These three systems mentioned above will now be explored in more detail.

2.1 Example 1: Radioactive Decay

Figure 2 shows radioactive decay. The stock represents an amount of a **radioactive compound** and the natural **rate of decay** of the compound into other compounds is the outflow. The **decay fraction** is the fraction of the initial radioactive compound that decays each time period and is characteristic of the specific compound. Assuming this is a closed system and there is no further addition of the radioactive compound, eventually the entire initial amount will transform into a stable compound. The implicit goal of the level for the system is zero.

The **rate of decay** = **radioactive compound** * **decay fraction**.

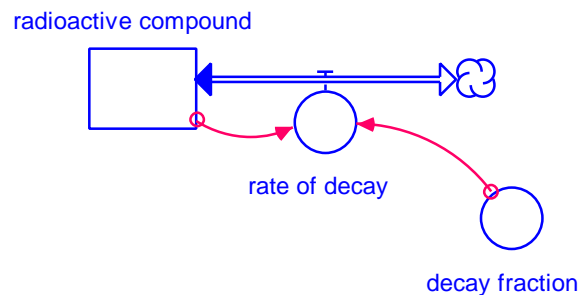


Figure 2. Radioactive Decay

2.2 Example 2: Population-Death system

Figure 3 models the dynamics of a population of mules. The **mule population** is the stock and the **death rate** is the outflow. The **death fraction** is the fraction of mules that die each year. The implicit goal of the mule system is zero. With no births in the system, the mules will eventually die out.

The **death rate** = **mule population** * **death fraction**.

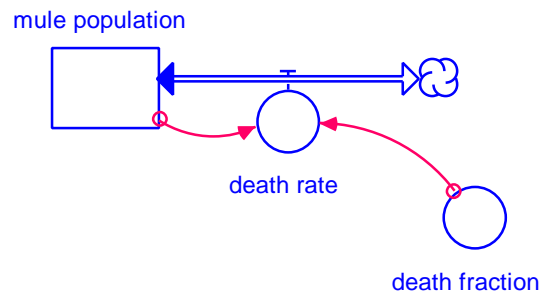


Figure 3. Population-Death system

Examples 1 and 2 both share the same underlying structure of a stock with an outflow proportional to the stock. Both have an implicit goal of zero, which drives the exponential decay.

2.3 Example 3: Company Downsizing System

The third example in Figure 4 shows a negative feedback structure with the **number of employees** in a company as the stock and the **firing rate** as the outflow. Instead of having an implicit goal of zero as in examples 1 and 2, the company's goal is the **desired number of employees**. The **distance to goal** is the difference between the level and the goal, and is simply the number of employees that the firm must reduce by to reach the goal. The

distance to goal = **number of employees** – **desired number of employees**.

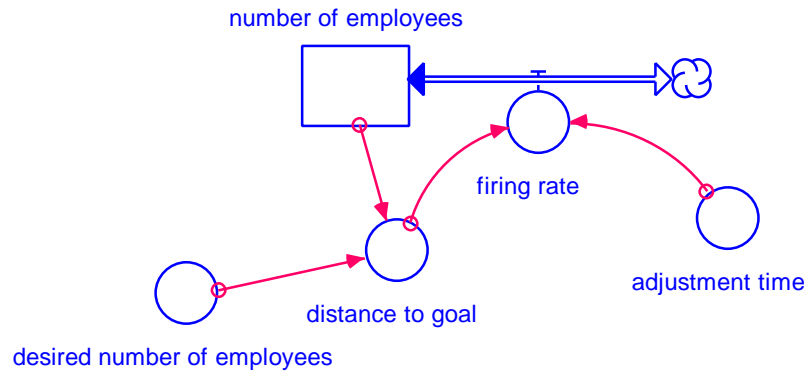


Figure 4. Company Downsizing System

The **firing rate** decreases the stock of employees. The **firing rate** is the number of employees fired per unit time, which is the same as the **distance to goal** spread out over the **adjustment time**. Therefore, the **firing rate** is equal to the **distance to goal** divided by the **adjustment time**.

$$\text{Firing rate} = \text{distance to goal} / \text{adjustment time}.$$

In the equation of the rate, there is division by the **adjustment time**, which is the time constant of the system. Dividing by the adjustment time is analogous to multiplying by a draining fraction as seen in examples 1 and 2. In the equation of the rate, multiplying the **distance to goal** by a draining fraction is identical to dividing by the time constant. The time constant is simply the reciprocal of the draining fraction.

Example 3 has the same basic structure as examples 1 and 2. It is possible to model examples 1 and 2 in this way. They are just specific cases of the generic structure where the goal equals zero. If the desired number of employees equals zero, then the distance to the goal would simply equal the number of employees. The new rate equation becomes:

$$\begin{aligned} \text{firing rate} &= \text{distance to goal} / \text{adjustment time} \\ \text{firing rate} &= (\text{number of employees} - \text{desired number of employees}) / \\ &\quad \text{adjustment time} \\ \text{firing rate} &= (\text{number of employees} - 0) / \text{adjustment time} \\ \text{firing rate} &= \text{number of employees} / \text{adjustment time} \end{aligned}$$

This last equation uses the simpler structure of examples 1 and 2.

3. The Generic Structure

Now examine the generic structure of negative feedback systems used in all 3 examples. First, a model of the generic structure will be presented. All 3 examples can be modeled using the general form of the generic structure. Then, the model equations for both cases — using a draining fraction or using a time constant — will be examined. Lastly, the characteristic behaviors of the model will be discussed.

3.1 Model Diagram

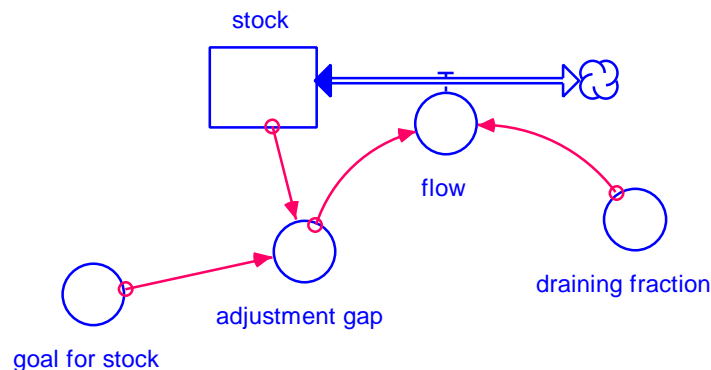


Figure 5. Generic Model

Figure 5 shows the generic structure of a negative feedback loop. This model of the generic structure can model examples 1, 2, and 3 as well as similar systems.

3.2 Model Equations

The equations for the generic structure are

$$\text{stock}(t) = \text{stock}(t - dt) + (- \text{flow}) * dt$$

DOCUMENT: This is the stock of the system. It corresponds to the amount of radioactive compound, the mule population, or the number of employees of a firm in the examples above respectively.

UNIT: units

OUTFLOWS:

flow = adjustment gap * draining fraction

DOCUMENT: The draining fraction and the value of the gap set the outflow to the stock. It corresponds to the decay rate, death rate, and firing rate in the above examples.

UNIT: units/time

adjustment gap = stock – goal for stock

DOCUMENT: The adjustment gap is the difference between the stock and the goal for the stock. In the radioactive and population examples it is equal to the difference between the stock and the implicit goal of zero, or simply the value of the stock. The adjustment gap also corresponds to the distance to goal in the employee example.

UNIT: units

draining fraction = *a constant*

DOCUMENT: The draining fraction is the fraction of the gap (equal to the stock when the goal is zero) that is closed each time period. The draining fraction corresponds to the decay fraction and the death fraction in the examples above.

UNIT: 1/time

goal for stock = *a constant*

DOCUMENT: This is the goal for the stock. The goal equals zero in the radioactive compound and population systems, and corresponds to the desired number of employees in example 3.

UNIT: units

Note: If we had a time constant instead of a draining fraction, the equation for the flow and the time constant would be

flow = adjustment gap/time constant

UNIT: units/time

time constant = *a constant*

DOCUMENT: This is the time constant. It represents the adjustment time for the stock.

UNIT: time

From the comparison of the two possible equations for the rate, we notice that the multiplier in the rate equation is given by²

multiplier in the rate equation ? draining fraction ? $\frac{1}{\text{time constant}}$

²For a more in depth explanation of time constants see the paper Beginner Modeling Exercises Section 3: Mental Simulations of Negative Feedback by Helen Zhu. (D-4536)

3.3 Model Behavior

The characteristic feature of exponential decay is its constant halving time which is the time for the gap to be cut in half. Because the draining fraction is constant at 0.2, the halving time remains constant for the entire simulation of the model. In Figure 6, for example, the initial stock is 100 and the goal is 50, making the gap equal to 50. It takes about 3.5 years for the gap to be cut in half to 25 (stock = 75) and another 3.5 years for the gap to be cut in half again to 12.5 (stock = 62.5)!

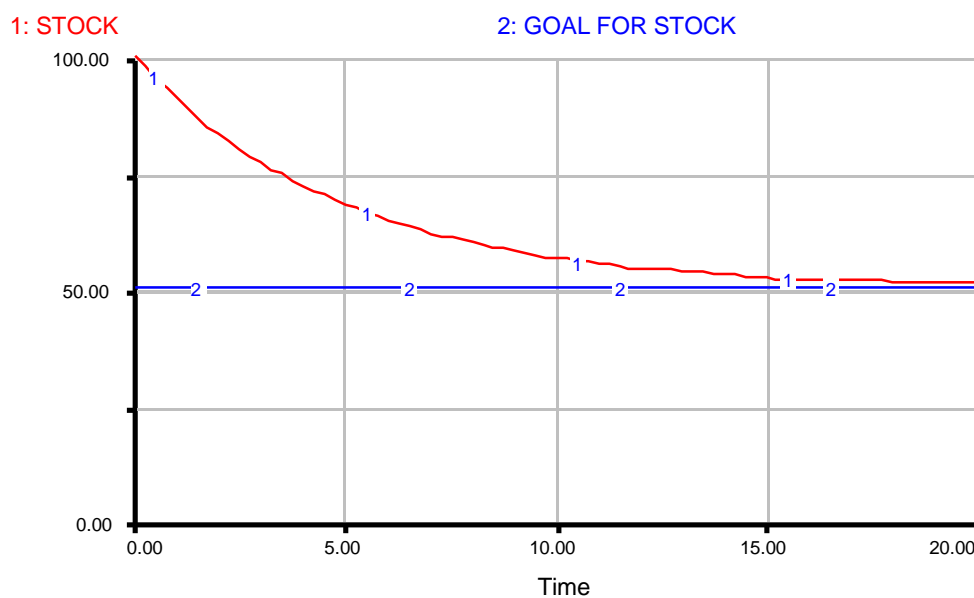


Figure 6. Results of Simulation

4. Behaviors produced by the generic structure

The behavior produced by this structure will vary, depending on the values of three parameters: the initial value of the stock, the goal, and the draining fraction.

4.1 Changing the initial value of the stock

This section explores the effect of varying the initial stock value. In our generic model, the stock has initial values of -8000, -4000, 0, 4000, and 8000 for runs 1 through 5 respectively. The goal is constant and zero, the draining fraction at 0.2.

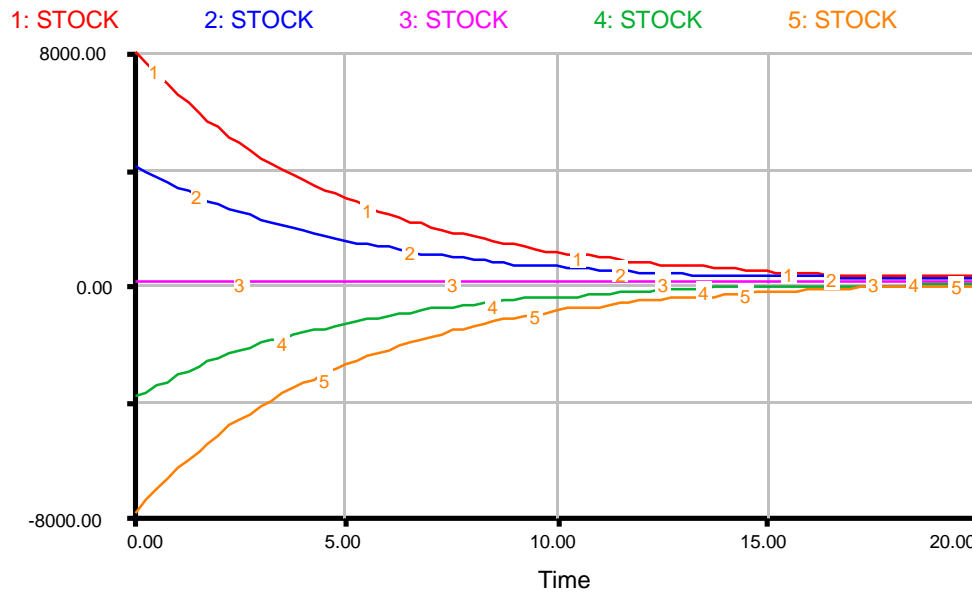


Figure 7. Simulation for different initial values of the stock

Figure 7 shows that the stock will always asymptotically approach its goal (in this case equal to zero) whatever its initial value is. In 5 halving times, the stocks are all about 97% of the way to their goal of zero.

We can clearly see that a negative feedback loop creates goal-seeking behavior. The stock will always asymptotically try to reach the goal to be in a state of stable equilibrium. The generic structure of a first-order negative feedback loop can exhibit three types of behavior: asymptotic (exponential) decay to equilibrium, steady state in equilibrium, and asymptotic growth to equilibrium.

4.2 Changing the value of the draining fraction

Changing the value of the draining fraction accelerates or retards the exponential decay of a system. To study this effect we will vary the draining fraction while keeping the initial value of the stock constant at 8000 and the goal set to zero. The draining fraction has values of 0, 0.1, 0.2, 0.3, and 0.4 for runs 1 through 5 respectively. The change of behavior of the stock due to varying the draining fraction is shown in Figure 8 below.

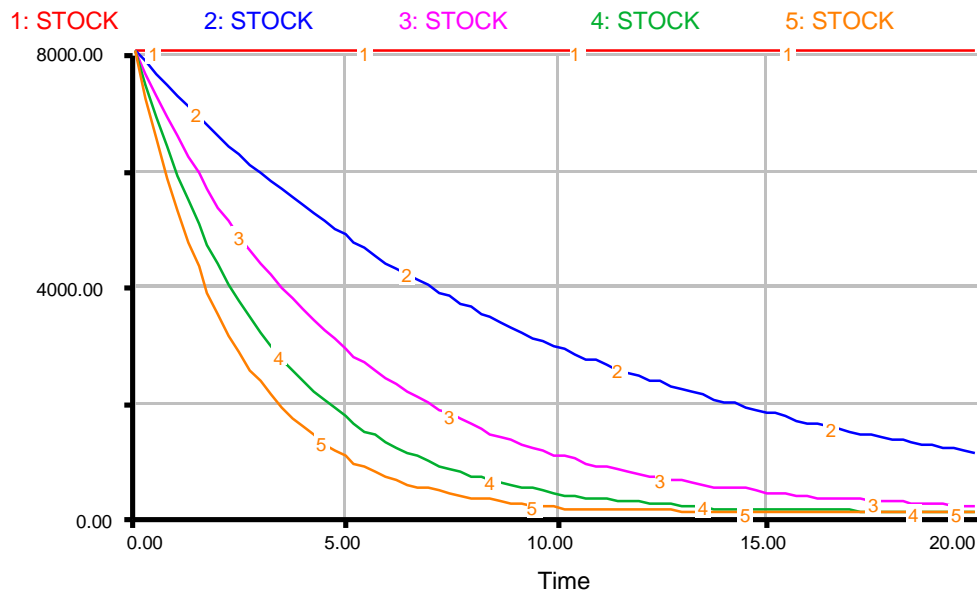


Figure 8. Simulation for different values of the draining fraction

Notice that when the draining fraction is equal to zero, the original level of the stock does not change. This is because the flow is equal to the draining fraction times the level. Zero multiplied by the stock creates a flow of zero. Also, the greater the value of the draining fraction, the faster the stock approaches equilibrium. A larger draining fraction accelerates the exponential decay. An examination of the halving time equation for different values of the time constant³ can quantitatively verify that acceleration. A draining fraction of 0.1 corresponds to a halving time of 7 time units. A draining fraction of 0.4 corresponds to a halving time of only 1.75 time units. (Note: For a negative initial value of the stock, the effect of the draining fraction on the asymptotic growth rate to the goal is similar. In that case, the stock grows asymptotically. The larger the draining fraction, the faster the stock grows.)

³ Halving time = $0.7 \times \text{time constant} = 0.7/\text{draining fraction}$. For a more in-depth explanation see Zhu, Helen. Beginner Modeling Exercises 3: Mental Simulations of Negative Feedback (D-4536). January 1996, MIT System Dynamics in Education Project

4.3 Changing the value of the goal

Changing the goal for the stock also creates interesting behaviors. We are again keeping the initial stock at 8000 and the draining fraction equal to 0.2. Values of the goal are 8000, 6000, 4000, 2000, and 0 for runs 1 through 5. Figure 9 shows the simulation for different values of the goal. Though the stock never actually reaches the goal, after about 5 halving times the stock is 97% of the way to the goal. All the different runs have the same halving times and traverse this percentage of the gap at the same time.

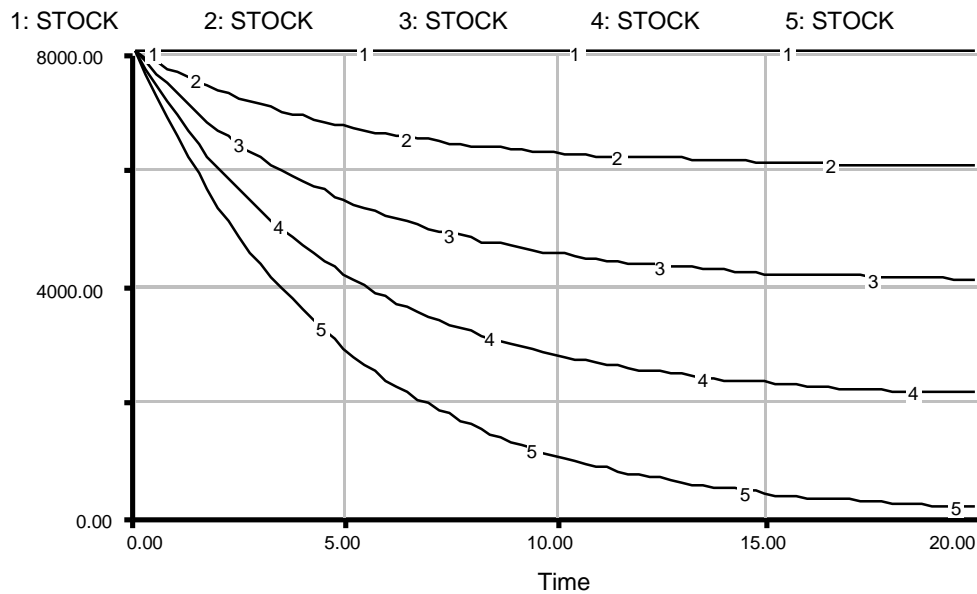


Figure 9. Simulation for different values of the goal for the stock

5. Summary of important characteristics

Structure:

The loop is a negative feedback loop if the flow is specified as an outflow in the model and the draining fraction is positive (or if the draining fraction is negative and the flow is specified as an inflow in the model).⁴

Behavior:

Figure 10 contains a summary of the behaviors that the negative feedback loop can exhibit. Although negative feedback loops are best known for their exponential decay, they do exhibit other behaviors.

The generic structure of a first-order negative loop can exhibit three types of behaviors: asymptotic decay to equilibrium, constant at equilibrium, and asymptotic growth to equilibrium. All three types of behavior are goal-seeking.

The behavior of the stock is in italics for each combination of parameter values. (assume goal = 0)		Stock		
		Negative	Zero	Positive
Draining Fraction	Zero	<i>equilibrium at neg. value</i>	<i>equilibrium at zero</i>	<i>equilibrium at pos. value</i>
	Positive	<i>asymptotic growth to equilibrium</i>	<i>equilibrium at zero</i>	<i>asymptotic decay to equilibrium</i>

Figure 10. Summary of the behavior of a negative feedback loop

⁴ Since STELLA specifies the outflow as negative in the equations of the stock, we will assume the draining fraction must be positive. Therefore, the simplest negative feedback loop requires a positive draining fraction for the outflow of the stock.

To sum up, asymptotic growth and decay require an initial value of the stock other than zero and have a constant halving time. The rate at which the decay occurs increases with the value of the draining fraction. If either the stock or the draining fraction is zero, the outflow is also zero and equilibrium exists.

Look over Figure 10 and all the graphs of simulation included in the paper. When you feel confident about your understanding of the behavior, you should go on to the exercises in the next section.

6. Using Insights gained from the generic structure

We have seen many examples of different systems, with both implicit and explicit goals with the same basic structure. Now, we apply the insight we gained from understanding the generic structure and its behavior to understand the behavior of other systems.

To do the exercises, you need not simulate the models; hand computation should suffice. However, after answering the questions, we encourage you to build and experiment with the models.

6.1 Exercise 1: Radioactive Decay

In section 2.1 we introduced the simple structure of radioactive decay. Carbon-14 decays into the stable element Nitrogen with a half-life of 5700 years.

1. Using the above information, draw the stock and flow diagram of the decay of Carbon-14.
2. What is the value of the time constant? the draining fraction?

6.2 Exercise 2: Package Deliveries

Below is a simple negative feedback system.

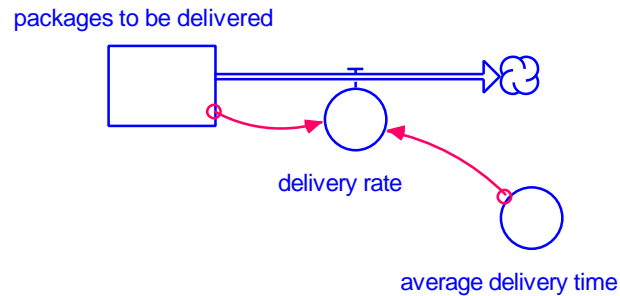


Figure 11. Package Deliveries

Jay runs a delivery service. His average delivery time is 2 days. A computer company, Nanosoft, just sent him 500 packages **to deliver** immediately. The more packages Jay has to deliver, the more pressure he is under to deliver them.

1. What is the time constant and halving time? Give their units. What are the units of the delivery rate?
2. What is the goal of the stock of this system?
3. How much time will it take for 50% of the packages to be delivered? 75% of the packages?

6.3 Exercise 3: Company Downsizing

Nanosoft has been losing money due to the competition of rival Picosoft. Managers at Nanosoft decided that by cutting the number of employees from 20,000 to 12,000 Nanosoft could save money and still maintain production levels. The total time allotted for the downsizing is 7 years. (Since it takes 5 halving times to reach 97% of the goal—close enough to consider the downsizing complete—the halving time is 1.4 years long and the time constant is 2 years.)

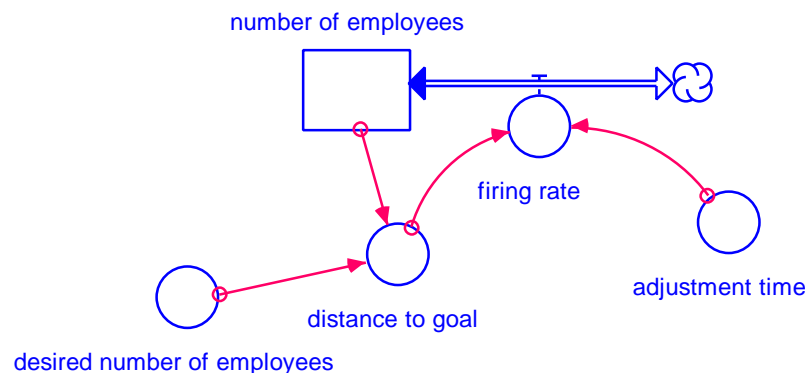


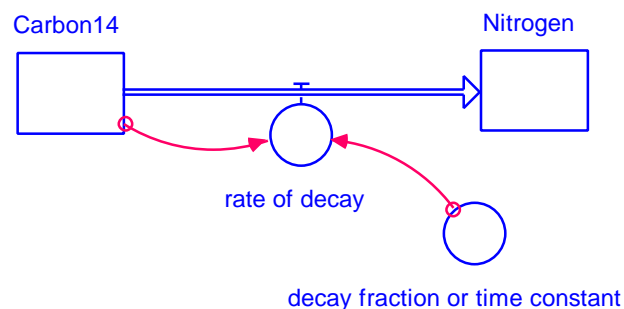
Figure 12. Company Downsizing

1. What is the draining fraction and the adjustment time? What is the halving time? Give their units.
2. In 3 years, what is the approximate number of employees working at Nanosoft?
3. Nanosoft decided they want exactly 16,000 employees working at the firm in 4 years. How can Nanosoft get this result by changing the adjustment time while keeping the desired number of employees at 12,000?

7 Solutions to exercises

7.1 Solution to 6.1: Radioactive Decay

1.



We have a set amount of Carbon-14 that does not grow, thus our stock has no inflows and one outflow for decay. Carbon-14 decays into Nitrogen, so the outflow from the Carbon stock is the inflow to the Nitrogen stock.

2. The halving time of Carbon 14 is 5700 years.

The time constant τ halving time / 0.7 τ 5700 / 0.7 τ 8142.86 years

The draining fraction = $1/\text{time constant}$ = $1/8142.86$ τ 0.000123

(NOTE to advanced modelers: The reason we can model the system in such a way, is because the unit of the stock is atoms. The number of atoms in the system is conserved. **Fifteen** atoms of Carbon 14 will decay into 15 atoms of Nitrogen. Had we done the problem with the units of the stock being grams, the system would not be valid. The mass

would not be conserved since the Carbon-14 is losing a beta particle (mass) to the atmosphere which is outside of the system as we modeled it).

7.2 Solution to 6.2: Package Deliveries Solution

1. The time constant = 2 days. The halving time $\approx 0.7 \times \text{time constant} \approx (2)(0.7) \approx 1.4$ days

The units for the delivery rate are packages/day.

2. The goal for the system is implicitly zero.

3. For 50% (1 halving time) of the packages to be delivered, Jay takes 1.4 days. For 75% (2 halving times) of the packages to be delivered, Jay takes 2.8 days.

7.3 Solution to 6.3: Company Downsizing

1. The time constant = 2 years, which is the adjustment time. The draining fraction = $1/\text{time constant} = 0.5$.

The halving time $\approx 0.7 \times \text{time constant} = (0.7)(2) = 1.4$ years.

2. In 3 years about 2 halving times go by. In two halving times, about 75% of the initial gap is filled. 75% of 8000 is 6000, therefore $(20,000 - 6,000) = 14,000$ employees are still working at Nanosoft.

3. In 4 years, Nanosoft wants 4,000 workers fired. This is 50% of the gap and should take 1 halving time. If 1 halving time = 4 years, the adjustment time $\approx \text{halving time} / 0.7 \approx 4/0.7 = 5.7$ years. Nanosoft should increase the adjustment time to 5.7 years.

8 Appendix

Model Documentation for Sections 2.1 to 2.3

Section 2.1: Radioactive Decay Model Documentation

radioactive compound(t) = radioactive compound(t – dt) + (– rate of decay) * dt

INIT radioactive compound = *a constant*

DOCUMENT: This is the amount of radioactive compound present.

UNIT: atoms

OUTFLOWS:

rate of decay = radioactive compound * decay fraction

DOCUMENT: This is the amount of radioactive compound that turns into a stable compound per year.

UNIT: atoms/year

decay fraction = *a constant*

DOCUMENT: This is the draining fraction of the negative feedback system.

UNIT: 1/time

Section 2.2: Population-Death System Model Documentation

mule population(t) = mule population(t - dt) + (- death rate) * dt

INIT mule_population = *a constant*

DOCUMENT: This is the number of live mules in the system

UNIT: mules

OUTFLOWS:

death rate = mule population * death fraction

DOCUMENT: This is the number of mules that die per year.

UNIT: mule/year

death fraction = *a constant*

DOCUMENT: This is the draining fraction of the negative feedback system.

UNIT: 1/years

Section 2.3: Company Downsizing Model Documentation

number of employees(t) = number of employees(t – dt) + (– firing rate) * dt

INIT number of employees = *a constant*

DOCUMENT: This is the number of employee who work for the company.

UNIT: employee

OUTFLOWS:

firing rate = distance to goal/adjustment time

DOCUMENT: This is the number of employees who are fired per week.

UNIT: employee/week

adjustment time = *a constant*

DOCUMENT: This is the time constant of the system.

UNIT: week

desired number of employees = *a constant*

DOCUMENT: This is the goal for the negative feedback system.

UNIT: employee

distance to goal = number of employees – desired number of employees

DOCUMENT: This is the adjustment gap for the negative feedback system.

UNIT: employee

Vensim Examples: Generic Structures: First-Order Negative Feedback

By Aaron Diamond
October 2001

2.1 Example 1: Radioactive Decay

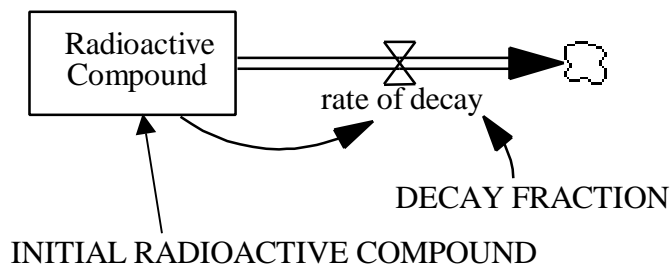


Figure 13: Vensim Equivalent of Figure 2: Radioactive Decay

Documentation for Radioactive Decay model

- (1) DECAY FRACTION=a constant
Units: 1/year
This is the draining fraction of the negative feedback system.
- (2) FINAL TIME = 100
Units: Year
The final time for the simulation.
- (3) INITIAL RADIOACTIVE COMPOUND=a constant
Units: atoms
- (4) INITIAL TIME = 0
Units: Year
The initial time for the simulation.
- (5) Radioactive Compound= INTEG (-rate of decay, INITIAL RADIOACTIVE COMPOUND)
Units: atoms
This is the amount of radioactive compound present.

- (6) $\text{rate of decay} = \text{Radioactive Compound} * \text{DECAY FRACTION}$
Units: atoms/year
This is the amount of radioactive compound that turns into a stable compound per year.
- (7) $\text{SAVEPER} = \text{TIME STEP}$
Units: Month
The frequency with which output is stored.
- (8) $\text{TIME STEP} = .0625$
Units: Year
The time step for the simulation.

2.2 Example 2: Population-Death system

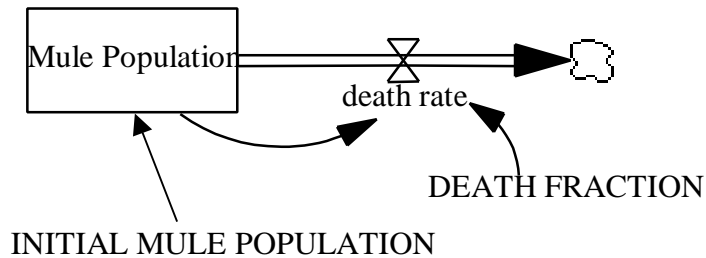


Figure 14: Vensim Equivalent of Figure 3: Population-Death system

Documentation for Population-Death model

- (1) DEATH FRACTION=a constant
Units: 1/year
This is the draining fraction of the negative feedback system.
- (2) death rate=Mule Population*DEATH FRACTION
Units: mules/year
This is the number of mules that die per year.
- (3) FINAL TIME = 100
Units: year
The final time for the simulation.
- (4) INITIAL MULE POPULATION
Units: mules
- (5) INITIAL TIME = 0
Units: year
The initial time for the simulation.
- (6) Mule Population= INTEG (-death rate, INITIAL MULE POPULATION)
Units: mules
This is the number of live mules in the system.
- (7) SAVEPER = TIME STEP
Units: year
The frequency with which output is stored.
- (8) TIME STEP = .0625
Units: year

The time step for the simulation.

2.3 Example 3: Company Downsizing System

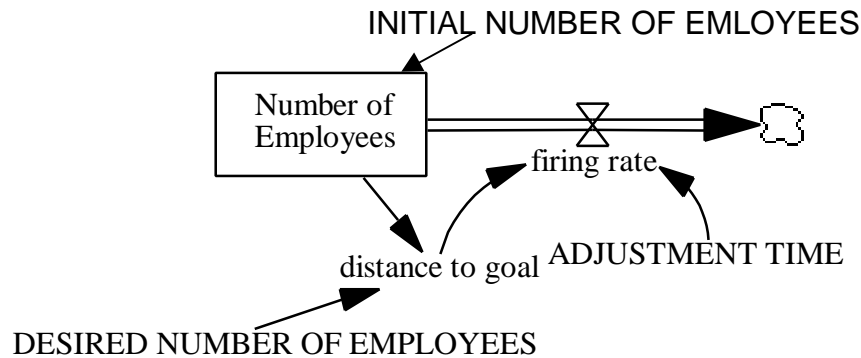


Figure 15: Vensim Equivalent of Figure 4: Company Downsizing System

Documentation for Company Downsizing model

- (01) **ADJUSTMENT TIME**=a constant
Units: week
This is the draining fraction of the negative feedback system.
- (02) **DESIRED NUMBER OF EMPLOYEES**=a constant
Units: employee
This is the goal for the negative feedback system.
- (03) **distance to goal**=Number of Employees-DESIRED NUMBER OF EMPLOYEES
Units: employee
This is the adjustment gap for the negative feedback system.
- (04) **FINAL TIME** = 20
Units: week
The final time for the simulation.
- (05) **firing rate**=distance to goal/ADJUSTMENT TIME
Units: employee/week
This is the number of employees who are fired per week.
- (06) **INITIAL NUMBER OF EMPLOYEES**=a constant
Units: employee
- (07) **INITIAL TIME** = 0
Units: week

- The initial time for the simulation.
- (08) Number of Employees= INTEG (-firing rate, INITIAL NUMBER OF EMPLOYEES)
Units: employee
This is the number of employees who work for the company.
- (09) SAVEPER = TIME STEP
Units: week
The frequency with which output is stored.
- (10) TIME STEP = 0.0625
Units: week
The time step for the simulation.

3.1 Model Diagram

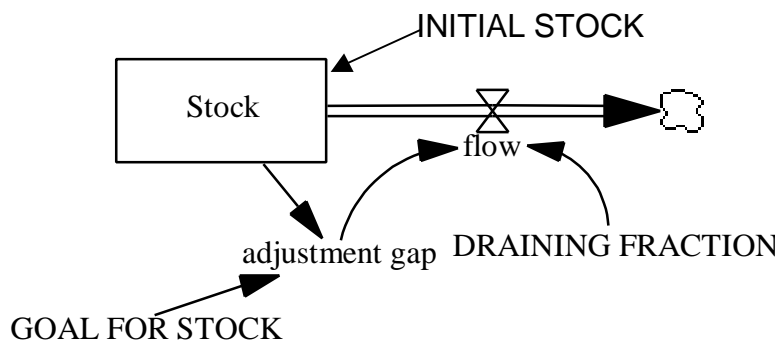


Figure 16: Vensim Equivalent of Figure 5: Generic Model

Documentation for the Generic Model

- (01) $\text{adjustment gap} = \text{Stock} - \text{GOAL FOR STOCK}$
 Units: units
 The adjustment gap is the difference between the stock and the goal for the stock. In the radioactive and population examples it is equal to the difference between the stock and the implicit goal of zero, or simply the value of the stock. The adjustment gap also corresponds to the distance to goal in the employee example.

- (02) $\text{DRAINING FRACTION} = \text{a constant}$
 Units: 1/time
 The draining fraction is the fraction of the gap (equal to the stock when the goal is zero) that is closed each time period. The draining fraction corresponds to the decay fraction and the death fraction in the examples above.

- (03) $\text{FINAL TIME} = 100$
 Units: time
 The final time for the simulation.

- (04) $\text{flow} = \text{adjustment gap} * \text{DRAINING FRACTION}$
 Units: units/time
 The draining fraction and the value for the gap set the outflow to the stock. It corresponds to the decay rate, death rate, and firing rate in the above examples.

- (05) GOAL FOR STOCK=a constant
Units: units
This is the goal for the stock. The goal equals zero in the radioactive compound and population systems, and corresponds to the desired number of employees in example 3.
- (06) INITIAL STOCK= a constant
Units: units
- (07) INITIAL TIME = 0
Units: time
The initial time for the simulation.
- (08) SAVEPER = TIME STEP
Units: time
The frequency with which output is stored.
- (09) Stock= INTEG (-flow, INITIAL STOCK)
Units: units
This is the stock of the system. It corresponds to the amount of radioactive compound, the mule population, or the number of employees of a firm in the examples above respectively.
- (10) TIME STEP = 0.0625
Units: time
The time step for the simulation.

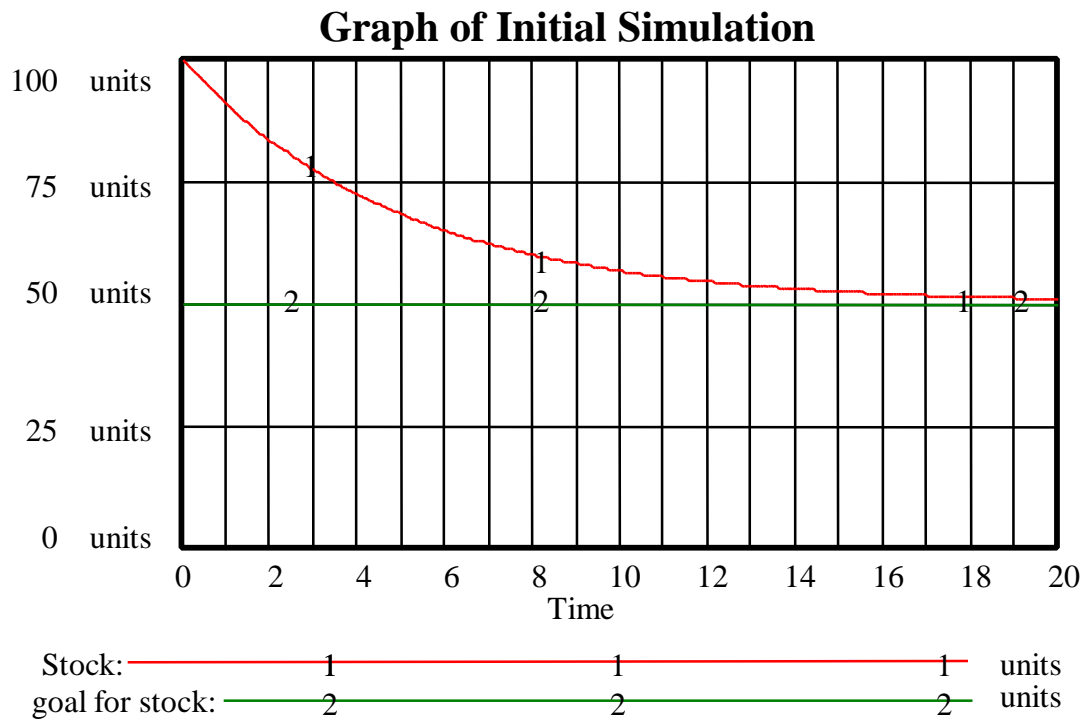


Figure 17: Vensim Equivalent of Figure 6: Results of Simulation

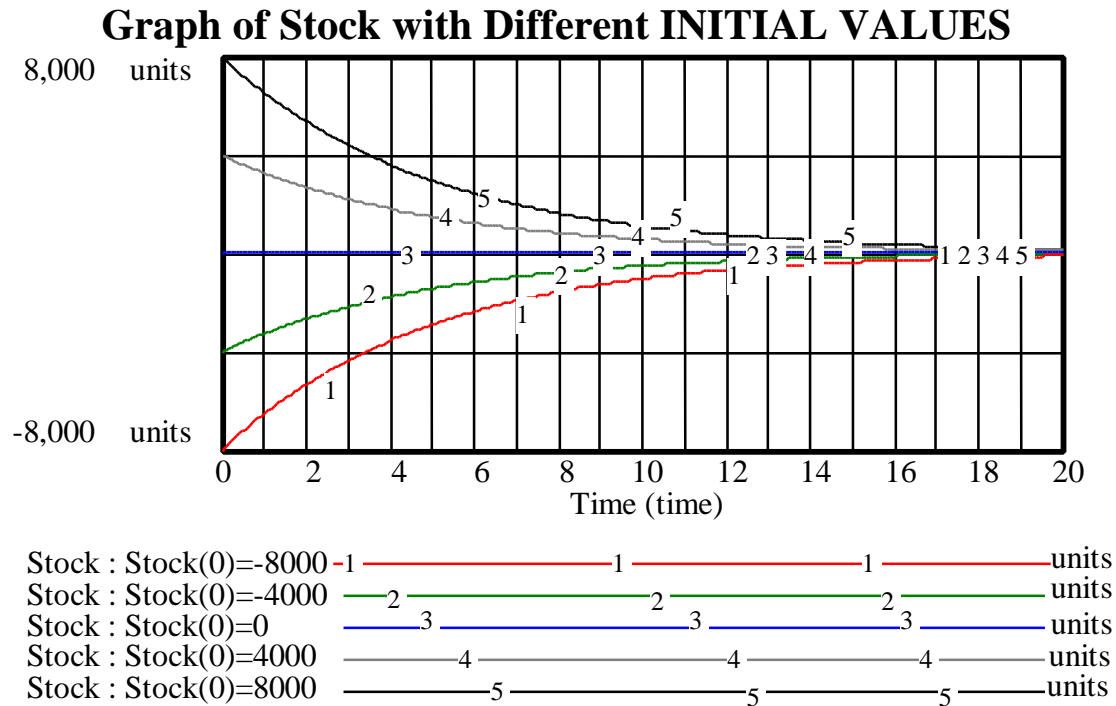


Figure18: Vensim Equivalent of Figure 7: Simulation for different INITIAL VALUES of the Stock

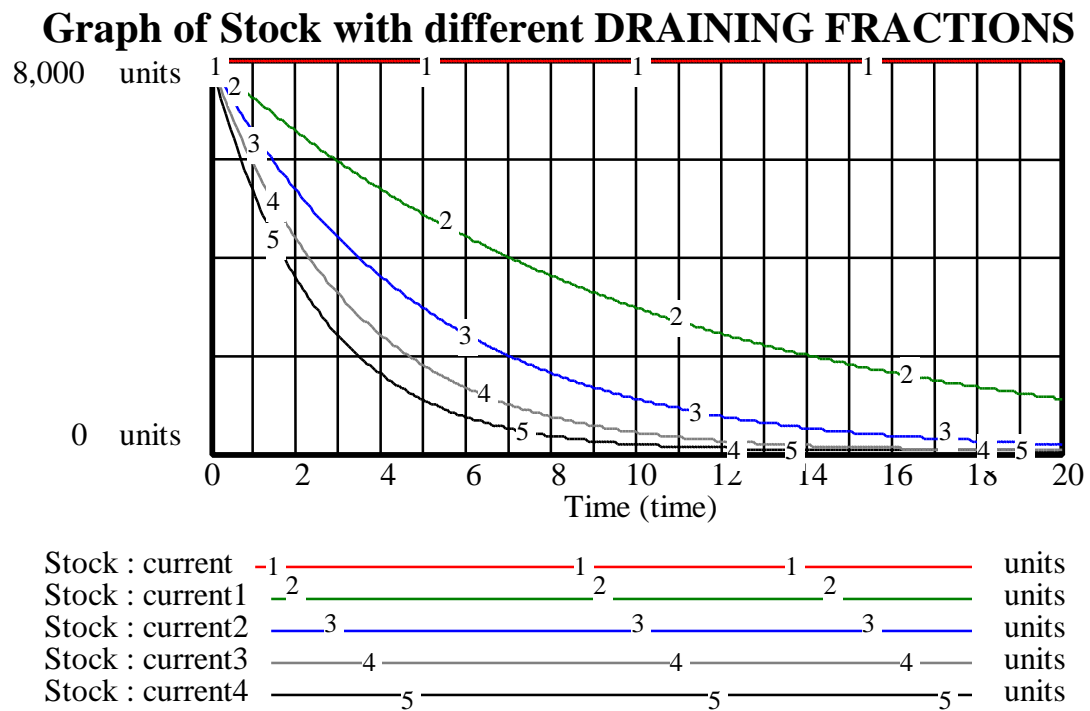


Figure 19: Vensim Equivalent of Figure 8: Simulation for different values of the DRAINING FRACTION

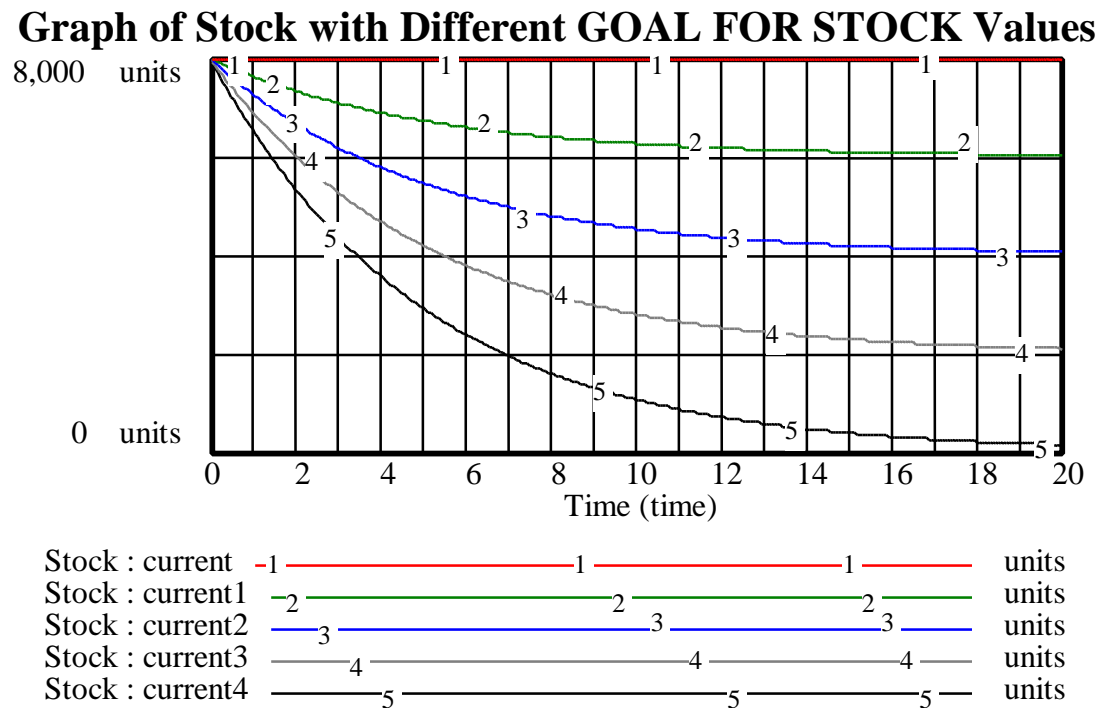


Figure 20: Vensim Equivalent of Figure 9: Simulation for different values of the GOAL
FOR STOCK