Name: Chia Wen CHENG

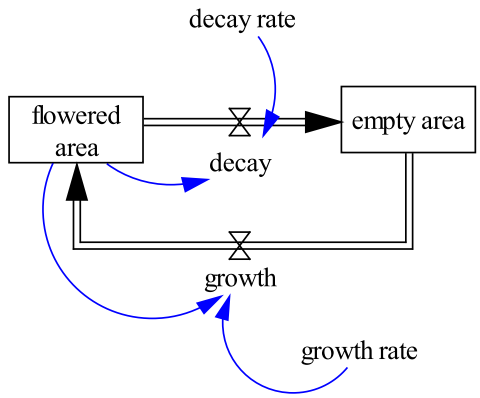
EAS 550/STRATEGY 566: Systems Thinking for Sustainable Development and Enterprise

Lab 6 Modeling S-shaped growth

In this lab you will explore S-shaped growth using three different system models.

1. Model the growth flowered area

Flowers grow and decay on a piece of land as described below:



Initial condition:

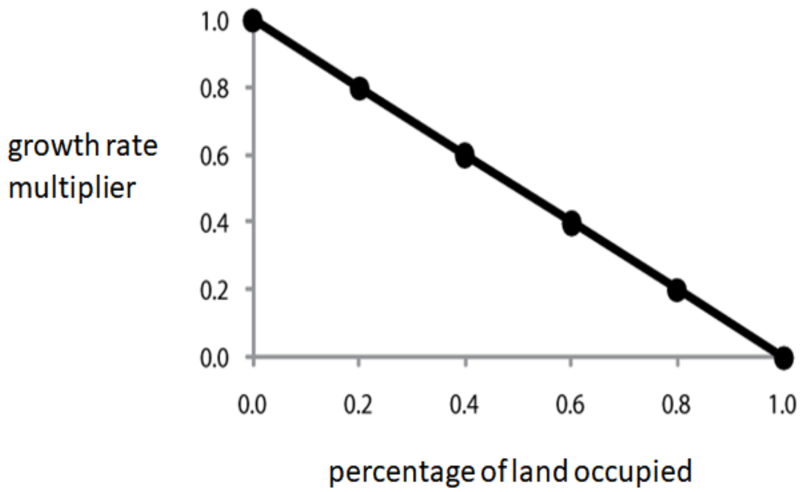
- Total area = 1000 acres
- Initial value of flowered area = 10 acres
- Initial value of empty area = 990 acres
- Decay rate = 20%/year
- Growth rate = 100%/year

In this initial condition, the growth of flowers is not restricted by space, and hence the flowers can spread with minimal limitations. In this instance, "Growth rate" is also referred to as "Intrinsic Growth Rate".

Flowered area net growth rate = growth rate – decay rate = 80%/year

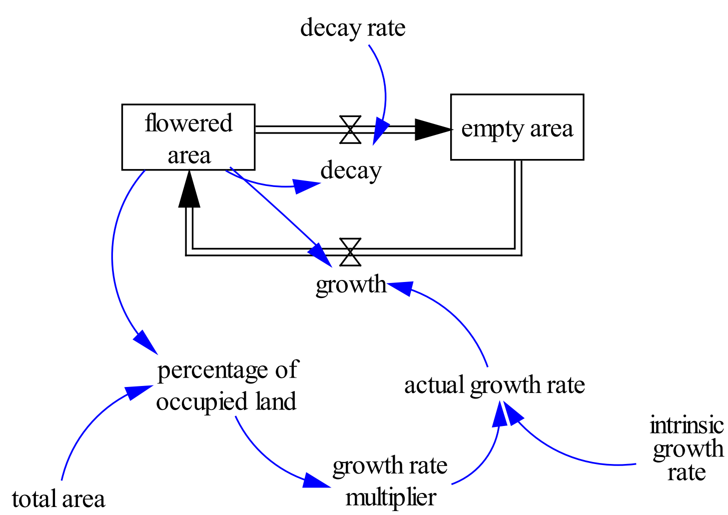
Outside of this initial condition, when the flowers begin to occupy more and more empty area, less empty area is available for germination. The "actual growth rate" is less than the intrinsic growth rate and is therefore a function of both a "growth rate multiplier", which lowers the actual growth rate over time, and the intrinsic growth rate. The growth rate multiplier will be increasingly constrained by the availability of land. Let's assume the flower growth rate multiplier is reduced in a linear manner.

Name: Chia Wen CHENG



Given the above information, construct the stock and flow diagram shown below to reflect the changes in growth rate:

- Growth = flowered area × actual growth rate
- Actual growth rate = intrinsic growth rate × growth rate multiplier
- Growth rate multiplier = lookup (percentage of occupied land)
- Percentage of occupied land = flowered area/total area
- Decay = decay rate × flowered area

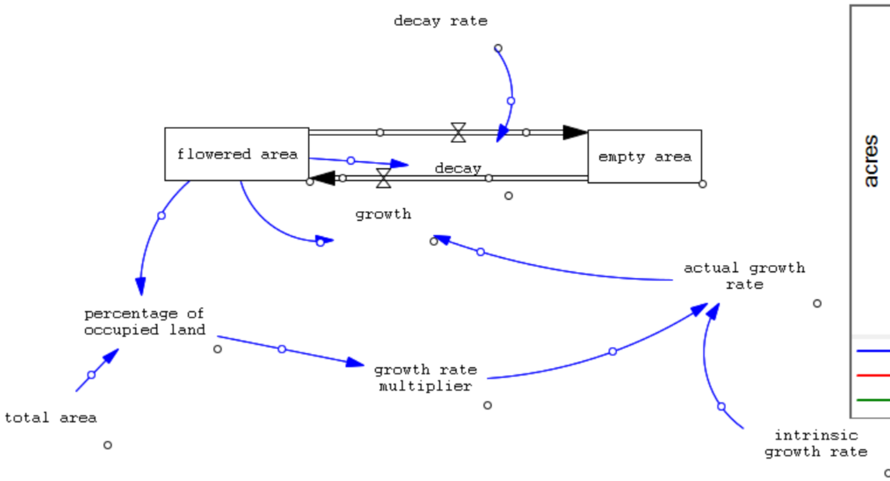


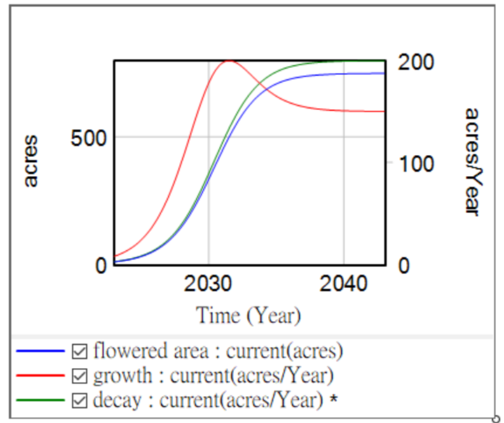
Process:

- Simulate the model for 20 years with a time step of 0.125 years (Euler integration).
- Create a graph of flowered area over time in **Control Panel**, then click **IO Object** tool, and then click on the empty area of your working space.
- In the popped-up window, select **Output Custom Graph** under **Object Type**, and then in the box located at the bottom of the window, select the name of your graph. This graph will now show up in your working space. You can adjust its size and location. After each simulation, the graph will be adjusted to show the results of your latest run.

Name: Chia Wen CHENG

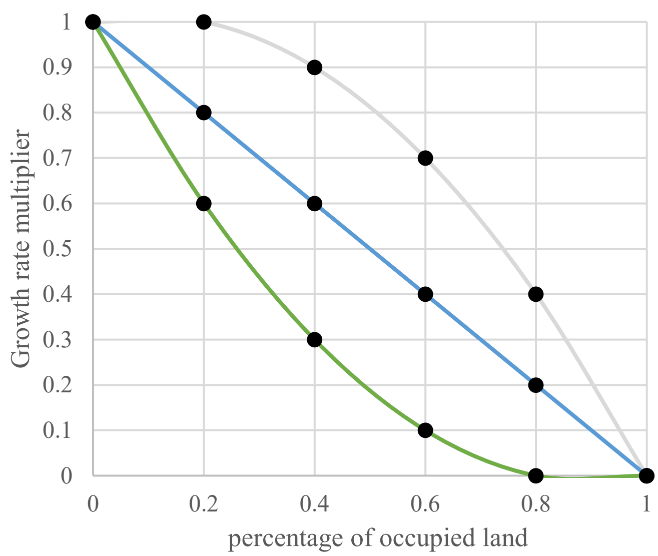
1.1 Equilibrium: Create a graph showing the results of flowered area, growth, and decay over time. Does the system reach equilibrium eventually? If yes, when does the system reach equilibrium, and how large is the flowered area at equilibrium? Insert your answers and graph below.



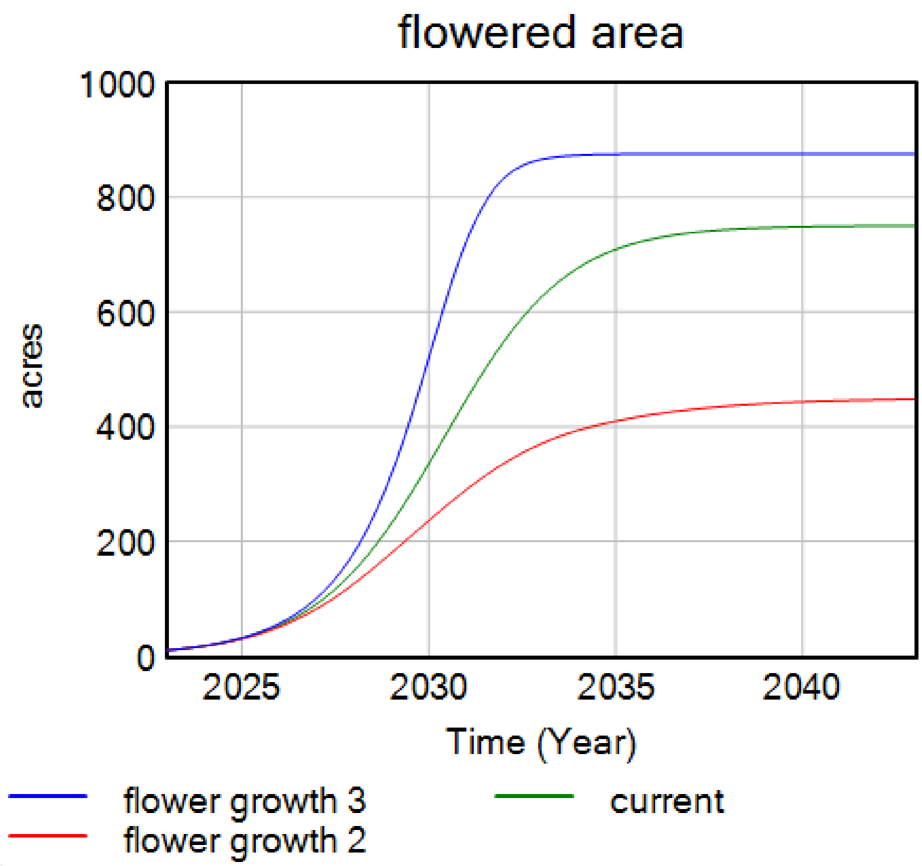


The system reach equilibrium eventually. The flowered area started reach its equilibrium in year 2038 and is 749.702 acres at equilibrium.

1.2 Change the growth multiplier: Simulate the non-linear correlations between actual growth rate and the percentage of occupied land as provided below. What will be the new changing trends of the flowered area? Provide a comparable time graph showing the results of flowered area for the three runs. What are the differences between these three results and what do you think causes the difference?



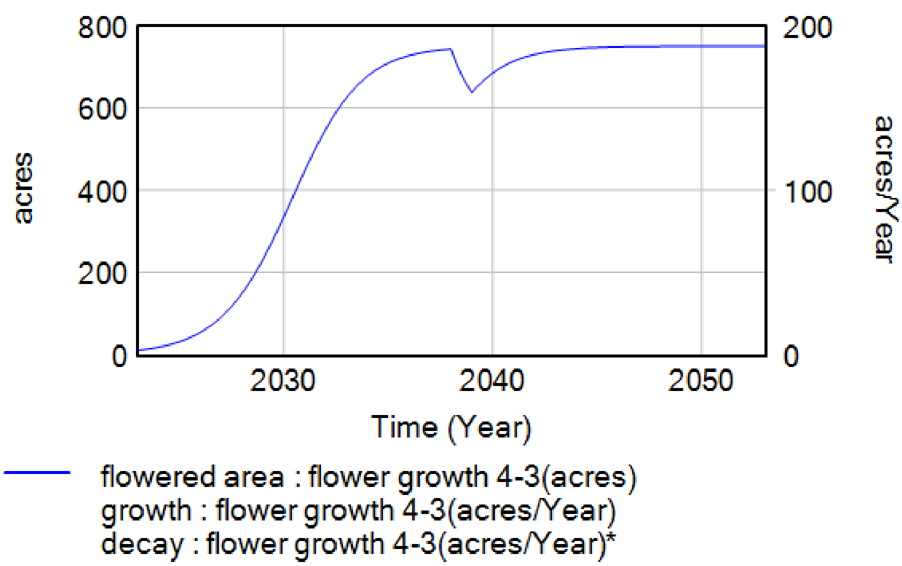
Name: Chia Wen CHENG



The three trends all reach their equilibriums approaching the end of our simulation years. However, with a non-linear relationship between the percentage of occupied land and the growth rate multiplier that has greater absolute values of slopes in the beginning and smaller ones in the end, which is the green line in the three relationship chart, the flowered area is the smallest at the end of our simulation. With a non-linear relationship between the same variables that has smaller absolute values in the beginning and greater ones in the end, which represents the white line, the flowered area is the largest at the end of our simulation. Different decreasing rates of the growth rate multiplier cause differences in flowered area throughout the simulation, while decay holds constant.

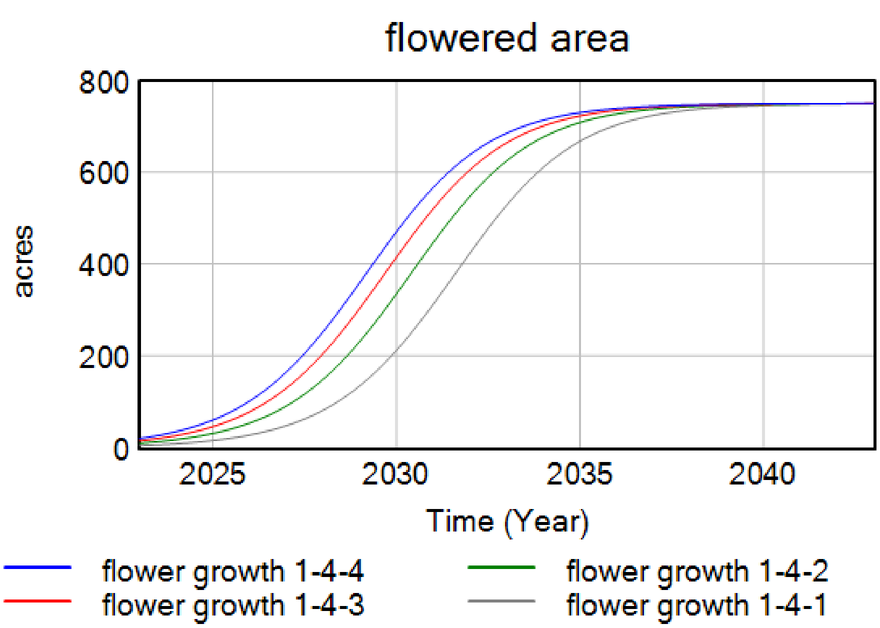
1.3 Stability of the flower equilibrium: Reset the relationship between growth rate multiplier and percentage of land occupied to be linear. Introduce a one-year disturbance to remove 20% of the flowers in the 15th year of the simulation (don't forget to make sure the definition of your stock accurately reflects the addition of this flow). Run the model for 30 years to see whether the equilibrium is stable. Provide your result below.

Name: Chia Wen CHENG



The flowered area reaches an equilibrium at 749.978 acres.

1.4 Importance of the initial conditions: Remove the disturbance flow (check to make sure your stock is correctly defined). Create a comparative time graph of the area of flowers from four simulations with different starting values for the flowered area. Set the starting values to 5, 10, 15, and 20 acres. Why do you think the four trends are different? *(Don't forget to adjust the starting values of the empty area accordingly!!)*



The four trends are different because the starting points are different but the decay and growth rates remain the same. But as time goes on, they all reach similar equilibrium at the end of our simulation at about 749 acres. The least starting flowered area simulation reaches the equilibrium the last and the largest starting flowered area simulation reaches the earliest.

Name: Chia Wen CHENG

2. Dunder Mifflin Paper Company

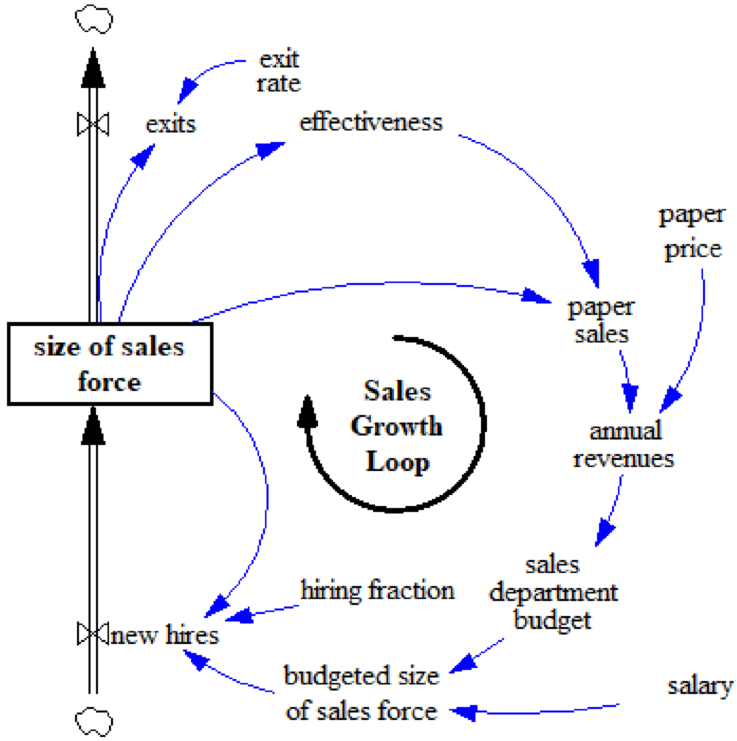
The Dunder Mifflin Paper Company has a sales force of 50 people. Each person can sell 2 boxes of paper per day for 365 days/year (sorry, no vacation). Total sales are 36,500 boxes. At $100 per box, the company's annual revenue is $3,650,000. The annual exit rate of the sales force is 20%. The company recruits new people based on the company's budget for the sales department (budgeted workforce size – current workforce), and the sales department budget is 50% of the company's annual revenues. The average annual salary of each salesperson is $25,000. Paper sales depend on the number of salespeople and their individual effectiveness. Effectiveness depends on the size of the sales force:

Size of sales force [people]	Effectiveness [boxes/(person*day)]
0	2.0
200	2.0
400	2.0
600	1.8
800	1.6
1000	0.8
1200	0.4

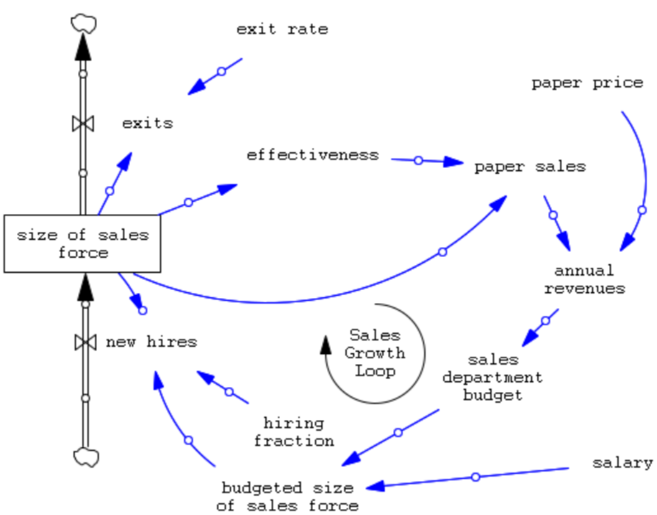
Build the stock and flow diagram (do not worry about including the "Sales Growth Loop" label):

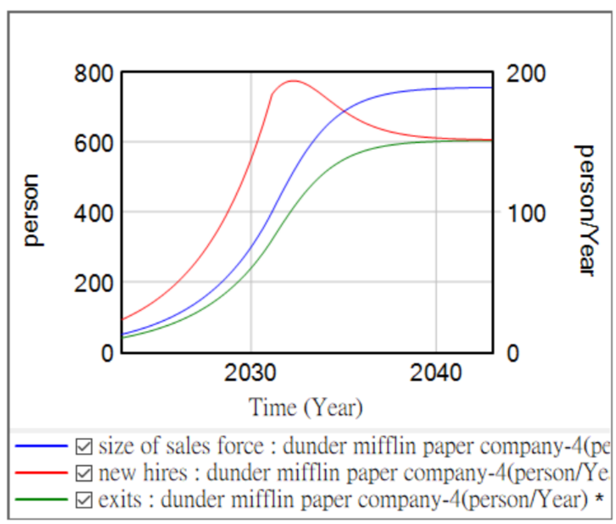
a. Start with stocks
   i. Size of sales force = new hires – exits
b. Find the variables affecting the flows, and their correlations
   i. Exits = exit rate × size of sales force
   ii. New hires = budgeted size of sales force - (size of sales force × hiring fraction)
   iii. Hiring fraction = 1/year
   iv. Budgeted size of sales force = sales department budget/salary
   v. Sales department budget = 50% × annual revenue
   vi. Annual revenue = paper sales × paper price
   vii. Paper sales = size of sales force × effectiveness × 365 days/year
   viii. Effectiveness = lookup (size of sales force)

Name: Chia Wen CHENG



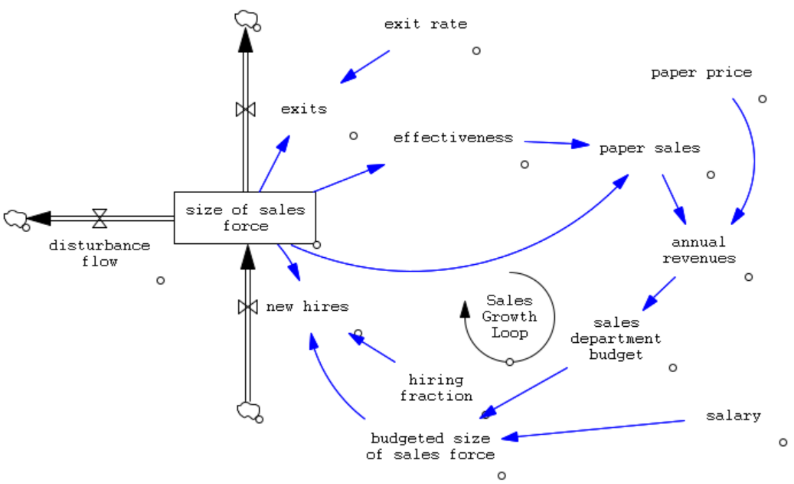
Simulate the model for 20 years with a time step of 0.125 years (Euler integration). Provide your results of size of sales force, new hires, and exits for the questions below.

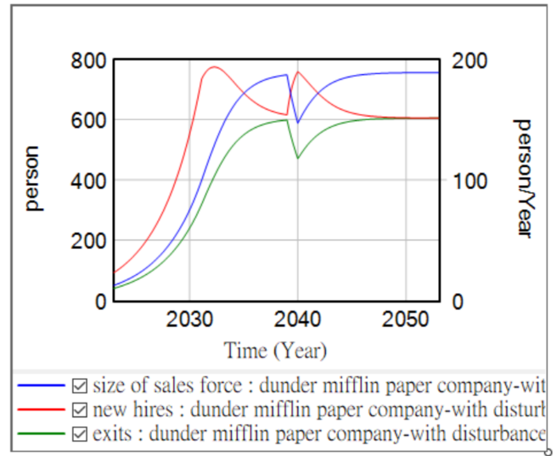




2.1 Stability of the sales model: Introduce a one year disturbance flow in the 16th year to remove 200 people from the sales force (don't forget to make sure the definition of your stock accurately reflects the addition of this flow). Run the model for 30 years to show whether the equilibrium is stable.

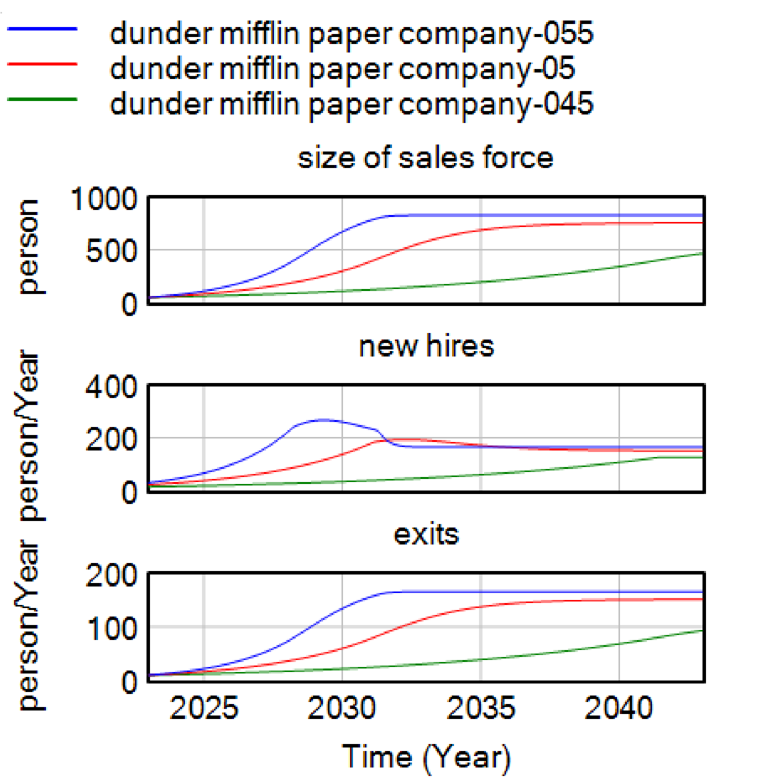
Name: Chia Wen CHENG





With the disturbance outflow, the size of sales force was decreased from 748.436 people to 587.94 people during the 16th year. However, it reaches the equilibrium at 756.034 people at the end of our 30-year simulation.

2.2 Build a bigger company: Remove the disturbance flow (check to make sure your stock is correctly defined). Use the model to learn if you can build a bigger company by devoting a larger fraction of company revenues to the sales department budget. Conduct a sensitivity analysis with the fractions of revenues allocated to the sales department set at 45%, 50%, and 55%.



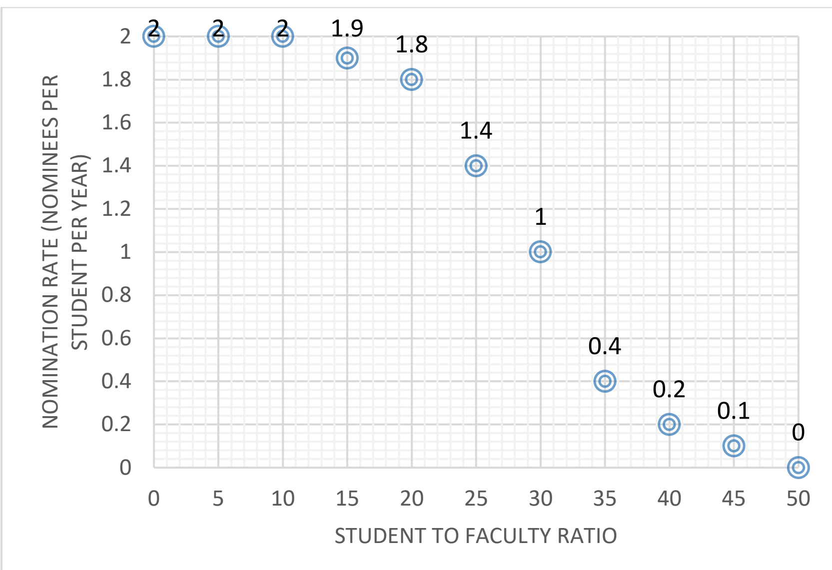
From the sensitive analysis, with a smaller fraction of company revenues to the sales department budget, the size of sales force will keep increasing by the end of our simulation, while the number of new hires gradually reaches its equilibrium. We can build a larger-

scale company with more sales force by increasing the fraction of company revenues to the sales department budget. The size of sales force will reach its equilibrium the earliest, while having the greatest amount at its equilibrium among the three different fractions.

Name: Chia Wen CHENG

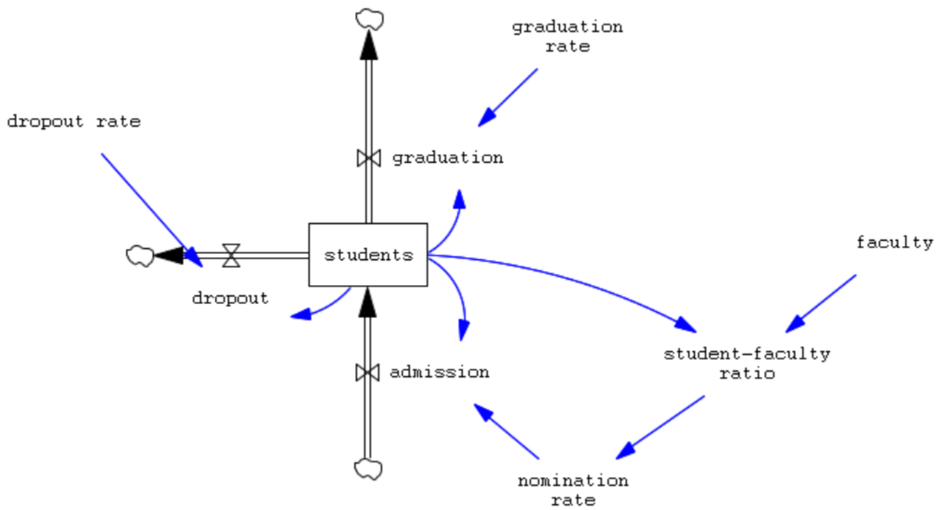
3. Growth of a private college

A private college has 200 **students** and 100 **faculty** currently (Year: 2023), so the current **student to faculty ratio** is two to one. Students normally require around 4 years to graduate, so the **graduation rate** is assumed to remain constant at 25%/yr. The outflow of **graduations** is then equal to the graduation rate × the number of students. The **dropout rate** is constant at 15%/yr, with an outflow of **dropouts** equal to the dropout rate × the number of students. A special feature of this college is that new students may only be **admitted** if they are **nominated** by an existing student. Each existing student has the right to propose two nominees per year. The existing students will fully exercise this right if they are impressed with their education. Let's assume the existing students will be impressed with their education when the student to faculty ratio is low. If the ratio should increase, however, the existing students will become less impressed, and they will be less willing to make nominations. The students' nomination rate is given by the nonlinear relationship the figure below. At ratios of 10 or less, the nomination rate will be 2 nominees per student per year. At the opposite extreme, the students' nomination rate will fall completely to zero if the student-faculty ratio climbs to 50.

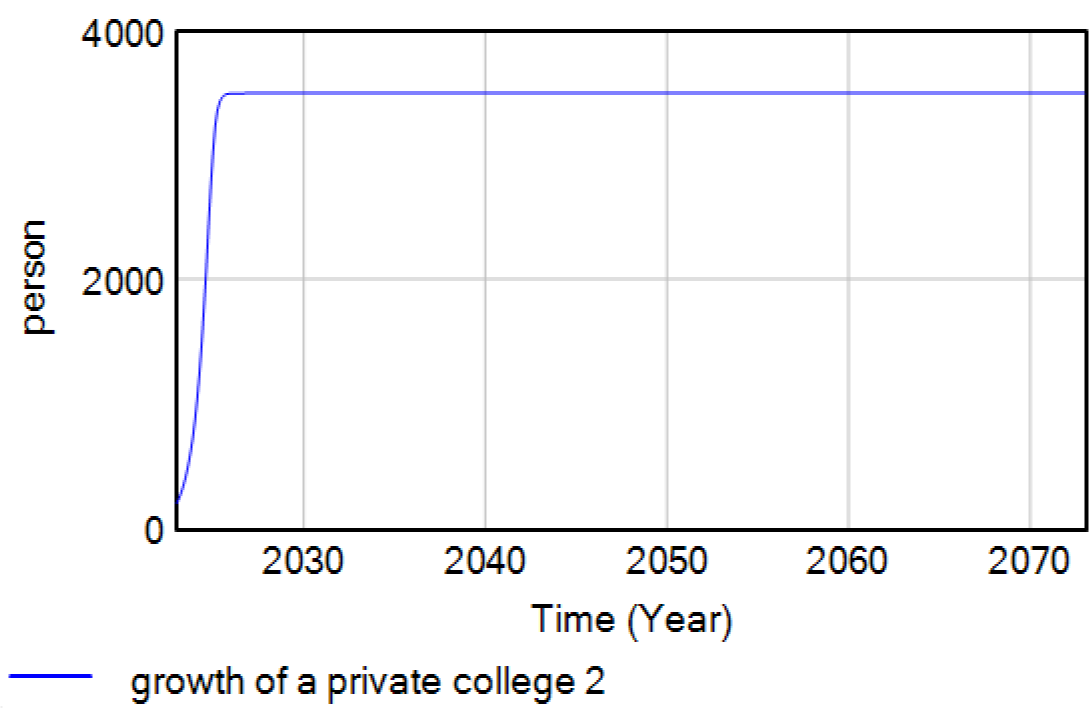


3.1 Create a stock and flow diagram to simulate the growth of students in this private college. Provide your model structure below.

Name: Chia Wen CHENG



3.2 How large will the existing student body become if the number of faculty is fixed at 100? (simulate 50 years of the model) What is the dynamic pattern of the student body and why?



The existing student body will become 3,500 people if the number of faculty is fixed to 100 people. The number of students grows rapidly at the first 3-4 years due to the high nomination rates. It starts slowing down since year 2024.12 when the number of existing students exceeds 1,000, and slows down even more since year 2024.62 when the number of existing students exceeds 2,000. However, it reaches its equilibrium quickly in year 2027,

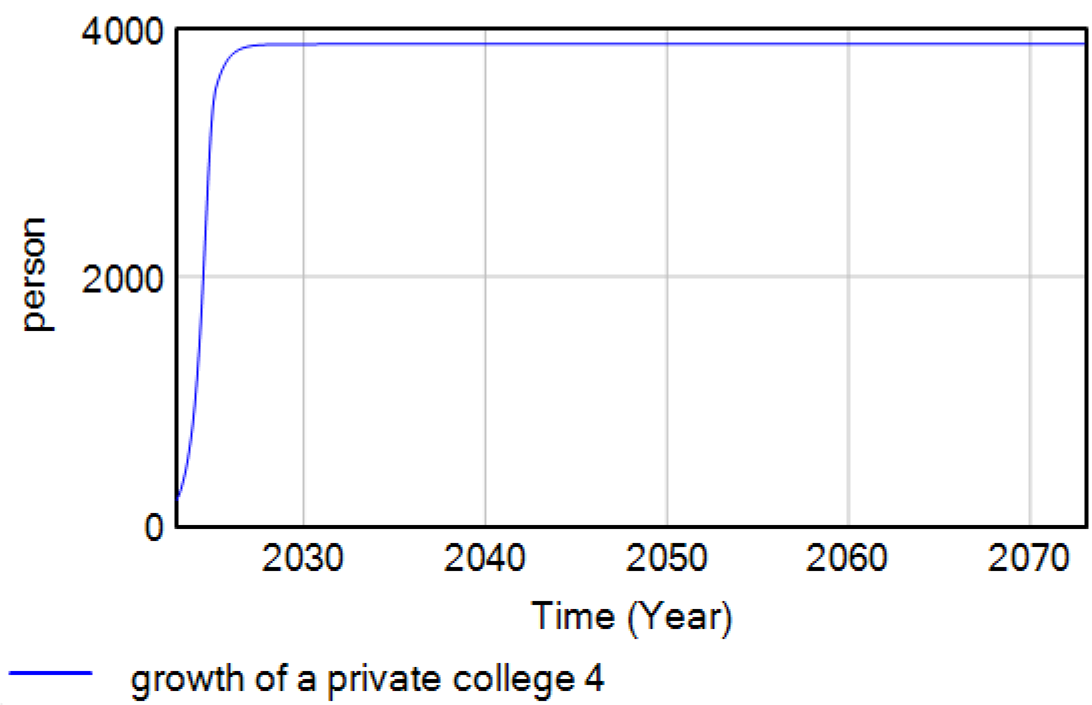
Name: Chia Wen CHENG

where the student-faculty ratio is 35 and the nomination rate of 0.4 equals to the aggregation of the graduation rate of 0.25 and the dropout rate of 0.15.

3.3 Is the equilibrium at the end of your simulation stable, unstable, or neutral?

The equilibrium at the end of our simulation is stable, remaining constantly at 3,500.

3.4 The school board wants to build a larger college, so they worked to reduce the dropout rate to zero. How much larger will the college become?



The college becomes larger with more students of 3,875 people if no one drops out from the school during their study. This is 1.107 times larger than it was.