CoreModels

Kinematics of Tailgating

A Core Learning Goals Activity for Science and Mathematics

Summary: Students will use a STELLA model to investigate factors involved in stopping and safe following. Students will apply the equations of kinematics and prepare a public service announcement based on their investigations.

Author: Charlotte M. Trout
Williamsport High School
Williamsport, MD
ctrout@isaac.williamsport.wa.k12.md.us
301-791-4216

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Maryland Virtual High School
51 University Blvd. East **(301) 649-2880**
Silver Spring, MD 20901 **http://mvhs.mbhs.edu**

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Overview:

In this unit, students will research stopping distance or deceleration values for automobiles. They will also investigate reaction times. They will use the equations of kinematics to solve simple tailgating problems and work with unit conversions. They will use a STELLA model to discover the relationship for the safest following distance based on velocity. They will also investigate the effect of varying velocities and reaction times. Finally, they will use their results to develop a public service announcement or add campaign for their peers.

Activities at a Glance:

Activity	Title	Required Materials	Est. Time
1	Traffic Safety and Tailgating	Internet connection or references	30 mins
2	Reaction Time	Stopwatches and rulers	30 mins
3	A Tailgate Problem	None	30 mins
4	The Tailgate Graph	None	30 mins
5	Tailgate Model: Carlength vs. Velocity	STELLA model and graphing program	45 mins
6	Tailgate Model: Worst Case Scenario	STELLA model and graphing program	60 mins
7	Tailgating: Safety First!	Depends	75 mins

Prior Knowledge/ Skills Required:

Students should be familiar with basic kinematics equations involving distance, time, velocity and acceleration. They should be familiar with distance vs. time, velocity vs. time and acceleration vs. time graphs and be able to explain their appearance. They should be able to perform simple unit conversions for distance and velocity. They should have basic computer skills. As written, they will work with an existing STELLA model, however, if students have experience with this software, they could develop the model themselves. If they have not previously worked with STELLA, they should work with the supplied pre-model, before beginning this unit.

Best Practices:

This activity occurs fairly early in the year. Students have done a few labs with motion, worked a few motion problems and built a simple STELLA model or two. Now they have a chance to examine (or build) a more complex model which can also be used to answer some questions about a topic they should be interested in. What is a safe following distance?

The unit has several strengths. It is an application of their newly acquired knowledge to a real-world problem. It allows them to review what they've learned by applying it to solve a problem and it shows the limitations of models (they are only as good as the programmers make them). It also emphasizes the confusion caused by having two sets of measuring systems.

In the classroom, students work through the first four activities at their own pace. The first is easily completed in a media center. The requested information about cars can be found in issues of Consumer Reports or Car and Track. The information about accidents is found in almanacs. Internet access can also lead to some of these answers.

The second activity is a simple lab. In classrooms where students have not yet done a lab with freefall, it is simple enough to give them the equation for time and the value for the acceleration. From this they can calculate their reaction time and they are usually not very curious about the origin of the acceleration value.

Activity 3 and 4 can be in class work or homework. However, activity 4 should be thoroughly discussed with students before they move onto activity 5. They need to be able to read the graph and understand all its implications. A rubric for scoring certain questions from activity 4 is included in the appendix. These questions should be scored before a review of the worksheet.

Classroom discussion should follow activity 5 as well. Students will find that the model allows for a closer following distance than they have been taught. This is an excellent time to discuss the limitations of models as well as the "ideal" conditions that have been entered (e.g. good reaction times, good brakes). One teacher uses this model and has the students increase the reaction time by 50% to simulate driving under the influence.

Students will need a great deal of help in organizing their attack on activity 6. This is an excellent time to discuss controlling variables, running experiments that are "useful", etc. The number of variables investigated here is dependent of time. The more variables, the more class time. In most cases, students are quite aware of how these variables will affect the experiment.

If students are using the "pre-built" model, they should look at the model itself at some time. Some class time should be spent on examining how it is constructed. Instructions for building simpler models are included in the Appendix. Experience suggests that students will benefit from building these first models before they use the tailgate model. Students could also be encouraged to add other factors to the pre-built model following Activity 6.

Kinematics of Tailgating
Teacher Guide

Introduction: You're in a hurry, traffic is heavy. How much space should you leave between you and the car ahead? How safe are you as a driver?

Activity One - Traffic Safety and Tailgating

Your teacher will divide you into groups. Discuss the following questions within your group.

Question 1.1: What is the rule for safe following distance between cars?

> **Often stated at 1 car length for every 10 mph**

Question 1.2: Is this a constant or a ratio? Explain your reasoning.

> **A ratio - the distance is not constant but depends on the velocity.**

Question 1.3: Why do you think the rule is stated this way?

> **Easier for people to remember and to estimate when driving.**

Using appropriate and available reference materials, research the following. Be sure to keep an accurate bibliography of your references.

Question 1.4: What percentage of traffic accidents are rear-end collisions?

> **About 6.0% of all accidents, but they are the majority of two-car accidents.**

Question 1.5: Find the stopping distance or deceleration rate of at least 3 models of automobiles. Stopping distances will be referenced to a particular velocity - be sure to include both numbers.

> **Some values supplied in the Nicklin article are:**
>
> **BMW M3 - stopping distance 120 ft or 37 m from 60 mph**
>
> **Lincoln Continental - 131 ft or 40 m from 60 mph**
>
> **Dodge Colt GL - 167 ft or 51 m from 60 mph**

Question 1.6: Under what conditions are these tests conducted?

> **Generally with brand new cars and ideal road conditions.**

Activity Two - Reaction Time

In this activity, you will use a simple procedure to determine your reaction time. You will need to work with a partner.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.3: Carry out scientific investigations ...

Math.CLG 3.1: Collect, organize, analyze and present data ...

Procedure:

Have your partner hold his/her thumb and first finger about a 1/2 inch apart. Hold a ruler so that the 0 mark is just above your partners fingers. You will release the ruler and your partner will close their fingers to catch it. Measure the point at which their fingers close on the ruler. Record this value. Repeat 4 more times and average the distances. Be sure to record all these values. Then switch roles with your partner and record your values.

	Partner	You
Distance 1		
Distance 2		
Distance 3		
Distance 4		
Distance 5		
Average Distance		

Note: If you haven't covered acceleration due to gravity, you may want to have students measure reaction time another way and skip calculation 1 below.

Calculations

Question 2.1: Now using the equations for free fall, determine your reaction time and the reaction time of your partner. Record those here:

Use $d = 1/2*g*t^2$ and solve for t

Question 2.2: Share your values with the class and record the class average and the range of values recorded in the class.

Typical times are between 0.2 and 0.7 sec

Question 2.3: Do you think your reaction time would be slower or faster when moving your foot? Why?

> **Slower - foot is farther from brain and different type of motor control but this would not be very much slower**

Question 2.4: How about moving the foot from the accelerator to the brake? Why?

> **Slower still because it involves a precise movement but again, this would be only slightly slower.**

Question 2.5: Besides the driver’s reaction time, what other factors might affect the distance required to stop a car? Especially note those conditions which might alter the deceleration data provided by the car manufacturer’s that you obtained in Activity One.

> **Students should list factors such as road conditions, make of car, condition of brakes and tires, actual traveling speed.**
>
> **Students should note that the stopping distances are for a particular velocity. Deceleration values may change with velocity.**

Activity Three - A Tailgate Problem

In this activity, you will review the equations for motion which you have studied previously and apply them to a simple tailgating problem.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.6: Use mathematical processes ...

Science.CLG 5.1: Know and apply the laws of mechanics ...

Math.CLG 1.2: Model and interpret real world situations ...

Question 3.1: From memory, your textbook or notes, recall and record below the basic equations of motion.

Question 3.2: Using the equations above and any necessary unit conversions, fill in the table below for the models of cars you researched in Activity One. Show any work in the space below the table.

	Values calculated	Stopping Distance		Deceleration	
Make of car	from velocity of	(feet)	(meters)	(ft/sec^2)	(m/sec^2)
1:					
2:					
3:					
4:					

Question 3.3: A particular make of car has a deceleration of 9.0 m/s^2 as reported in the literature. Two cars, both of this make, are both traveling down a highway at 60 mph. The front car slams on its brakes. Using the average class reaction time you determined in Activity Two, determine the minimum distance that the second should have been behind the first, in order to avoid a rear-end collision. Show your work in the space below.

60 mph = 27 m/s

Front car stops in 41 meters

Back car travels (using reaction time of 0.45 sec) 12 meters before applying brakes and then requires 41 meters to stop

Safe distance = 12 meters

Question 3.4: Vehicle car lengths vary, but an average length would be about 16 ft. Translate the distance above into the number of car lengths that should have been between the cars.

16 ft = 5 meters (approx.)

About 2.5 car lengths

Activity Four - The Tailgate Graph

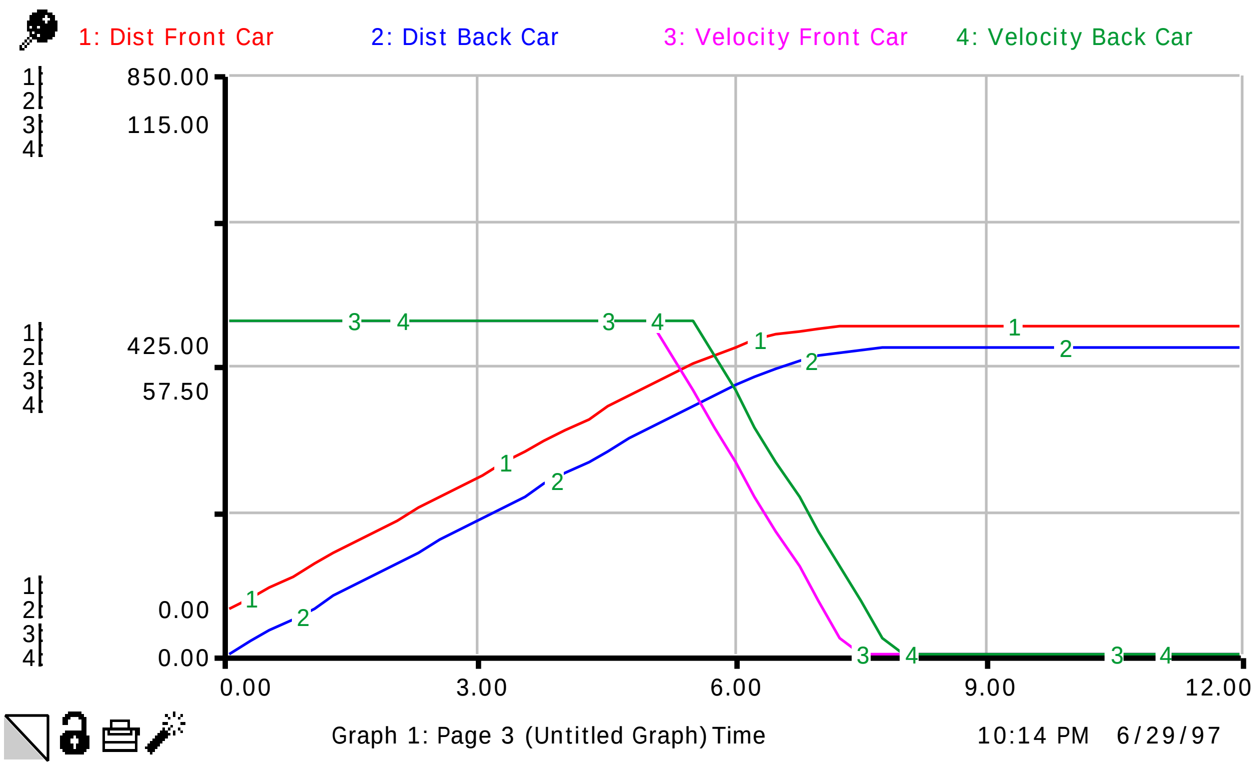
Before actually using the tailgate model, you will interpret a copy of the graph. Then when you use the model, you will be able to interpret your results quickly.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.4: Demonstrate that data analysis is vital ...

Science.CLG 5.1: Know and apply the laws of mechanics ...

For the graph below, both drivers were traveling at 45 mph and both had a deceleration rate of 28 ft/sec^2.



Refer to the graph to answer the following questions:

Question 4.1: Why is the y-intercept for the distance of the front car larger than that of the back car?

> **The front car starts at some distance in front of the back car and the y-intercept represents this distance (car lengths in ft).**

Question 4.2: Why are the velocity graphs flat at the beginning?

Both cars are traveling at constant velocity to begin with.

Question 4.3: At what time does the front driver apply the brakes? What is your evidence?

At five seconds, the velocity of the front car starts to decrease. This is shown by the negative slope of the line.

Question 4.4: Why do the velocity graphs have a downward slope in the second part of the graph?

Both cars are braking (decelerating) and therefore are slowing down. The velocities are getting smaller and smaller until they reach zero.

Question 4.5: Why do the distance graphs curve and then go flat?

As the velocities slow down, the distances covered become less per unit time and so the graphs curve. This is evidence of the deceleration. When each car's velocity reaches zero, no more distance is traveled and the graphs go flat.

Question 4.6: Do these cars collide? What is your evidence?

No, the distance graphs do not overlap. Students may be confused by the velocity graphs and some may try to use these to argue that the cars overlap. Point out that the first car comes to a stop before the second, but that the second stops before they overlap. Then the graphs continue at zero.

***** Note: You may choose to have the students build a tailgating model before proceeding to the next step (see Appendix E). If STELLA is not available, suitable models can be built using spreadsheets as in the Nicklin article. If students have not used STELLA before, you might want to use the pre-model and activity first. This would also serve to introduce the use of sliders if students haven't used these before. ******

Activity Five - Tailgate Model: Car Length vs. Velocity

In this activity you will use a STELLA model to investigate the relationship between velocity and the number of car lengths between vehicles that permits safe driving.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.4: Demonstrate that data analysis is vital ...

Skills.CLG 4.2: Use technology effectively ...

Skills.CLG 5.2: Work cooperatively ....

Math.CLG 1.2: Model and interpret real-world situations ...

Math.CLG 3.1: Collect, organize, analyze and present data ...

Your teacher will assign you to one of 11 groups. Together the class should choose one reaction time and one deceleration rate to use so that class data can be compared.

Use the model to determine the maximum velocity which two cars can travel at for your assigned car length. For simplicity, both cars should be traveling at the same velocity. Record your value in the table below and fill in the rest of the table with data supplied by other groups in the class.

Reaction time: __**0.45 sec**__ Deceleration Value: __**28 ft/sec^2**__

Max. Velocity (mph)	Actual Max. Velocity (mph)	Separation Dist. (Car lengths)
25	25.00	1.19
30	29.95	1.35
35	34.90	1.58
40	39.85	1.82
45	44.80	2.06
50	50.25	2.3
55	55.20	2.54
60	60.15	2.77
65	65.10	2.93
70	70.05	3.17
75	75.00	3.41

Now graph the separation distance vs. maximum safe velocity

See Appendix D

Question 5.1: What relationship appears to exist between separation distance and maximum safe velocity?

The relationship is linear. Students should realize that this is the case since the only factor affecting the required separation distance is the reaction time when both cars are traveling at the same speed and have the same deceleration rate.

Question 5.2: Does the rule you described in Activity One hold?

At this point, it should appear that the rule is overly cautious.

Question 5.3: What limitations were set in this experiment?

Both cars traveling at the same speed, both cars have the same braking ability, tailing driver has a moderately good reaction time.

Question 5.4: For each of the factors mentioned in question 3, suggest how variations in that factor may improve the following distance or make it worse.

If the tailing driver has a poorer reaction time, then the situation would be worse.

If the lead car has better brakes than the tailing car the situation would be worse, but if the better brakes are on the tailing car then the situation is better.

If the road conditions are bad, the situation would be worse.

If the lead car is traveling slower than the tailing car, the situation could be worse, but if the tailing car is traveling slower the situation could be better.

Question 5.5: In an actual driving situation, which of these factors are you aware of?

You know your velocity and roughly that of the other car. You may have a vague idea of your reaction time and some idea of your car's braking ability. You also have an idea about the road conditions.
You have no idea about the other driver's reaction time or the other car's condition.

Activity Six - Tailgate Model: Worst Case Scenario

In this activity you will use a STELLA model to investigate factors which affect tailgating safety. In particular, you will be looking for the worst combinations of factors and determining the best car length to velocity ratio in these cases.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.2: ... suggest experimental approaches ...

Science.CLG 1.4: Demonstrate that data analysis is vital ...

Skills.CLG 1.5: Apply acquired knowledge and skills ...

Skills.CLG 4.2: Use technology effectively ...

Skills.CLG 5.2: Work cooperatively ....

Math.CLG 1.2: Model and interpret real-world situations ...

Math.CLG 3.1: Collect, organize, analyze and present data ...

Look back at your answers to question 4.4 in Activity Four.

Question 6.1: What was varied and what stayed the same?

Velocity and separation distance were varied while deceleration and reaction time are held constant.

Question 6.2: What other factors in the model could be varied?

Deceleration rates, especially with a difference between the front and back car. Reaction time.

There are thousands of possible combinations in this model. In an organized and reasonable manner, suggest in writing how the class might investigate the other factors (relative car velocities, decelerations and reaction times) to determine the safest following distance in worse combinations of conditions and still avoid collisions.

Students should be suggesting controlled variable experiments, such as keeping the velocities constant while investigating reaction times. Or keeping velocities constant while investigating different decelerations.

You want to guide students toward suggesting that the front car have good brakes while the tailing car has worse brakes and a poor reaction time. then students would vary car lengths and velocities since this is the way the rule is stated. Since most traffic travels at a relatively constant velocity, it will be a good simplification to continue to have the front and back car travel at the same velocity. This is another chance to have the class discuss simplifications made to models to keep them manageable.

Collect student ideas on a board or overhead. Then, together with the students, determine which experiments will be run and divide the class accordingly.

Use the model to perform the variations assigned to you. Be sure to keep accurate records of your results.

See some sample data in Appendix D.

After the class has finished, report your data to the class. As a class organize and summarize this data by using spreadsheets or graphs. Record the summary below.

Depending on your students abilities, you may wish to guide them in their organization and summary skills or you may choose to assign a few class leaders and let the class develop its own scheme.

Question 6.3: How do these results compare to the rule?

Students should now discover that the 1 car length per 10 mph rule is a better rule and in cases of high speeds or poor conditions, even greater distances are recommended.

Question 6.4: What factors which were not included in the model could affect your results? How might they affect them?

> **At this point students should be mentioning road conditions which would change the deceleration rates, driver conditions which would affect reaction times and age of the vehicles which would further affect deceleration times.**

Question 6.5: Considering your results and these additional factors, would you change the rule and how?

> **Students should see that the model suggests that the rule isn't cautious enough for the worst conditions.**

Activity Seven - Tailgating: Safety First!!

In this activity you will work with a group of students to design a public safety announcement (PSA) about the dangers of tailgating. You should use any data you acquired in this unit to date as well as additional resources. You may use any method (poster, overhead, video, audio or hypermedia) to present your PSA.

This activity meets in full or in part, the following Maryland Core Learning Goals and Expectations:

Science.CLG 1.6: Appropriate methods for communicating ...

Skills.CLG 3: Communication Skills

Skills.CLG 5.2: Work cooperatively ....

> **Divide the class in groups of three or four. You will want to give the students some time in class to work (45 mins?), some overnight time and about 30 mins for the total class to present.**

You and your group are junior members of an advertising firm. You have a chance to get the advertising contract with the State Department of Transportation and that could mean promotions for all of you. First, you must prepare a sample PSA, no longer than 1 min in length, which promotes traffic safety by focusing on the dangers of tailgating. You are competing with other advertising firms and all groups will present their ads on the same day. A decision about the awarding of the contract will be made at the end of the presentations.

Appendix A

Core Goals and 5 E's Match

Engagement:

Activity 1

Exploration & Explanation Cycle:

Activity 2 Science.CLG 1.3: Carry out scientific investigations ...
Math.CLG 3.1: Collect, organize, analyze and present data..

Activity 3 Science.CLG 1.6: Use mathematical processes ...
Science.CLG 5.1: Know and apply the laws of mechanics ...
Math.CLG 1.2: Model and interpret real world situations ...

Activity 4 Science.CLG 1.4: Demonstrate that data analysis is vital ...
Science.CLG 5.1: Know and apply the laws of mechanics ...

Activity 5 Science.CLG 1.4: Demonstrate that data analysis is vital ...
Skills.CLG 4.2: Use technology effectively ...
Skills.CLG 5.2: Work cooperatively ....
Math.CLG 1.2: Model and interpret real-world situations ...
Math.CLG 3.1: Collect, organize, analyze and present data ...

Extension:

Activity 6 Science.CLG 1.2: ... suggest experimental approaches ...
Science.CLG 1.4: Demonstrate that data analysis is vital ...
Skills.CLG 1.5: Apply acquired knowledge and skills ...
Skills.CLG 4.2: Use technology effectively ...
Skills.CLG 5.2: Work cooperatively ....
Math.CLG 1.2: Model and interpret real-world situations ...
Math.CLG 3.1: Collect, organize, analyze and present data ...

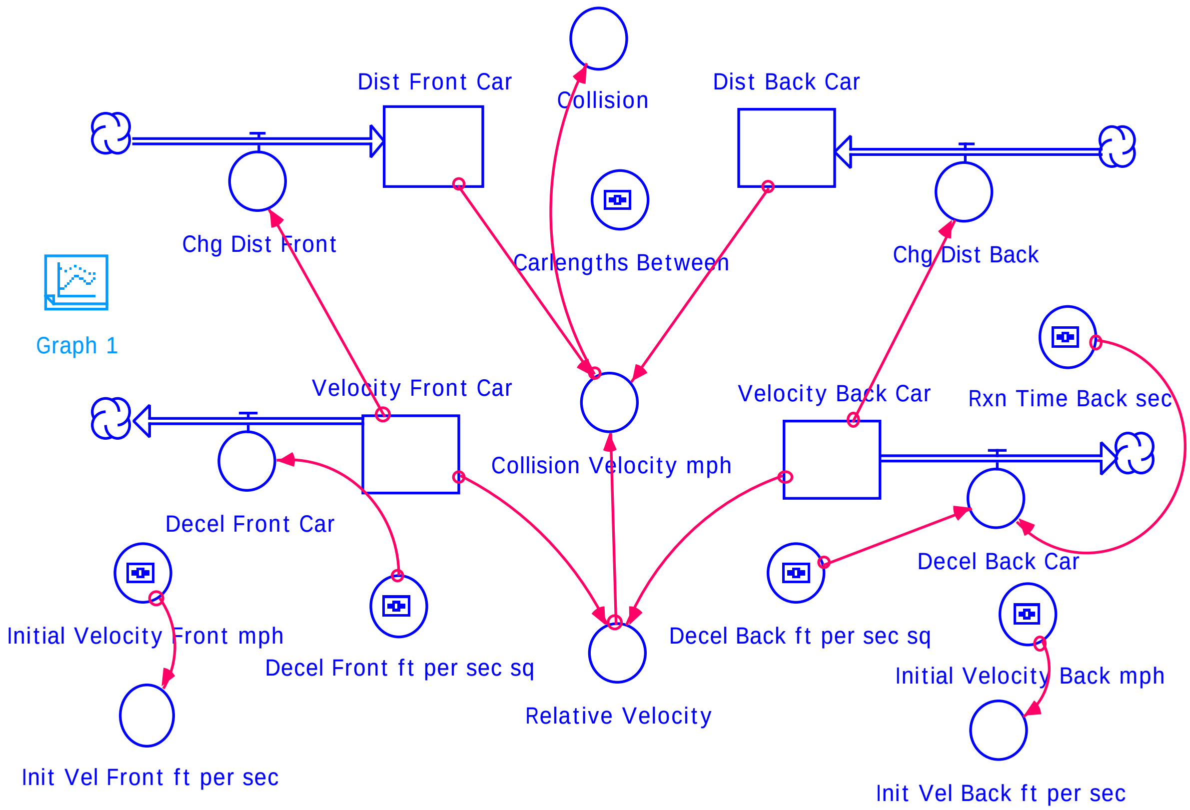
Evaluation:

Activity 4 Science.CLG 1.4: Demonstrate that data analysis is vital ...
Science.CLG 5.1: Know and apply the laws of mechanics ...

Activity 7 Science.CLG 1.6: Appropriate methods for communicating ...
Skills.CLG 3: Communication Skills
Skills.CLG 5.2: Work cooperatively ....

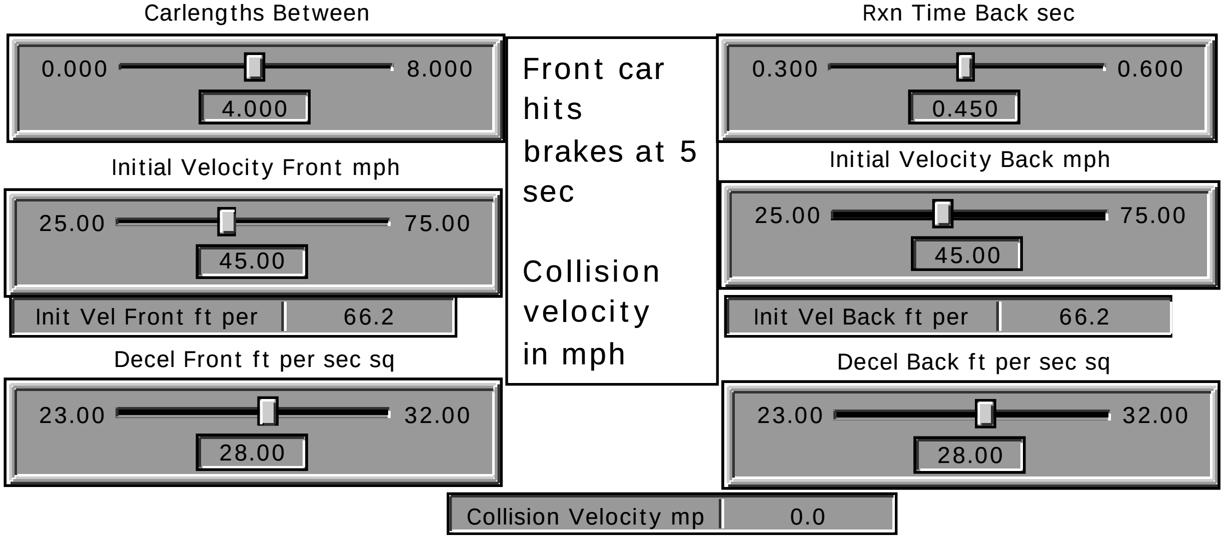
Appendix B

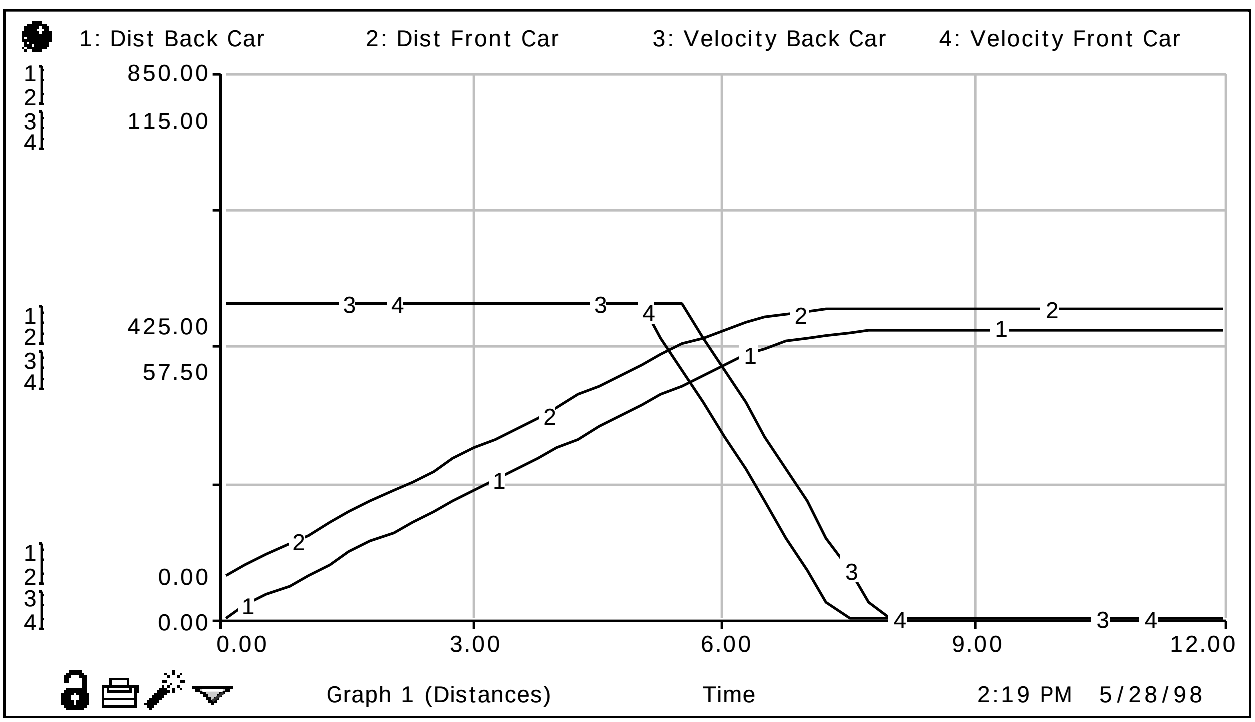
STELLA Model - Tailgate




```
Dist_Back_Car(t) = Dist_Back_Car(t - dt) + (Chg_Dist_Back) * dt
INIT Dist_Back_Car = 0
Chg_Dist_Back = Velocity_Back_Car
Dist_Front_Car(t) = Dist_Front_Car(t - dt) + (Chg_Dist_Front) * dt
INIT Dist_Front_Car = Carlengths_Between*16
Chg_Dist_Front = Velocity_Front_Car
Velocity_Back_Car(t) = Velocity_Back_Car(t - dt) + (- Decel_Back_Car) * dt
INIT Velocity_Back_Car = Init_Vel_Back_ft_per_sec

Decel_Back_Car = if time<(5+Rxn_Time_Back_sec) then 0 else
Decel_Back_ft_per_sec_sq
Velocity_Front_Car(t) = Velocity_Front_Car(t - dt) + (- Decel_Front_Car) * dt
INIT Velocity_Front_Car = Init_Vel_Front_ft_per_sec

Decel_Front_Car = IF time<5 then 0 else Decel_Front_ft_per_sec_sq
Carlengths_Between = 4
Collision = if Collision_Velocity_mph>0 then PAUSE else 0
Collision_Velocity_mph = if (Dist_Front_Car-Dist_Back_Car)>0 then 0 else
Relative_Velocity/1.47
Decel_Back_ft_per_sec_sq = 28
Decel_Front_ft_per_sec_sq = 28
```

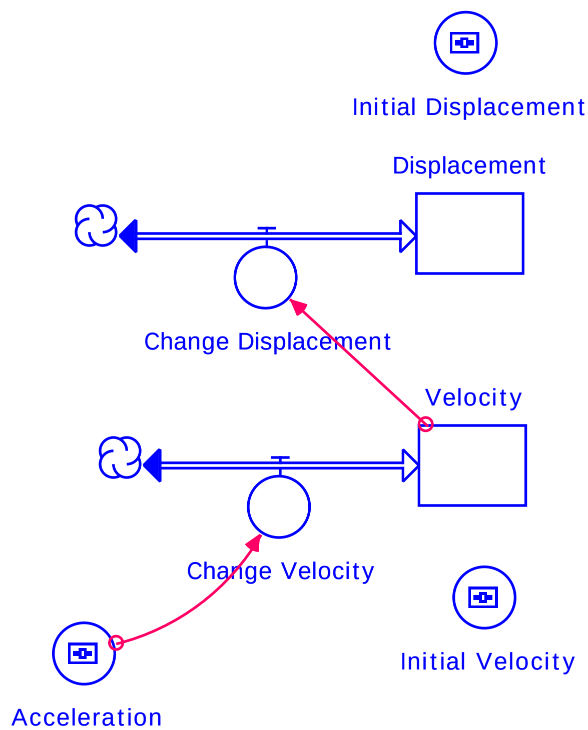
```
Initial_Velocity_Back_mph = 45
Initial_Velocity_Front_mph = 45
Init_Vel_Back_ft_per_sec = Initial_Velocity_Back_mph*1.47
Init_Vel_Front_ft_per_sec = Initial_Velocity_Front_mph*1.47
DOCUMENT:  1.47 = 5280 ft /mile  divided by 3600 sec/hour

Relative_Velocity = ABS(Velocity_Back_Car-Velocity_Front_Car)
Rxn_Time_Back_sec = 0.45
```





Appendix C

STELLA Pre-Model




```
Displacement(t) = Displacement(t - dt) + (Change_Displacement) * dt
INIT Displacement = Initial_Displacement
Change_Displacement = Velocity
Velocity(t) = Velocity(t - dt) + (Change_Velocity) * dt
INIT Velocity = Initial_Velocity
Change_Velocity = Acceleration
Acceleration = 0
Initial_Displacement = 0
Initial_Velocity = 0
```

Pre-Model Activity - Student Worksheet

Open the model. Manipulate the sliders to achieve the values given in the questions below. Run the model, observe the graph and explain it.

1. Set Displacement to 0, Velocity to 3 and Acceleration to 0. Sketch the graph and explain.

2. Set Displacement to 5, Velocity to 2 and Acceleration to 0. Sketch the graph and explain.

3. Set Displacement to 0, Velocity to 0 and Acceleration to 2. Sketch the graph and explain.

4. Set Displacement to 0, Velocity to 3 and Acceleration to 2. Sketch the graph and explain.

5. Set Displacement to 10, Velocity to 5 and Acceleration to -2. Sketch the graph and explain.

Pre-Model Activity - Annotated Student Worksheet

Open the model. Manipulate the sliders to achieve the values given in the questions below. Run the model, observe the graph and explain it.

1. Set Displacement to 0, Velocity to 3 and Acceleration to 0. Sketch the graph and explain.

This is a simple constant velocity graph.

2. Set Displacement to 5, Velocity to 2 and Acceleration to 0. Sketch the graph and explain.

This is constant velocity with an initial displacement. This should help students with the questions asked about the y-intercept in the tailgate graph.

3. Set Displacement to 0, Velocity to 0 and Acceleration to 2. Sketch the graph and explain.

This is a simple constant acceleration graph.

4. Set Displacement to 0, Velocity to 3 and Acceleration to 2. Sketch the graph and explain.

Constant acceleration with initial velocity.

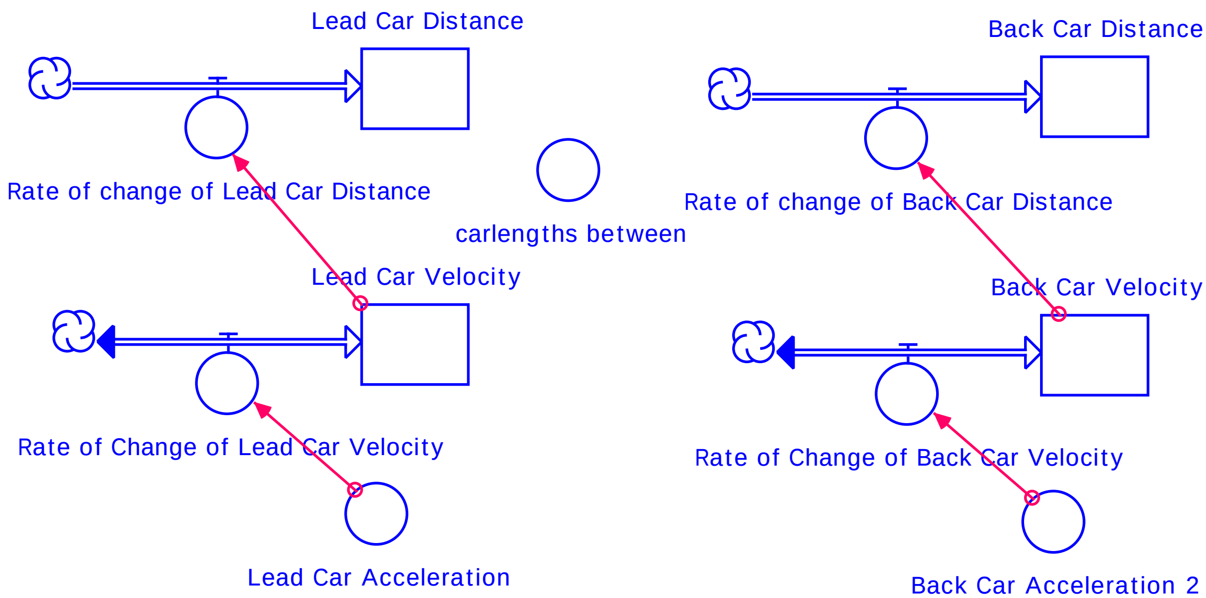
5. Set Displacement to 10, Velocity to 5 and Acceleration to -2. Sketch the graph and explain.

This example should prepare the students for the distance and velocity graphs which are seen in the tailgate model.

Appendix D

Building a Tailgate Model

Students can build a tailgate model if they have some experience with STELLA and the simple kinematics model or the pre-model included in this packet. Below is a possible simple model. The following page is intended as a student guidesheet to get them started. The simplest model can eliminate the “carlengths between” converter. It is nice to have for reference when working through some of the other worksheets.



Building a Tailgate Model

Let’s try building a simple model which can yield some information about two cars, one of which might be tailgating the other. Both cars will start with an initial velocity. The leading car will slam on the brakes (begin to decelerate) after 3 sec. The following car will hit the brakes a split second (reaction time) later.

Begin by building one set of icons for accelerated motion. You might want to refer to your previous motion models. Label all icons as the lead car (e.g. lead car position, lead car velocity,etc). In this case, the car must be able to decelerate, so velocity should be allowed to decrease (rate of change of velocity will be a biflow), but distance should not.

Q1: Will either velocity or distance be negative? ____________

Q2: What should the rate of change of distance flow equal? __________

After you have a set of icons for accelerated motion, have your teacher check them. Don’t worry about question marks in the stocks or acceleration converter at this point, they will be filled in later. Choose select all from the edit menu. Then choose copy and then paste. A second set of icons will appear with names like “lead car position 2”. While this set of icons is highlighted, move the group of them to a clean area of the screen. Then click on them one at a time and edit the names by replacing lead with back and deleting the 2’s. Have your teacher check the model when you are finished.

Now we’re ready to put some numbers in. You have to choose a set of units to run the model in. If velocity is to be in m/s then the braking (deceleration) should be in m/s^2. In the tailgate worksheets that follow, you will enter assigned values, but for the moment, decide on the units you will use (meters or feet) and enter the values as described below.

Both Position stocks should start at 0. Enter the initial velocity for each car in each velocity stock (60 mph = 27 m/s = 88 ft/s). Enter the braking rate for each car in the deceleration stock (9 m/s^2 = 29.6 ft/s^2). In the rate of change of velocity flow for the lead car, type

```
if time < 3 then 0 else lead_car_acceleration
```

This tells the model to have the car travel at constant velocity (acceleration = 0) for 3 seconds and then hit the brakes. Make sure your equation uses your terms for the lead car acceleration. For the velocity flow for the back car

```
if time <3.5 then 0 else back_car_acceleration
```

Q3: Why is the time greater? ______________________________________

Create a graph with both positions and velocities. Run the model and have your teacher check it. The model can be used to do the other tailgate worksheets.

Annotated Building a Tailgate Model

Let's try building a simple model which can yield some information about two cars, one of which might be tailgating the other. Both cars will start with an initial velocity. The leading car will slam on the brakes (begin to decelerate) after 3 sec. The following car will hit the brakes a split second (reaction time) later.

Begin by building one set of icons for accelerated motion. You might want to refer to your previous motion models. Label all icons as the lead car (e.g. lead car position, lead car velocity,etc). In this case, the car must be able to decelerate, so velocity should be allowed to decrease (rate of change of velocity will be a biflow), but distance should not.

Q1: Will either velocity or distance be negative? _ **No** __________

Q2: What should the rate of change of distance flow equal? **Velocity**

After you have a set of icons for accelerated motion, have your teacher check them. Don't worry about question marks in the stocks or acceleration converter at this point, they will be filled in later. Choose select all from the edit menu. Then choose copy and then paste. A second set of icons will appear with names like "lead car position 2". While this set of icons is highlighted, move the group of them to a clean area of the screen. Then click on them one at a time and edit the names by replacing lead with back and deleting the 2's. Have your teacher check the model when you are finished.

Now we're ready to put some numbers in. You have to choose a set of units to run the model in. If velocity is to be in m/s then the braking (deceleration) should be in m/s^2. In the tailgate worksheets that follow, you will enter assigned values, but for the moment, decide on the units you will use (meters or feet) and enter the values as described below.

Both Position stocks should start at 0. Enter the initial velocity for each car in each velocity stock (60 mph = 27 m/s = 88 ft/s). Enter the braking rate for each car in the deceleration stock (9 m/s^2 = 29.6 ft/s^2). In the rate of change of velocity flow for the lead car, type

```
if time < 3 then 0 else lead_car_acceleration
```

This tells the model to have the car travel at constant velocity (acceleration = 0) for 3 seconds and then hit the brakes. Make sure your equation uses your terms for the lead car acceleration. For the velocity flow for the back car

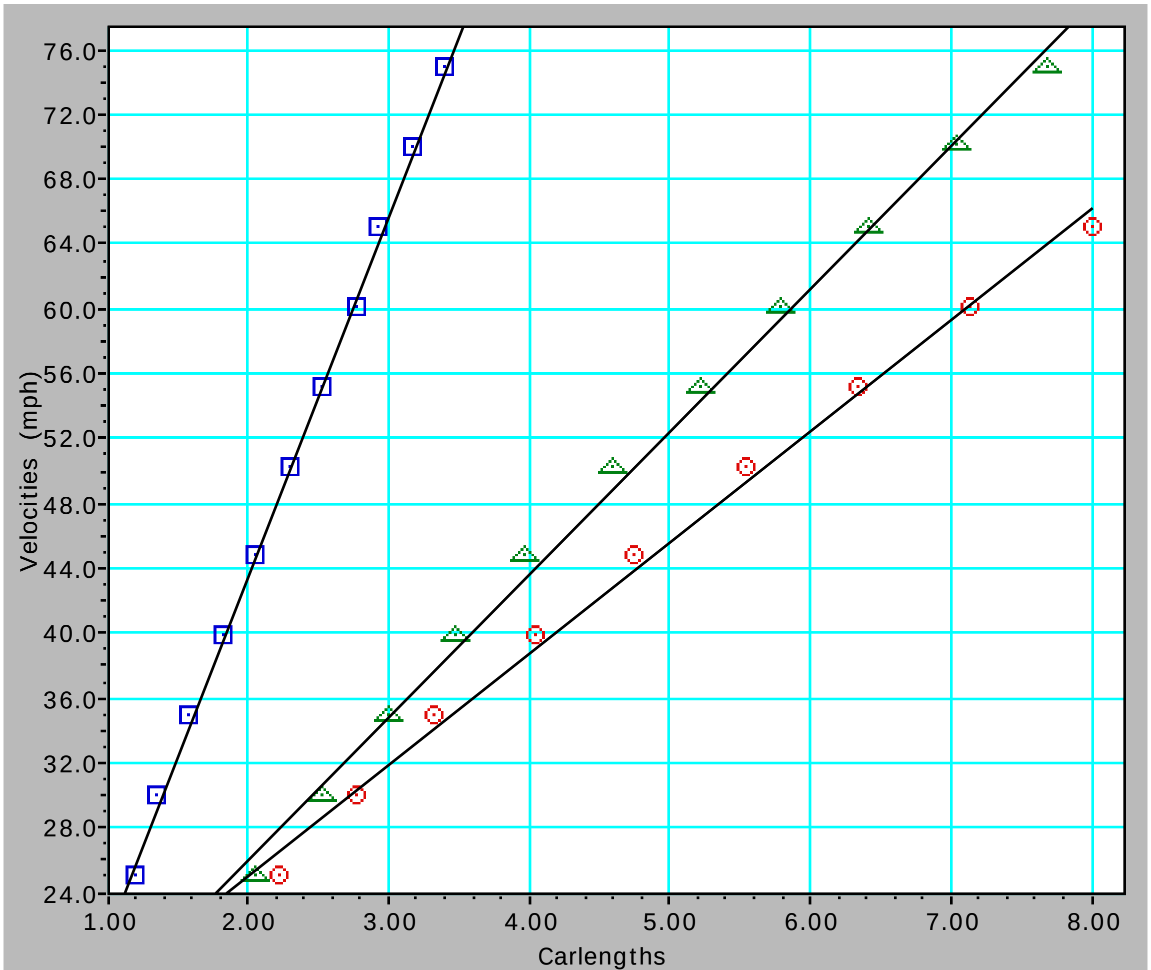
```
if time <3.5 then 0 else back_car_acceleration
```

Q3: Why is the time greater? **It includes a reaction time of 0.5 s**

Create a graph with both positions and velocities. Run the model and have your teacher check it. The model can be used to do the other tailgate worksheets.

Appendix E

Sample Results for Activity 5 and 6



Statistics:	Slope	Y Intercept	C.O.R.
Data Set 1	22.2±0.231	-0.768±0.552	1.00
Data Set 2	8.83±0.175	8.41±0.882	0.998
Data Set 3	6.87±0.170	11.3±0.892	0.998

Data Set One is for Activity Five - Decel = 28 ft/sec^2 and Reaction time = 0.45 sec
This data suggest 1 car length per 22 mph

Data Set Two and Three are Sample data for Activity Six
This data suggests 1 car length per 8.8 mph and 6.9 mph respectively
Set 2: Deceleration Front = 29.95 ft/sec^2, Deceleration Back = 24.96 ft/sec^2 and Reaction time = 0.52 sec
Set 3: Deceleration Front = 32 ft/sec^2, Deceleration Back = 23 ft/sec^2 and Reaction time = 0.6 sec

Sample Data for Graph Above

Data Set 1

Max. Velocity (mph)	Actual Max. Velocity (mph)	Separation Dist. (Car lengths)
25	25.00	1.19
30	29.95	1.35
35	34.90	1.58
40	39.85	1.82
45	44.80	2.06
50	50.25	2.3
55	55.20	2.54
60	60.15	2.77
65	65.10	2.93
70	70.05	3.17
75	75.00	3.41

Data Sets 2 and 3

Max. Velocity (mph)	Actual Velocity (mph)	Car lengths (Data Set 2)	Car lengths (Data Set 3)
25	25.00	2.06	2.22
30	29.95	2.54	2.77
35	34.90	3.01	3.33
40	39.85	3.49	4.04
45	44.80	3.96	4.75
50	50.25	4.59	5.55
55	55.20	5.23	6.34
60	60.15	5.78	7.13
65	65.10	6.42	8
70	70.05	7.05	8+
75	75.00	7.68	8+

Appendix F

Scoring Tool for Tailgate Worksheets

Activity 4:

Models: Student can use the graphical output generated by the computer model to explain the consequences of mathematical relationships underlying the model.

Questions from the Activity:

4.1: Why is the y-intercept for the distance of the front car larger than that of the back car?
4.2: Why are the velocity graphs flat at the beginning?
4.3: At what time does the front driver apply the brakes? What is your evidence?
4.4: Why do the velocity graphs have a downward slope in the second part of the graph?
4.5: Why do the distance graphs curve and then go flat?
4.6: Do these cars collide? What is your evidence?

Rubric Levels:

Outstanding(4): Student correctly answer each question about the graph in terms of the physical action (car is stopping) and the mathematics (car is stopping, which means it is decelerating and this will result in a negative slope for the velocity curve since the slope of that curve is the acceleration of the car).

Good(3): Student correctly answers 4 of the 6 questions using physical explanations and uses mathematical reasoning for at least 2 of these questions.

Fair(2): Student correctly answers 3 of the 6 questions using physical explanations and uses mathematical reasoning for at least 1 of these questions.

Poor(1): Student correctly answers 3 or fewer questions using physical explanations only.

Activity 6:

Models: Student recognizes the model as one of many potential models of the phenomenon under study and that the model is not identical to the phenomenon under study.

Questions from the Activity:

6.3: How do these results compare to the rule?

6.4: What factors which were not included in the model could affect your results? How might they affect them?

6.5: Considering your results and these additional factors, would you change the rule and how?

Rubric Levels:

Outstanding(4): Student identifies several factors that are not included in the model (e.g. road conditions) as well as others that are idealized and highly variable (e.g. reaction time and brake conditions). Student states that other models might include these factors and suggests that the driving rule possibly considers the worst combination of these.

Good(3): Student identifies several factors that are not included in the model (e.g. road conditions) or factors that are idealized and highly variable (e.g. reaction time and brake conditions). Student states that other models might include these factors and suggests that the driving rule possibly considers these.

Fair(2): Student identifies factors that are not included in the model (e.g. road conditions). Student states that other models might include these factors and suggests that the driving rule possibly considers these.

Poor(1): Student identifies one factor not included in the model. Student does not discuss other possible models and the rule that might develop from those models (i.e. student answers to questions 6.3 and 6.5 are minimal)

Appendix G
References

Background Article

Nicklin, R.C. "The Kinematics of Tailgating" The Physics Teacher, vol 35, Feb 1997, p 78-79

Web Pages

Onroads Rear End Accidents
http://onroads.com/onroads/mar_apr96/rearend.html

Excellent site for safety information, click on buttons at the bottom of the page

Software

STELLA by High Performance Systems