



# DESIGNING HIGHWAY INTERCHANGES



## DESIGN CHALLENGE

Design a highway interchange that allows drivers to approach from any highway and leave by any highway without crossing any lanes of traffic.

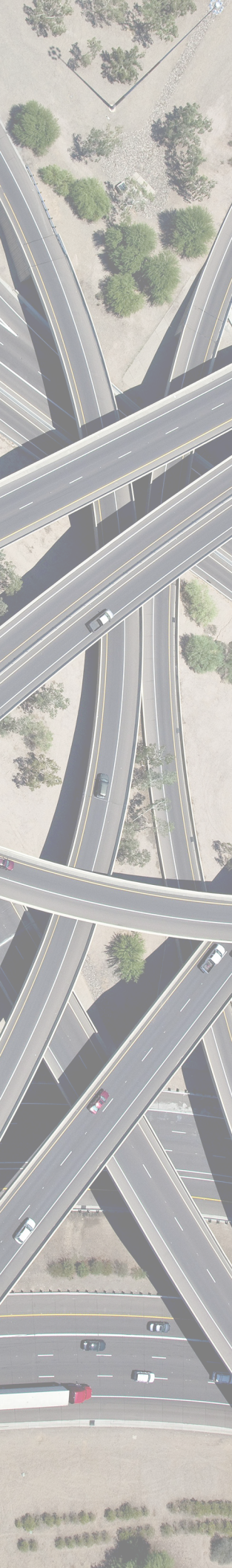
## SUPPLIES AND EQUIPMENT

### For each model highway:

- Two 2-lane highway sections made of foam core, approximately 20" long x 4" wide
- Wooden blocks 4" x 4" x 2" (i.e., 4" sections cut from a 2 x 4)
- Masking tape
- Markers
- Optinal: Large piece of cardboard that can swivel, to set the model highway on

### Per team:

- 1 model highway
- 15–20 sections of flexible cord or rope of different lengths ranging from 12" to 20"
- Scissors
- Jumbo paper clips or binder clips
- Small pieces of paper and pens for making road signs
- Die-cast cars (optional)

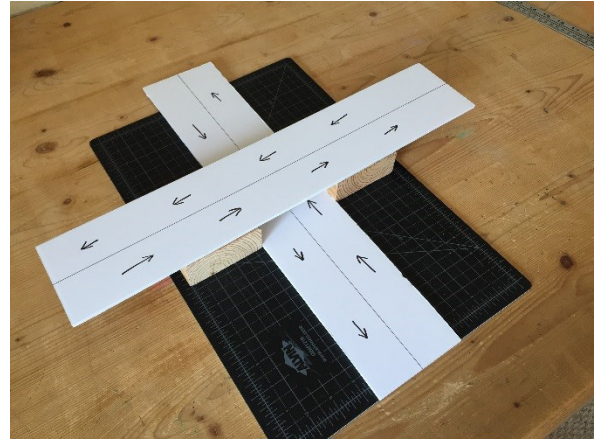


## GETTING READY

Cut the foam core into sections about 20" long by 4" wide. Use markers to draw a center line and direction arrows to represent a section of highway. Also mark which direction is north, south, east, and west.

Use wooden blocks and highway sections to create a highway intersection, with one road passing over the other. You may want to use masking tape to hold this intersection together.

Cut rope into sections ranging from 12" to 20". Each team should have a supply of 15–20 sections. (Teams can cut their own rope lengths from a spool of rope; subsequent groups can use the cut pieces from earlier groups.)

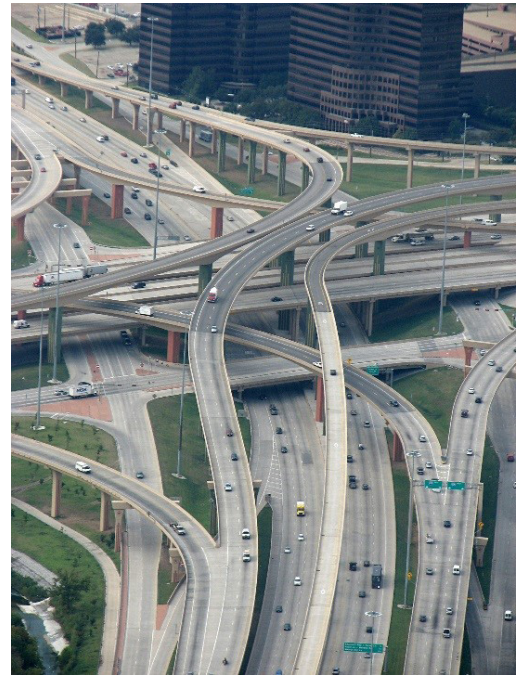


It is also helpful to put your interchange model on a large piece of cardboard so that participants can swivel it around when making their rope connections.

## INTRODUCTION

Give participants the following information, adapted to their age: Modern highways are filled with cars, each trying to go somewhere. To get where they want to go, cars often need to move from one roadway to another using on and off ramps. These ramps are called highway interchanges. Engineers design highway interchanges to keep cars as safe as possible, which means not making them have to cross lanes of traffic or come to a stop as they move from one highway to another. Before engineers plan the construction of these interchanges, they must figure out how the roadways will connect to each other. Otherwise, with cars traveling on many roadways going in many directions, the ramps will become a confusing, dangerous tangle.

Did you know that there are different kinds of mathematics? To figure out how roadways should connect to each other, engineers use the kind called topology, the mathematics of how things are connected.



Intersection of I-635 and US Route 75 in Dallas, Texas.  
Credit: Austrini



## INSTRUCTIONS

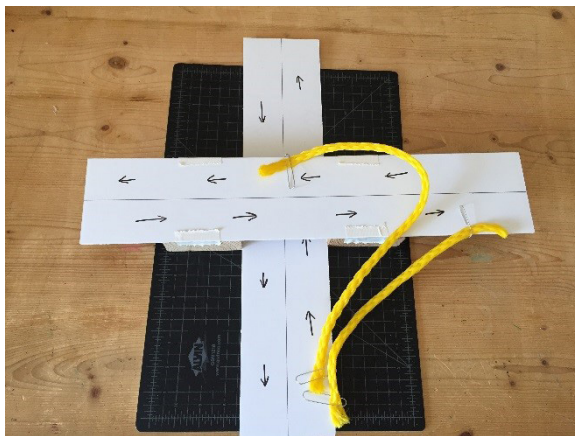
Ask participants about their experiences with being a passenger in a car on the highway. If there is an adult driver present, ask that person to describe what highway driving is like (shifting lanes, merging into traffic on the ramp, etc.).

Show participants the foam core model of two highways and which way is north, south, east, and west on your model. Younger participants may benefit from a brief discussion of how important these compass points are when driving or traveling by any means, even walking, and why they often work better than just saying “turn here” or “turn left.”

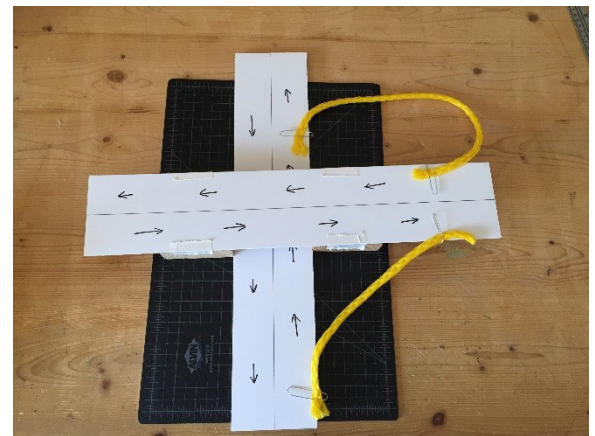
Pose the following question: If a driver who is headed north wants to switch highways and head east, what ramp would you have to build? Use rope and paperclips to show how to put that ramp onto your model. Use your finger (or model car) to show the path of the car from one highway, onto the ramp, then onto the next highway, so that everyone knows how the model works.

Now pose this question: Suppose the driver who is headed north wants to go west. What ramp would you need to build? Take suggestions and ask, “Are there any other ways to do this?”

Demonstrate two ways to build ramps so that the northbound driver can turn either east or west. One uses an overpass to turn west. The other uses a cloverleaf to turn west. Make sure younger participants know what shape a cloverleaf is.



Example model showing overpass.



Example model showing cloverleaf.

To make the model less abstract and more comprehensible, have one or two of the participants use a finger to follow the traffic flow. Ask any participants of driving age to describe what it’s like to use on and off ramps to also make the model more real: “I get into the right lane, slow down, watch for the sign...”

Place participants in small teams and state the challenge: Design an interchange so that drivers starting in any direction can leave the interchange in any other direction. Instruct them to use pieces of rope and clips to indicate their interchange, as you showed them.



## INSTRUCTIONS (CONTINUED)

Distribute team materials. Encourage each team to talk through several options and to play with the ropes as they try out different ideas. They can also make signs to clarify how cars should use the interchange they choose.

Ask teams to demonstrate their interchange for the other teams. Decide as a whole group which interchanges would work best and why.

## ACTIVITY VARIATIONS

- Label the north-south highway as HWY 1 and the east-west highway as HWY 2. Now make little signs to put on your model that show drivers where to turn. For example: **HWY 1 South, Next Right.**
- For older participants: Design the ramps needed for a three-way interchange. (They should consider: Does every roadway need to connect to every other roadway, or can you get from the first to the third by passing through the second, thereby reducing the number of ramps?)
- Print out photos of actual interchanges so that participants realize that you're not making this up: they are actually very complicated in real life. Participants can look for patterns such as cloverleaves in the actual photos.
- Print out diagrams of a variety of highway interchange designs for people to peruse.

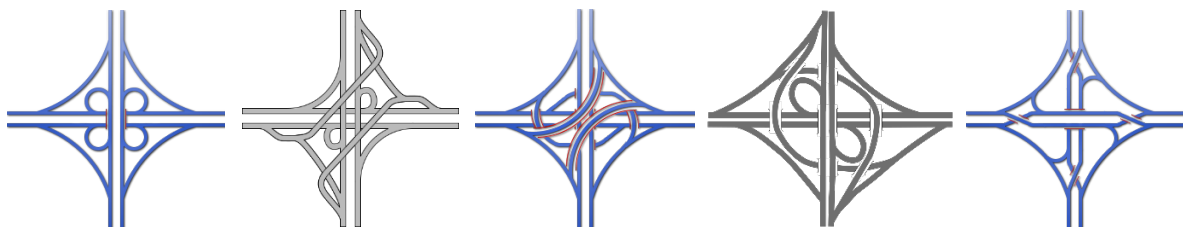
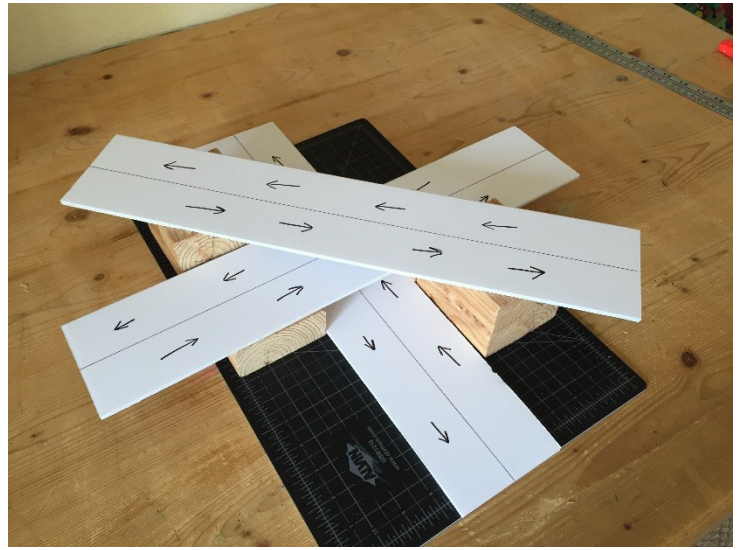


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## RELEVANT TERMINOLOGY

**Constraint:** A real-world limitation, such as the amount of space or money or time you have to build something.

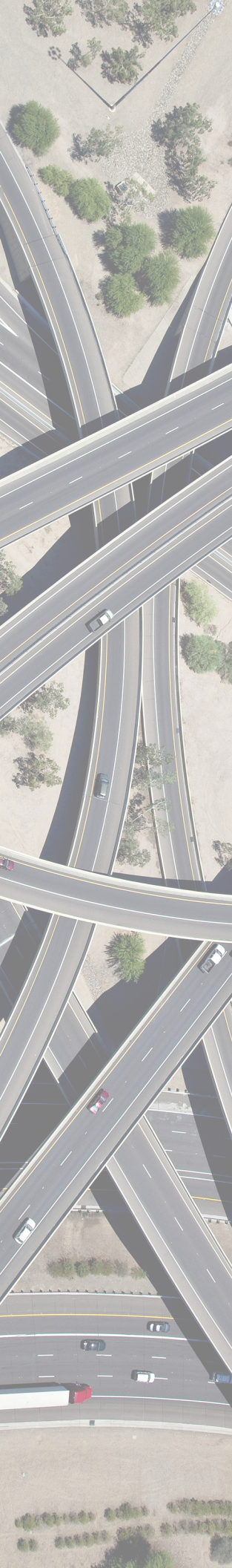
**Cloverleaf:** A type of interchange where cars go left by making right-hand turns and looping 270° around a large ramp that looks like the leaf of a clover.

**Interchange:** A place where multiple highways or roadways cross each other.

**On ramp / Off ramp:** A roadway that allows cars to enter or exit a highway.

**Overpass / Underpass:** A section of roadway that passes over (or under) another roadway. This can be accomplished with a bridge, ramp, or tunnel.

**Topology:** The branch of mathematics that studies how things are connected.



# GUIDANCE FOR YOUNGER CHILDREN

## QUESTIONS TO ASK AFTER THE ACTIVITY

- How many ramps did you think your interchange will need?
- How did you decide which interchange would work best?
- What if your interchange had to be built in a place with very cold, snowy winters and lots of blizzards? Would that affect the design you pick?

## ENGINEERING CONNECTIONS

Engineers don't just look for a solution to a problem—they often look for the best solution. Best can mean different things. For example, best could mean the least expensive way to build an interchange. Or, it could mean an interchange that can handle the most traffic. It could also mean the interchange that needs the fewest number of on and off ramps but still meets all of your needs. (What other things could *best interchange* mean?) Finding the best solution is called optimization, and is very important in engineering.

And, after all of the plans are made for what type of interchange you want and how you will connect the roads, you must then think about how you will actually build this interchange. To figure all this out requires teamwork. Transportation engineers, traffic engineers, construction engineers, civil engineers, and even engineers who specialize in water and soil work together to plan the interchange.

## MATH AND SCIENCE CONNECTIONS

Designing the pattern of ramps, bridges, and tunnels to connect two highways is a problem in a type of mathematics called topology. Topology is concerned with how objects are connected. For example, when you are deciding which roadways are connected to which, you are not worried about how big those ramps are. They could be very short and straight or they could be long and wiggly, so long as they connect the correct roadway to the correct roadway. Later in the engineering process, you will need to deal with exactly how big to build that roadway, which involves geometry. But when you are figuring out the connections, you can use string, because in topology the exact shape doesn't matter.



# GUIDANCE FOR OLDER YOUTH AND ADULTS

## QUESTIONS TO ASK AFTER THE ACTIVITY

- If your team talked about whether to design a cloverleaf or an overpass, what made you choose one or the other? Or, if you came up with another solution, why was it better?
- What if your interchange was built in a country where you drive on the left side of the road instead of the right? How would your interchange differ?

## ENGINEERING CONNECTIONS

Engineers must work within constraints that define and limit the project. Finding the best solution is called optimization and is very important in engineering. Typical constraints might include the project's cost, the terrain of the area, and how attractive the final project should be.

Once they have decided which highways need to connect with each other, and where those connections need to be placed, engineers are faced with many practical questions: What size must the curves be in an interchange? If cars are going fast, they need a larger curve in which to turn, and it may need to be banked to prevent skids. How about actual construction? What materials will be used? How long will construction take? How will traffic need to be rerouted during construction? Will workers need to put down temporary roadways?

These are the types of questions that engineers need to ask as the project goes from idea to construction. Many answers can be found by studying what has been done before. In addition, there are many rules, regulations, and engineering guidelines that help an engineer make wise decisions when designing an interchange.

## MATH AND SCIENCE CONNECTIONS

Designing the pattern of ramps, bridges, and tunnels to connect two highways is a problem in a type of mathematics called topology. Unlike geometry, which deals with exact shapes, angles, measurements, and sizes of objects, topology is concerned only with how those objects are connected. For example, when you are deciding which roadways are connected to which, you are not worried about how big those ramps are. They could be very short and straight or they could be long and wiggly, so long as they connect the correct roadway to the correct roadway. Later in the engineering process, you will need to deal with exactly how big to build that roadway; these decisions involve geometry. But when you are figuring out the connections, you can use string, because in topology the exact shape doesn't matter.



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