PREPARATION

Time	1 hr of study/preparation + 1 hour in class

PART 1 - ORIENT STUDENTS | Problem & Tech

Instructor: How would you reduce traffic in a realistic way?
Students: We can add more lanes and roads.

Instructor: To figure out which strategies help and hurt transportation, scientists and engineers create computer and mathematical models. In this lesson, we'll do this same with this model.

In this system, there is a starting point called the *origin* on the left side.

There's also an ending point called the *destination* on the right side.

The river through the middle divides the road system evenly in half…so that we have the top path with a curved, wide road (*A*) and a narrow, straight road *(b)*

Let's call that path Ab.

And the bottom path with a straight narrow road (*a*) and a wide, curved road (*B*). Let's call that path aB.

Instructor: What happens if we play the model and watch simulated cars, trucks, buses, and motorcycles cross these paths? Which path do you think will be quicker?

Students: Any guesses are fine.

Adjust the default settings to the following:

Vehicle Launch Rate:	0.55
Congestion Coefficient:	0.50
Routing Mode:	selfish

"Selfish routing" means that drivers choose routes to minimize time.
"Random routing" means that drivers choose routes randomly.

Click "Go" and observe the results. After about 3000 vehicles have crossed each path, click "Stop" and wait a bit of time for the model to stop running. This delay will be caused by lagging vehicles that need some time to reach the destination. This process will take a few minutes, so have a separate tab before the activity that has it set to 3000 vehicles total.

[*Record all values observed in the* "Lesson 2.0 Graph" Excel Spreadsheet.]

Total vehicles will be approximately 3100 and an average time across all vehicles should be around 1.7. Each run of the model may be a bit different.

Notice that the Ab path took 1.795 time units and the aB path took 1.649 time units/hours. It appears that no major difference exists between the efficiency of both paths. They help vehicles get to the destination equally quickly.

Instructor: What would happen if we change the model so that a bridge exists where the red X is placed in the center of the screen?

Students: Any reasonable responses are OK

[*double-click the red X in the center of the screen to create a bridge across the river*]

PART 2 - GUIDED EXPLORATION | EFFECTS OF BRIDGE

[*click Go*]

Instructor: This time, we'll wait until a total of 3,000 vehicles reach the destination.

[*wait until 3,000 vehicles get to the destination*]

Instructor: What happened?
Students: Any response is acceptable.

Instructor: The total number of vehicles is around 3,000 and the average time in this model is about 1.9. In the last model, what was the average time?

Students: 1.7

Instructor: What can we say about adding the bridge? Did it improve the travel time?

Students: Adding the bridge to the model increased the travel time by about 0.2.

Instructor: Right! Why's that?

Students: General observations can include:
- People were all choosing the shortest path (*ab*), but that made things worse.
- The path with two wide roads (AB) ended up being really slow.
- The original top path (*Ab*) ended up being the fastest.

[*Record all values observed in the* "Lesson 2.0 Graph" Excel Spreadsheet.]

Path		Congestion Coefficients					
			0.15		0.50		0.90
		count	time	count	time	count	time
Ab	bridge	0	0.00	0	0.00	0	0.00
	no bridge	0	0.00	0	0.00	0	0.00
aB	bridge	0	0.00	0	0.00	0	0.00
	no bridge	0	0.00	0	0.00	0	0.00
AB	bridge	0	0.00	0	0.00	0	0.00
	no bridge	0	0.00	0	0.00	0	0.00
ab	bridge	0	0.00	0	0.00	0	0.00
	no bridge	0	0.00	0	0.00	0	0.00

[Go to the "Lesson 2.0 Graph" Excel Spreadsheet.]

Much of science and engineering involves dealing with the details of managing and sharing data. Have students work on entering their own data.

Instructor: Scientists and engineers *validate data* by checking for errors. Even they make simple mistakes that need to be corrected much later. So you should always check your own work and then have someone else check it.

PART 3 - UNGUIDED EXPLORATION - LOW & HIGH CONGESTION

Instructor: Traffic engineering is a complicated science because we need to think about how people will behave selfishly and according to their own needs.

This idea is called "Braess Paradox" (pronounced: "Bray's Paradox") where building extra roads *sometimes* creates *more traffic*. And *sometimes removing roads helps*. But we still need to figure out how to help the travelers in this model. In our original model, the average time was about 1.7. What can we do to beat this time?

Students: We could change the variables on the bottom like "congestion coefficient."

Instructor: Let's run the model two more times now in different tabs with low congestion and high congestion. Congestion is just another word for "traffic."

The vehicle launch rate will be kept constant. To study the effects of the bridge, four models will need to be run.

[*run the model in two tabs with congestion values of 0.15 and 0.90*; *allow 3,000+ vehicles to reach the destination across the four models*]

MODEL 1: no bridge; low congestion (0.15)
MODEL 2: bridge; low congestion (0.15)
MODEL 3: no bridge; high congestion (0.90)
MODEL 4: bridge; high congestion (0.90)

[Pair up students to find the results and organize them in a large table or other data visualization of their choice. This is a great opportunity to have students grapple with the problem of recording, organizing, and communicating the results of a model exploration study. For advanced students/pairs, encourage them to click "more controls" on the bottom right. They can design their own exploration and add those results to their information graphic (table or set of horizontal bar plots) as well.]

Instructor: What did we find for low, moderate, and high congestion values? Do extra bridges matter or not?

Here's an expected set of results (tabs 2.1, 2.2 in "Lesson 2.0 Graph" Excel Spreadsheet).

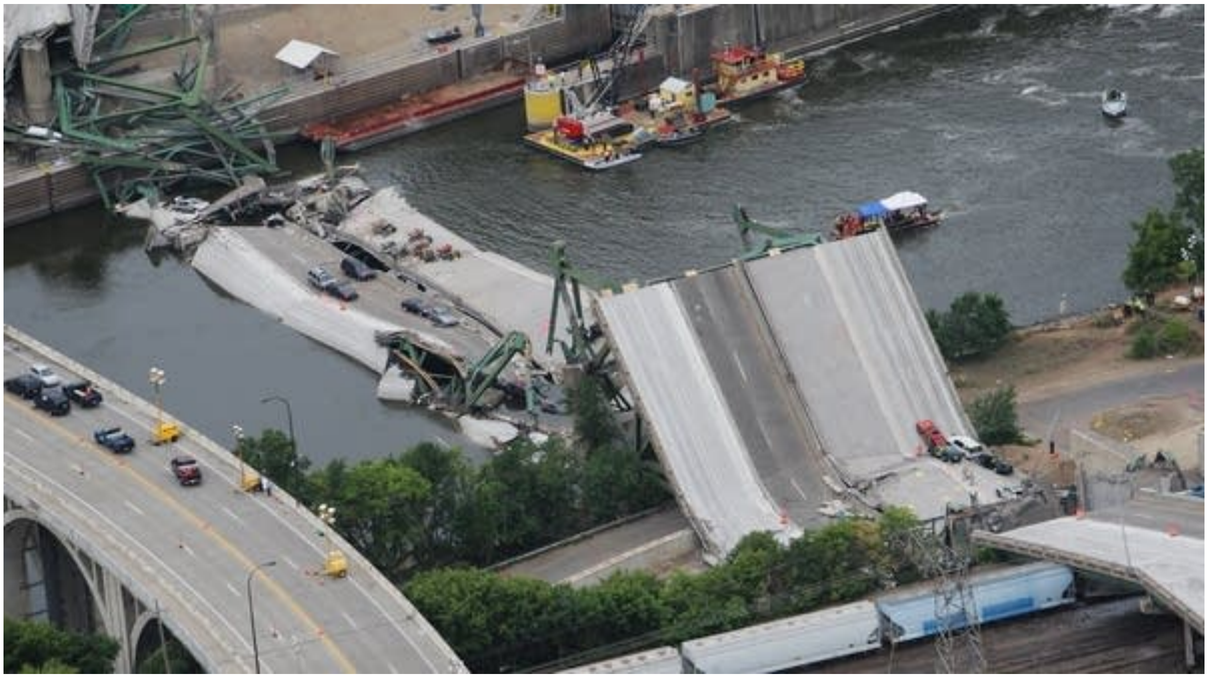
Compare your model results to this graph and see if they match.

[*Optional: The "Expected" examples in tabs 2.1 and 2.2 are model simulations run by this module's curriculum designer. They can be ignored if you like.*]

Instructor: Who can help interpret this graph?

Students: The purple line shows what happens when we have a bridge open and people drive selfishly. If traffic density (number of vehicles) is also low, then leaving a bridge open results in lower travel times. But the effect vanishes at the 0.3 mark for traffic density and then continues to rise relative to the blue line, creating the Braess Paradox. This means that leaving the bridge open worsens traffic because drivers selfishly choose the better route.

Instructor: Right. And even more surprisingly, if drivers change roads randomly instead of selfishly by choosing the shortest route, that will *minimize* average travel times.



One local story might help hit the message home for students. In 2007, there was a major bridge collapse in Minneapolis carrying Interstate 35W across the Mississippi River.

Here's an excerpt from the *American Scientist* article *Playing in Traffic*.

"...As the replacement bridge was completed a year later, [researchers]... prepared a before-and-after study. Tracking devices were installed in the automobiles of 187 volunteers, whose commuting routes and trip times were recorded over eight weeks. No evidence of a Braess paradox was found: Average travel times improved after the new bridge was opened. A later lane closing on another bridge had a larger effect, but again the change was not in the paradoxical direction. Urban street grids look nothing like the small and simple networks considered in these models. Cities have hundreds of streets, and drivers navigate between many points of origin and destination..."

Instructor: As we've seen, we make models to find out what *might* happen, but all kinds of variables can affect our results. As more drivers use GPS technology in their cars and on their phones, they'll be able to switch to the best routes quickly. But if everyone does that, it will just make traffic worse. One solution may be to have cars communicate with each other and negotiate travel plans that help everyone overall.

Here's a video explanation of that kind of technology [*play video*].

This final video reviews the transportation design paradox covered in the beginning and explores a few new solutions not covered in this lesson plan.

[*play video: pause around 10:00 to ignore the advertisement*].

As you have seen, some of these solutions use technology, others use the law, and the rest focus on designing the actual shapes of roads differently.