Individual Based Modeling: Let's Go For a Hike

You've learned about individual based models (IBMs) in Appendix C. These exercises will allow you to practice with an IBM of the four hikers depicted in Figure 1. The sketch shows 4 hikers heading up the trail. The distance traveled is measured in yards. The gaps between the hikers are also measured in yards.

Let's start with hiker #1 which is in rear position. She is the strongest hiker, and her natural pace is 30 yards/minute which amounts to 1,800 yards/hour. There are 1,760 yards in a mile, so her pace is 1.02 miles/hour. It's a 5 mile hike, so her natural pace would allow the hike to be completed in less than 5 hours. The 1st hiker will travel at her natural pace if she is happy with the gap between herself and the 2nd hiker. If the gap becomes too large, she will increase her pace in an attempt to close the gap. If the gap becomes too small, she will slow her pace to allow the gap to grow.

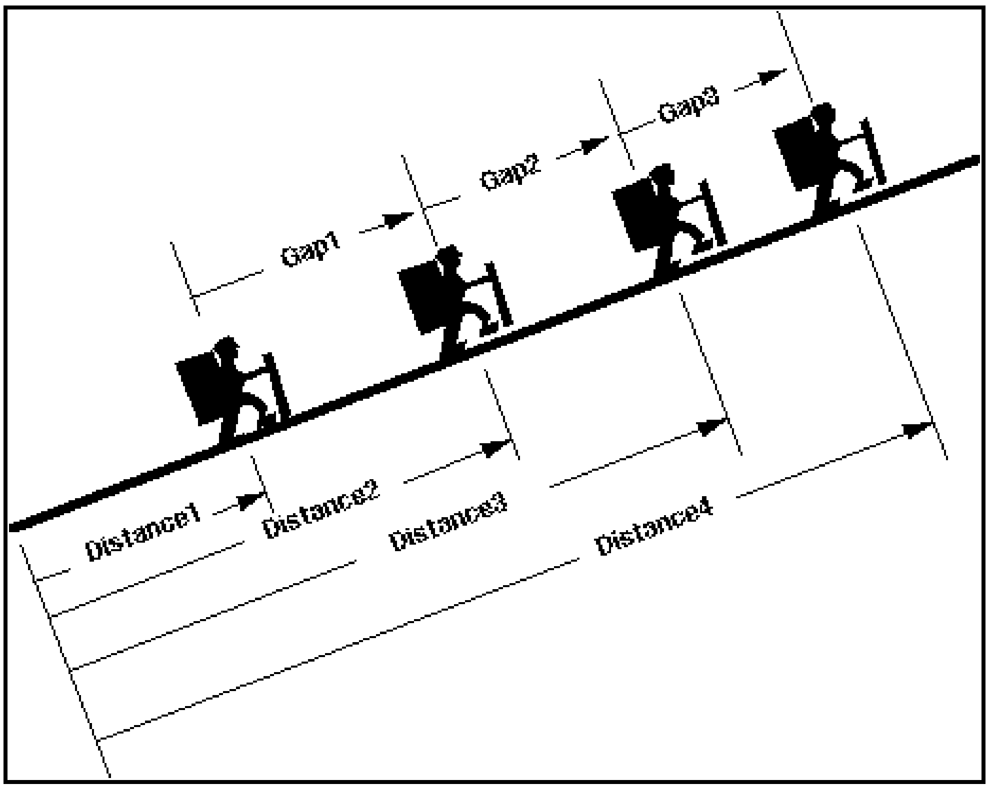


Figure 1. Distances traveled by four hikers heading up the trail.

The 2nd and 3rd hikers follow a similar approach. They speed up when the gaps get too big; they slow down when the gaps become too small. The 4th hiker is in the front position. She leads the way. There is no gap to worry about, so she hikes at her natural pace.

The group of hikers decided that the best approach is to start with the slowest hiker in the front, the next slowest in the 2nd position, the 3rd slowest in the 3rd position and the fastest hiker in the rear. They reason that this positioning will allow the hikers to remain in closer contact during the long hike, so they can call out to each other if there is a problem. The hike begins at noon, and the entire team must complete the 5 mile hike before nightfall (6 pm).

The following exercises challenge you to build and test a model of the hikers' progress up the hill. The exercises conclude with interesting reading from ***The Goal***, Goldratt's (1986) "novel" on manufacturing.

Exercises

#1. Build and Simulate:

Figure 2 shows a simple model to simulate the distance traveled by each hiker. The stocks accumulate the distance traveled in yards; the flows give the pace of travel in yards per minute. The natural paces are:

1st hiker - rear	30 yards/min
2nd hiker	27 yards/min
3rd hiker	26 yards/min
4th hiker- front	22 yards/min

The 4th hiker leads the way traveling at her natural pace. (This is achieved by making "Pace 4" flow identical to the "Natural Pace 4.") The 3rd hiker adjusts her pace based on "Gap 3," the gap in front of her. The "Pace Adjustment 3" is a nonlinear graph (~) whose value is 1 when the 3rd hiker can travel at her natural pace. Values below 1 mean she is slowing her pace because the gap is too small. Values above 1 mean she is increasing her pace because the gap is too large. The 1st and 2nd hikers follow a similar approach and make the same adjustments. Use the ~ to implement the following adjustments in pace:

- if gap is 20 yards, the pace adjustment is 1 which means 20 yards is considered the ideal gap;

- if gap is between 0 and 20 yards, the pace adjustment falls below 1.0. This means the hiker is slowing her pace to allow the gap to return closer to 20 yards. Think of how you would slow your pace under these conditions, and draw the nonlinear graph to represent your own adjustments.

- if gap is between 20 and 40 yards, the pace adjustment increases above 1.0. Let's assume that the hikers cannot exceed their natural pace by more than 5%. (Hiking much faster would drain their energy, so better to make graduate adjustments to close the gap.) So, you should set the maximum upward adjustment to 1.05.

Build the model in Figure 2 and simulate with time in minutes. Set DT to 0.5 minutes and let the simulation run for 360 minutes. (This corresponds to the 6 hours from noon to 6 pm). You may initialize the four stocks with the hikers only 5 yards apart:

distance1= 0 yards
distance2= 5 yards
distance3=10 yards
distance4=15 yards

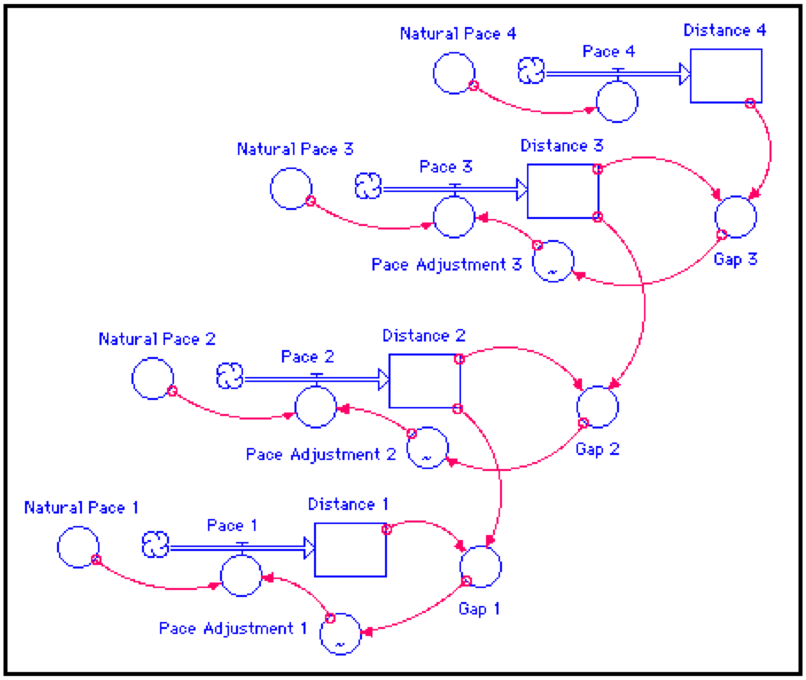


Figure 2. Model of distances covered by four hikers.

Document your simulation with a time graph of the distances traveled by all 4 hikers. Include a second time graph showing the three gaps between the hikers. Let's assume a gap beyond 50 yards is considered unsafe (because the hikers could not communicate clearly with each other.) Include a third graph of the pace of each of the four hikers. Does the hike proceed in a safe manner? What is the pace of the four hikers after 60 minutes? After 120 minutes? Do all four hikers complete the 5-mile hike within 6 hours?

#2. A Second Model to Focus on the Gaps

Figure 3 shows a more compact form of the same model. This approach was suggested by Professor K. K. Fung (1999). He uses stocks to simulate the gaps between the hikers. For example, Gap 1 is the gap in front of the 1st hiker; it decreases due to the pace of the 1st hiker and increases due to the pace of the 2nd hiker. The gap will remain constant if the two hikers travel at the same pace

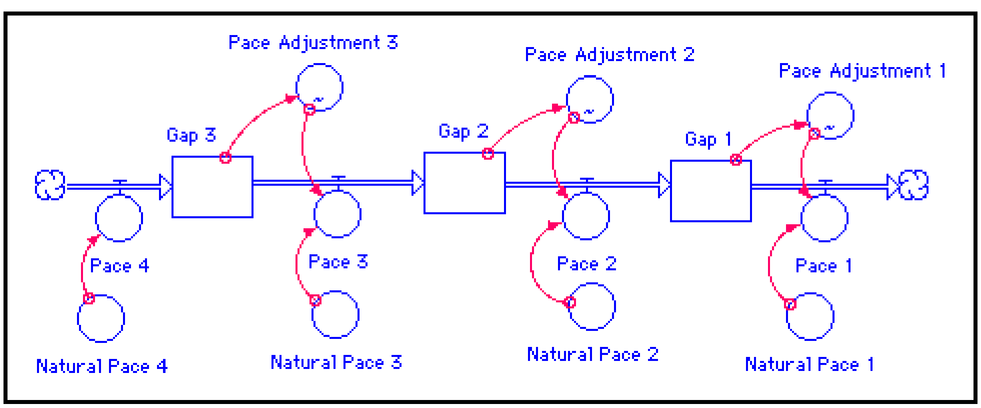


Figure 3. Second model to represent the gaps as stocks.

Build this model and assume the natural paces are the same as the previous exercise, and the pace adjustments are the same as the previous exercise. Build this new model with time measured in minutes. Initialize each of the gaps at 5 yards; set DT to 0.5 minutes and simulate the model for 360 minutes. Document your results with a time graph of the three gaps and the four paces Do you get the same results for the gaps as in the previous exercise? Do you get the same results for the paces as in the previous exercise?

#3. Let the Fast Hikers Go to the Front

Let's use the model in Figure 2 to simulate the hike with the fastest hiker in front and the slower hikers behind. (Every hike from my youth turned out this way -- the fastest hikers made their way to the front. My friends and I brought up the rear.) This approach can be simulated by changing the natural paces to:

1st hiker (in rear):	22 yards/minute
2nd hiker:	26 yards/minute
3rd hiker	27 yards/minute
4th hiker (front)	30 yards/minute

Simulate the model for 360 minutes with the initial values of the gaps at 5 yards. Document your results with a time graph of the 3 gaps. Does the hike proceed in a safe manner (i.e., do the gaps remain less than 50 yards?).

#4. Mr. Rogo's Solution:

Eliyahu Goldratt describes this hike in ***The Goal***. The hikers are Boy Scouts, and Mr. Rogo is the scout master. (Mr. Rogo is also the head of a troubled manufacturing facility, the lead character in Goldratt's novel about manufacturing.) Mr. Rogo puts the slowest hiker at the front of the pack; the faster hikers are at the rear. The hike proceeds in a safe manner, but the fast hikers are constantly grumbling about the restrictions on their pace. They direct a lot of abusive comments at Herbie, the slow hiker who is leading the way. Mr. Rogo is constantly forced to restrain the fast hikers from bolting to the front. He is also constantly admonishing the fast hikers to limit their abusive remarks about Herbie (while wishing to himself that Herbie would walk a little faster).

The hike proceeds in a safe manner as far as the gaps are concerned. But Mr. Rogo becomes concerned that they will not reach their destination in a timely manner. He sees that Herbie's slow pace is the key constraint in the system, so he decides to take a closer look at Herbie’s situation. He notices that Herbie's backpack is larger than the other scouts, so he calls the troop to a halt. They examine Herbie's backpack and are surprised by what they see. It is filled with canned soda pop, jars of pickles, candy bars, frying pans, etc. (Herbie is following the scout's motto to "Be Prepared.")

Mr. Rogo then seizes on a new solution. Herbie's supplies are split up among the remaining scouts. With their heavier backpacks, the fast hikers find that their natural pace is reduced. Herbie's backpack is much lighter, and he can now travel at 25 yards/min (instead of 22 yards/min). He is still the slowest hiker, so Mr. Rogo puts him at the head of the pack.

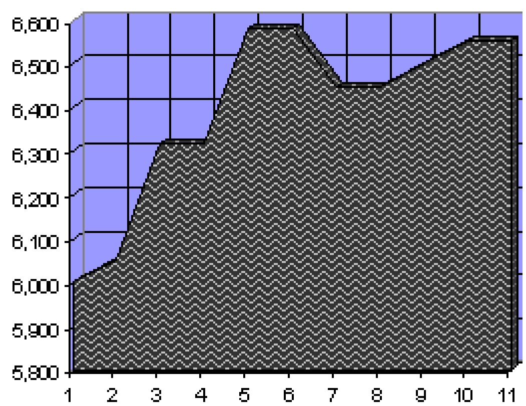
Use the model in Figure 2 to simulate Mr. Rogo's solution based on the natural paces shown below:

1st hiker (in rear):	28.0 yards/minute
2nd hiker:	26.0 yards/minute
3rd hiker	25.5 yards/minute
4th hiker (front)	25.0 yards/minute

Document your results with a time graph of the distances traveled by the four hikers and the three gaps. Does the hike proceed in a safe manner? Do all four hikers complete the 5-mile hike within 6 hours?

#5. <u>Variable Slope on the Trail</u>:

Figure 1 shows the hikers heading up a hill with constant slope. Each hiker has a natural pace that does not change during the hike. This assumption may be reasonable if the hikers face the same slope for the entire 5 miles. But suppose the hikers are heading up the slope shown in Figure 4. The hike begins at an elevation of 6,000 feet. Five miles later, they make camp at 6,554 feet. They climb 554 feet after 5 miles. With 5,280 feet/mile, you can calculate that the average slope is 2.1%
the elevations every half mile:



6,000 feet
6,053 feet
6,317 feet
6,317 feet
6,581 feet
6,581 feet
6,449 feet
6,449 feet
6,502 feet
6,554 feet
6,554 feet

Figure 4. Elevation varies along the trail.

Let's assume that each hiker's natural pace listed in exercise #4 applies when the slope is 2%. But their paces will be lower when they are hiking on a steeper slope; they will be 20% higher when hiking on a flat slope; and they will be even higher when hiking downhill. Use the chart in Figure 5 to represent the change in each hiker's natural pace with changes in the slope.

Figure 5. Change in hikers' natural pace depends on the slope of the trail.

The horizontal axis shows the slope (in %) ranging from a downhill slope of 10% to an uphill slope of 10%. The multiplicative effect on natural pace is shown on the vertical axis. The neutral point is 2% where the "multiplier" is 1.0. If the slope falls to zero, the multiplier rises to 1.2 which means that each hiker's natural pace will be 20% faster. Each hiker's natural pace can be up to 80% faster (when the slope reaches -4% or lower). On the other hand, each hiker's natural pace can fall to 10% of normal values if the slope reaches 10%.

Expand your model from the 4th exercise to represent the change in each hiker's natural pace due to changes in the slope. The slope at the start of the hike is around 2%, so the natural paces should be the same as in the previous exercise at the beginning of the simulation. Simulate the new model and document your results with two graphs. The first is a time graph of the gaps between the hikers. (Can the hikers maintain proper gaps in the new situation?)

The second graph is an X-Y graph with slope (experienced by the first hike) on the X axis and the multiplicative effect on the first hiker's natural pace on the Y axis. (Does the X-Y graph match the expected pattern?)

If your new model seems to working properly, use it to learn if Mr. Rogo's solution will bring all the hikers to camp within 6 hours.

6. Is DT = 0.5 min Short Enough?

Repeat the simulation from the 5th exercise with DT cut in half. Do you get essentially the same result? Now repeat the simulation from the 1st exercise with DT cut in half. Do you get essentially the same result? Do you think that the introduction of a variable slope would require us to consider a shorter DT to maintain numerical accuracy in the simulation?

#7. ***The Goal*** and Manufacturing

If you are interested in manufacturing, read Goldratt's (1986) ***The Goal***. You will learn his analogy between the four scouts on a hike and four machines on a manufacturing line:

- The scout master is concerned with yards/minute of hiking pace; the operations manager is concerned with parts/minute of processing speed.

- The scout master is concerned with gaps accumulating between hikers. The operations manager is concerned with inventories accumulating between machines.

To reinforce the analogy, draw a stock and flow diagram of a manufacturing line comprised of four machines. The first machine is fed by a steady flow of parts. (The flow is timed to match the 1st machine's natural pace of operation.) The 1st machine refines the part and deposits the refined part in an inventory. This inventory provides the buffer for the inflow to the 2nd machine. The 2nd machine has its own natural pace of operation, but that pace will be adjusted downward if the inventory falls too low. On the other hand, if the inventory climbs to excessive levels, the 2nd machine can be operated slightly faster than normal. The output from the 2nd machine is deposited into inventory to buffer the flow to the 3rd machine. The 3rd machine has variable operation and deposits its refined parts into an inventory to feed the 4th machine. The 4th machine is the final machine in the manufacturing line. It has variable operation based on the inventory produced by the 3rd machine. The final products are the parts that emerge from the 4th machine.

Does your model diagram resemble the model shown in Figure 2 or in Figure 3?

Could your model be used to simulate the three inventories?

Could your model be used to simulate the parts/minute that produced by the fourth machine?

Could your model simulate the total production of final parts in a 6-hour run of the assembly line?

References

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K. K. Fung, Follow the Laggard? -- Not all Bottlenecks Are Created Equal, *System Dynamics Review*, Vol 15, No. 4, 1999. Also viewable at one time at
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Eliyahu Goldratt and Jeff Cox, *The Goal*, North River Press, Box 241, Croton-on-Hudson, NY 10520.