LOS ANGELES POLICE DEPARTMENT
TRAFFIC COLLISION INVESTIGATION INTERMEDIATE
1850-33630
Expanded Course Outline

Instructional Goal: To provide students with the knowledge and skills necessary to effectively conduct traffic crash investigations through proper physical evidence identification and documentation. Then, based on the accurate documentation of physical evidence, estimate the minimum speed of vehicles involved in a crash

Performance Objectives: Using lecture and learning activities, the students will:

- Understand the definitions and terminology used in the area of Traffic Crash Investigation and Reconstruction
- Properly and accurately identify and document different types of physical evidence
- Identify the basis for each numeric component of speed estimate equations
- Estimate the minimum speeds of vehicles based on physical evidence commonly encountered at the scene of traffic crash
- Complete time and distance analyses to determine position and sight line for drivers based on the aforementioned speed estimates

Day 1

I. COURSE INTRODUCTION AND OVERVIEW (1 Hr.)

A. Topic 1.0 - Introduction and Orientation

1. Instructors introduce themselves
2. Review POST attendance criteria
3. Orient students to facility

B. Brief Overview of training goals and objectives

1. Build upon the information taught in the POST Basic Academy and Basic Collision Investigation school
2. Definitions and terminology used in the area of Traffic Collision Investigation and Reconstruction
3. Identification and documentation of different types of physical evidence
4. The basis for each numeric component of speed estimate equations
5. Minimum speeds of vehicles based on physical evidence commonly encountered at the scene of traffic collisions
6. Calculation of time and distance analyses to determine position and sight line for drivers based on the aforementioned speed estimates

C. Required materials

1. Review what is needed to bring to class

   a. Calculator with square root function
   b. Blue Blitz ruler (provided)
   c. Compass
   d. Clipboard, pencil and eraser

D. Student responsibilities

1. Dress attire

2. Court

3. Sign in sheet

E. Skill Assessment

1. Conduct a survey of the class to see the level of math experience each student has

2. The first few hours of the course may be dry for those with strong math backgrounds, while stressing the importance of starting with the basics for those with strong backgrounds in other areas

3. **DISTRIBUTE:** Skill Assessment Survey

   a. Directions:

      1) Complete the survey to the best of their ability
      2) The survey is designed for the instructors to gauge where the class is, as a whole, mathematically
      3) Upon completion bring the paper to the front of the class

   b. An instructor will correct the Assessment Survey. The information obtained from the survey can be used by the instructors to determine a starting place for the learning activities during this course

F. Common Terminology

1. ACCELERATION (a)

   a. Rate of change of velocity with respect to time
   b. Acceleration may be either a positive value (acceleration), or a negative value (deceleration)

2. CHORD (C)
    a. A straight line connecting two points on an arc.

3. COEFFICIENT OF FRICTION or MU (f or μ)

    a. A number, expressed as a decimal, representing the resistance of an object sliding on a level surface

4. DISTANCE (d)
    a. A measurement between two points
    b. Can be expressed in any increment of measure (inches, meters, etc). Expressed in decimal feet for this class

5. ENDING VELOCITY (v_e)

    a. An ending rate of motion during any change of position with respect to time
    b. Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in feet per second for this class

6. ENERGY (E)

    a. The capacity to do work
    b. There are various kinds of energy; among them are:

        1) Potential energy
        2) Kinetic energy
        3) Heat energy
        4) Light energy
        5) Chemical energy

7. FORCE (F)

    a. That which influences motion
    b. A push or pull expressed in pounds

8. GRADE (G)

    a. The change in elevation in a specified direction along the centerline of a roadway or the path of a vehicle
    b. Grade is positive (+) if the surface rises in the specified direction and negative (-) if it falls in that direction

9. GRAVITY (g)

a. The force that pulls all things to the ground
b. The acceleration force of gravity is 32.2 fps^2

1) fps^2 is stated "feet per second squared"
2) **DEMONSTRATE**: This means that for every foot an object is falling, it is accelerated at a rate of 32 feet per second, every second:
   (a) In the first second the object falls 32.2 feet;
   (b) In the second, second, because the object is accelerating, it falls 64.4 feet;
   (c) In the third second, the object falls 96.6 feet for a total of 163.2 feet in 3 seconds

10. HEIGHT (h)

a. A vertical distance measured in inches or feet
b. The distance from the apex of something upright to the surface the object is resting on

11. INITIAL VELOCITY (v_i)

a. A starting rate of motion during any change of position with respect to time
b. Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in feet per second for this class

12. KINETIC ENERGY (KE)

a. Energy possessed by a body based on that object's motion

13. MASS (m)

a. The amount of matter in an object
b. Measured by the objects weight divided by the acceleration of gravity

14. MID-ORDINATE (m)

a. A line perpendicular to a chord which connects the mid-point of the chord to a point on the arc
b. Used to calculate an arc's radius

15. RADIUS (R)

a. A line segment from the center of a circle and any point on its circumference

16. RESULTANT COEFFICIENT OF FRICTION or DRAG FACTOR (f_r)

    a. An adjustment to the coefficient of friction, or mu (pronounced "mew"), taking into account the roadway grade, superelevation, and / or the braking efficiency of the vehicle involved

    b. A number, expressed as a decimal representing the coefficient of friction, plus or minus the grade of the surface, times the braking efficiency

17. SPEED (S)

    a. The rate of progress, usually without regard to direction
    b. Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in miles per hour (mph) for this class

18. TIME (t)

    a. A measurement, generally in seconds with respect to collisions
    b. The time over which a collision sequence occurs

19. VELOCITY (v)

    a. The rate of change of distance with respect to time
    b. Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in feet per second for this class

20. WEIGHT (w)

    a. The product of mass times gravity
    b. Can be expressed in any value of weight (pounds, kilograms, etc). Expressed in pounds for this class

    NOTE: The letter or symbol in parenthesis after each term is the letter or symbol variable used in the mathematical equations they will be using later in the week

    NOTE: Clarify any misinformation and ensure each student is familiar with the terms

G. Reinforce key learning points

1. In order to properly investigate and report traffic collisions, the investigator must have a clear understanding of the terminology that is accepted around the world in the traffic collision field

2. Knowledge of the terminology ensures accurate, consistent documentation and reporting

3. Knowledge of the basis for the variables used in the speed calculation equations enables an officer to use the equations in criminal cases and, if required, testify to them with confidence in court

II. TIRE MARKS & PHYSICAL EVIDENCE (2 Hr.)

A. Topic 2.0 - Introduction and Orientation

1. Brief overview of goals and objectives

   a. Identify types of tire marks
   b. Identify the characteristics unique to each type of tire mark presented
   c. Identify the methods used to establish direction of travel from tire marks
   d. Recognize methods of tire mark photography under differing conditions such as daylight, nighttime, etc

2. Importance of Tire Marks

   a. Tire marks are the most important type of physical evidence left by the vehicles at a traffic collision scene because they tell the complete story of how the collision occurred
   b. The collision investigator must properly identify and interpret the tire marks in order to accurately report the scene physical evidence for later analysis by either them (after this class), or a trained collision reconstructionist
   c. An important part of physical evidence documentation is photography
   d. Different photography techniques must be used in different situations in order for the photographs to properly depict the scene as it was at the time of the investigation

3. Basic principles of physics

   a. In the 1680s, Sir Isaac Newton studied and defined how objects move and interact with one another. Newton's cradle demonstration
   b. Newton's First Law of Motion
      1) A body will remain at rest or in uniform motion unless it is acted upon by an unbalanced force
      2) When a vehicle skids, it loses directional stability and slides in a straight line until it comes to a stop. This is an example of directional uniform motion. The vehicle comes to a stop because of the friction between the tires and the roadway (the unbalanced force)

3) Now add a collision into the mix. Without a collision, the vehicle described above slides in a straight line. If another vehicle collides with it while it is skidding (an unbalanced force), its direction changes
4) These changes in direction in tire marks are very important for collision investigators in that they can be used to establish the Area of Impact

c. Newton's Second Law of Motion
   1) The acceleration of an object is directly proportional to the applied force and inversely proportional to its mass, or, if the net force acting on a body is not zero, the body will be accelerated in the direction of the force
   2) This is why in traffic collisions, “size and speed wins”

d. Newton's Third law of Motion
   1) For every action there is an equal and opposite reaction, or, whenever one body exerts a force upon a second body, the second body exerts force upon the first
   2) This concept is used in more advanced accident reconstruction to determine the speeds of the vehicles and is beyond the scope of this class

4. Tire mark definition and characteristics

   a. Tire mark definition:
      1) A mark left on any surface by a tire through friction
      2) The term "tire mark” includes all evidence of marking

   b. The three basic methods of leaving visible tire marks:
      1) Extreme deceleration
         a) Braking causing the wheels to cease rotation
         b) Damage causing the wheels to cease rotation
      2) Extreme change of direction
         a) From an intentional effort on the part of the driver
         b) From an impact/contact with another object/vehicle
      3) Extreme acceleration
         a) Propelling force or thrust generated exceeds the pavements frictional resistance
         b) “Peeling out”: accelerating at a rate where the rear tires lose traction with the roadway

   c. What tire marks indicate
      1) The vehicle's actions
         a) Braking
         b) Accelerating

c) Turning

2) In some cases, the minimum speed of the vehicle
3) The vehicle's direction of travel
4) Location of the vehicle on the roadway surface
5) Point or area of impact
6) Possible mechanical failure

d. Types of tire marks: refer to "Characteristics of Tire Marks" in the Student Manual

1) Impending: wheel rotating slower than the forward motion of the vehicle
2) Locked wheel (Slides 17 & 18)
    a) Non-rotating wheel, moving in a straight or curved line in the original direction travel
    b) If tires in line with the skid, striations will be parallel to the direction of travel
    c) Front vs. rear characteristics
        (1) Front are darker on the outside edges and striations are lighter in color due over-deflection
        (2) Rear have light outside edges and darker striations due to under-deflection
        (3) Over-deflection and under-deflection caused by weight shift around the vehicle's pitch axis during heavy braking

NOTE: Safety Guidelines and instruct students to review and follow the guidelines

DEMONSTRATE: Use demonstration vehicle to describe the (3) axes of the vehicle:

a) Pitch Axis – horizontal axis from side to side; causes dip in front end of vehicle during braking
b) Roll Axis – horizontal axis from front to rear; causes lean to outside during turns
c) Yaw Axis – vertical axis from top to bottom; vehicle in spin rotates around this axis
    (1) All (3) axes pass through the vehicles center of mass

3) Four-wheel locked overlapping vs. four-wheel locked Independent
    a) Four wheel locked overlapping tire marks occur when the rear tires skid and mark directly over the marks left by the front tires. When calculating speed from four wheel locked, *overlapping* tire marks, deduct the

wheelbase or a standard 10 feet from the total skid length

b) Four wheel locked independent tire marks occur when all four skids can be seen independent of one another. No deduction of 10 feet for the wheelbase should be taken when applying the tire marks to a skid chart

4) Scrub marks
   a) A locked, braked, or rotating wheel of a vehicle sliding in other than a forward direction
   b) Usually left after impact, except when known to be caused by centrifugal force

5) Yaw marks
   a) Rotating tire mark made from a vehicle turning at a rate greater than the frictional force of the roadway
   b) Striations are perpendicular to the direction of travel
   c) Refer to the yaw mark diagram in the student manual to explain driver action evidence in the striations
      (1) The top drawing depicts the striation pattern left by a tire that is neither being braked or accelerated through the turn. The striations will be **very near perpendicular to** the path of travel
      (2) The middle diagram depicts the striation pattern left by a vehicle that is being braked through the turn. The striations will be at an angle **toward** the path of travel
      (3) The bottom diagram depicts the striation pattern left by a vehicle that is being accelerated through the turn. The striations will be at an angle **away** from the path of travel

6) ABS tire marks
   a) A mark left by a vehicle equipped with an Anti-lock Braking System
   b) The marks are generally very light in consistency and hard to see
   c) The tire motion is kept in the impending mode due to the application-release action of the brakes
   d) If turning during an ABS application, the resulting tire marks may look like the conventional yaw mark on the outside of the turn, and a conventional locked wheel tire mark on the inside of the turn

7) Skip skids

a) A mark left by a locked tire that loads and unloads on the roadway surface
b) This can be due to weight shift, a poor suspension or an uneven roadway
c) The gaps in the marks must be less than 5 feet

8) Gap skids
   a) A mark left by locked tires where the brakes have been applied, released and then reapplied
   b) The gaps in the marks must be over 5 feet

9) Acceleration marks
   a) A mark left on the roadway surface when the propelling force or thrust generated by the vehicle exceeds the roadway surface's frictional resistance causing the tires to spin
   b) Can resemble a locked wheel tire mark in that the striations will be parallel to the direction of travel. Differences are:
      (1) Weaved in nature
      (2) Start dark and end light and uneven
      (3) May see shards of rubber and roadway removed at the start of the mark

e. Other types of marks on the roadway
   1) Gouge marks
      a) Left by contact between a hard portion of the vehicle and the roadway (undercarriage, wheel, etc.), where roadway material is removed
      b) Occurs at Maximum Engagement where the vehicles can no longer crush, but have momentum that has to be dispelled. Generally the vehicles will be forced downward onto the roadway, causing the gouge marks
      c) Good indicator of the Area of Impact

   2) Scrape marks
      a) Left by contact between a hard portion of the vehicle and the roadway (undercarriage, sheet metal during rollover, etc.), where no roadway material is removed
      b) Can indicate post-impact direction and orientation of the vehicles

   3) Fabric transfer
      a) Left when an ejected motorist, pedestrian, bicyclist or motorcyclist slides across the roadway

b) Friction between the clothing and the roadway will tear fabric from the clothing or leave a colored "haze"

4) Human tissue transfer
   a) Also left when an ejected motorist, pedestrian, bicyclist or motorcyclist slides across the roadway
   b) Friction will tear exposed skin from person leaving a transparent deposit of tissue
   c) May or may not have blood with it

5) Vehicle fluids
   a) Spatter, pooling and runoff will indicate post-impact direction of travel, orientation and at rest position
   b) Document path as you would a tire mark

B. Photographing tire marks
   1. During daylight hours
      a. Take overall photographs of the tire marks in 20-foot increments, unmarked with chalk, as they were when you arrived at the scene. These photographs should follow the path of the tire marks
         1) Mark the starting points of the tire marks with chalk
         2) Mark the tire marks at 10-foot intervals from the point of impact back to the start of the tire mark
         3) Mark the ending points of the tire marks
         4) Mark the post impact tire marks from the point of impact forward to the end of the tire marks
         5) Re-photograph the marks from start to end at 20-foot intervals

      b. Photographing during darkness
         1) Identify types of lighting available at the scene
            a) Pop-up 35 MM flash unit
               (1) Short range
               (2) 10 - 12 feet
            b) Separate flash unit
               (1) Short to long range
               (2) As far as 150 feet, depending on the unit used
            c) Flash light or vehicle head lights
               (1) Short to medium range
               (2) Range depends on the amount of light supplied
            d) <u>Be aware</u> of the limits of your flash unit

         2) Nighttime photographing procedure
            a) Take overall photographs of the tire marks in 10-foot increments, unmarked with chalk, as they were when you arrived at the scene. These photographs should follow the path of the tire marks

b) Mark the starting points of the tire marks
c) Mark the tire marks at 10-foot intervals from the point of impact back to the start of the tire mark
d) Mark the end points of the tire marks
e) Mark the post impact tire marks from the point of impact forward to the end of the tire marks
f) Re-photograph the marks from start to end at 10-foot intervals. Follow through the point of impact to the ending point of the marks
g) Remember, you want a logical depiction of the tire marks from start to finish in both a unmarked state and then marked for identification

c. Other areas to photograph
   1) The at rest positions of the vehicles: These photos should be taken depicting the vehicles in relation to each other or a recognizable landmark
   2) Vehicle damage and identification
   3) Damage to objects

d. Other evidence:
   1) Scrapes or gouges in the roadway
   2) Fluid from vehicles or other sources
   3) Physical features of the roadway, including anything obscuring your vision
   4) There is a "Tire Mark Glossary" at the back of section 3.0 in the Student Manual for future reference

2. Court testimony
   a. Once calculations have been completed and are used to establish a violation for which one is to be prosecuted, they may have to be explained to a jury
   b. One of the main points of contention by the defense is usually the interpretation of the physical evidence (type of tire mark) and then its use to calculate the minimum speed of the vehicle

C. CLOSING: Reinforce key learning points

2. Officers assigned to collision investigation units cannot be mere report takers. They must be investigators

3. Knowledge of the characteristics of the physical evidence one may encounter at the scene of a traffic collision is necessary:
   a. To ensure accurate reporting and documentation of the collision

b. Because the speed calculations that are going to be learned this week are based on proper interpretation of the physical evidence

III. **MATH REVIEW** **(5 Hr.)**

A. Topic 3.0 - Introduction and Orientation

1. Brief overview of goals and objectives
   a. Demonstration of the ability to solve equations
   b. Demonstration of the use of a scientific calculator
   c. Application of basic algebra concepts to collision investigation equations

B. Algebra Review

1. Equipment needed:
   a. Ensure that each student has a working scientific calculator
   b. Several students may have taken algebra courses in school. This class may be a review and seem simple to you, but may be somewhat harder for others. If you have an algebra background, we may have you assist with some of the students that are having problems

2. Overview the following ground rules
   a. Notes on notation
      1) Multiplication signs: "x" or "●" or "()"
         a) 4 x 3 = 12
         b) 4 ● 3 = 12
         c) 4(3) = 12; This will be the notation used in this course

      2) Division sign: "÷" or "$\frac{x}{y}$" or "$\overline{)\quad}$"
         a) 12 ÷ 4 = 3
         b) $4\overline{)12}$ with quotient 3
         c) $\frac{12}{4} = 3$; This notation will be used in this course

      3) Radical sign: $\sqrt{\quad}$
         a) Used to notate the operation of finding the square root of the number under the radical
            (1) This is the number, that when multiplied by itself, equals the number under the radical

Example: $\sqrt{81} = 9$

4) Exponents: x^2

    a) Used to notate the operation of multiplying the base number by itself
    b) The only exponent used in this course will be the base number squared

Example: $9^2 = 81$

b. Use of a calculator in this class
    1) will be permitted
    2) Do not use the calculator to get ahead of the class
    3) Avoid use of the calculator's "arithmetic logic"
        a) Work out each step
        b) This enables the instructors to find any problems in the mathematical order of operations you may have had

c. It is important to know the calculator's functions. Officers have been asked to work through an equation in front of a jury

C. Using and Understanding Calculators
    1. Procedures

        a. Some of the students may be very familiar with the use of a calculator. Students with pre-existing mathematical knowledge will be paired up with those who have less math knowledge

    2. Four basic types of calculators:

        a. Basic
            1) Handles basic math operations as entered by the user
            2) Does not utilize the "Fundamental Order of Operations" when completing a series of calculations

        b. Arithmetic Logic
            1) Handles basic math operations as entered by the user
            2) Utilizes the Fundamental Order of Operations without user instruction

                - The Fundamental Order of Operations

3) For algebraic equations to produce the correct answer, the user has to follow a strict order of simplification while working toward the final result
4) Within each equation, the user must simplify in the following order:
    a) Parenthesis
    b) Exponents
    c) Multiplication
    d) Division
    e) Addition
    f) Subtraction

c. Scientific
1) Same as the Arithmetic Logic
2) Several additional functions such as

- Exponentiation and square roots

3) A single key is set to calculate the exponent function
4) A single key is set to calculate the square root function

- Logarithms

5) Exponent of the power to which it is necessary to raise a fixed number (the base) to produce the given number
6) For example, the logarithm of 100 (base 10) is 2 because 10^2 equals 100

- Trigonometric Functions

7) An area of mathematics involving triangles
8) Trigonometric calculations use the relationships between the sides and the angles of triangles to calculate position, distance, speed, and many other things
9) A variation on the scientific calculator replaces the scientific functions with statistical functions such as Standard Deviation and 'Sigma' functions

d. Programmable
1) Same as Scientific (or Statistical)
2) Have a limited memory that allows formulae to be entered and recalled

3. Determining Your Calculator's Functions

a. Enter the following equation exactly as given

2 <plus button> 3 <multiplication button> 4 <equal button>

a) If the answer is 20, then you have a Basic Calculator only
b) If the answer is 14, then you have a calculator with Arithmetic Logic
c) If you have any other answer, you did something wrong. Go back to the start and try again

b. If the calculator has Arithmetic Logic, it is no longer necessary to be concerned with the Fundamental Order of Operations in calculations
c. Example:
1) 50 - 2 + 4 * 3 * 2 =
2) Solution: (as your calculator "sees" it)
3) 50 - 2 + 24 =
4) 48 + 24 =

Answer: 72

d. It is still necessary to watch for parentheses

D. Basic Mathematical Principles

1. Exponents

a. A small figure placed to the upper-right of a number showing the number of times to multiply that number by itself
b. This class will only use the square exponent

Example: $9^2 = 81$ is the same as writing 9(9) = 81. We multiply the base number (9) by itself, one time

c. Determining the square of a number (by use of the calculator)
1) Enter the number you are seeking to find the square of
2) Push the Square Key [x^2]

Example: Enter 9; Press [x^2] ; The answer should show 81

3) Some calculators may have to use the “Inverse” or “2nd” function to calculate the square

Example: Enter 9; Press [2nd] or [INV] ; then [$\sqrt{\ }$] ;

The answer should show 81

2. Multiplication

   a. Multiplying factors in an equation
   b. May be seen as described before, two numbers multiplied together notated by parenthesis

   Example: 4(3) = 12

   c. May also be seen in an equation as two variables (symbols) placed next to each other

   Example: $d = \bar{v}t$ Where: d = distance in feet
   v = velocity in feet per second
   t = time in seconds

   To calculate the distance, one has to multiply the velocity factor by the time factor

3. Division

   a. Dividing factors in an equation
   b. Will be notated as one number "over" another. Always divide the top number, the numerator, by the bottom number, the denominator

Example: $\frac{12}{3} = 4$ Divide the bottom number into the top number

4. Addition - Adding the factors in an equation

5. Subtraction - Subtracting the factors in an equation

6. Square root

   a. The root of a number is another number that, when multiplied by itself, equals the original number
   b. Determining the root of a number (by use of the calculator)

      1) Enter the number you are seeking to find the root of

      2) Push the Square Root Key [$\sqrt{\ }$]

Example: Enter 81; Press $\sqrt{}$; The answer should show 9

3) Some calculators may have to use the "Inverse" or "2^{nd}" function to calculate the square root

Example: Enter 81; Press [2^{nd}] or [INV] ; then [x^2] ;

The answer should show 9

E. The Rules of Algebra

1. The rules of algebra show us how to rearrange symbols in an equation
2. Typically, accident reconstruction formulas allow us to calculate a quantity, such as speed in the slide-to-stop equation:

$$S = \sqrt{30\ d\ f}$$

3. In this equation, several symbols appear, with the unknown quantity represented by a symbol that is isolated all by itself on the left side of the equation. All of the known quantities in the equation are either numbers or symbols representing values that have been obtained through measurements, or that have been supplied to us. To solve for the unknown quantity, we simply substitute in the numbers and do the mathematical operations indicated by the formula. For instance, if f = 0.7 and d = 84 feet

$$S = \sqrt{30\ d\ f}$$
$$S = \sqrt{30\,(84)(\,0.7\,)}$$
$$S = \sqrt{1764}$$
$$S = 42\ \text{MPH}$$

4. When we begin with the underlying physical principles that lead to the reconstruction formulas, the unknown quantity usually isn't isolated on the left-hand side initially. We therefore must use the rules of algebra to move the various symbols around until the unknown symbol is all by itself on the left-hand side

5. Not many rules are required, but for those who have not used algebra extensively, some practice is required to become proficient at applying those rules. We will express each rule in words, then symbolically, and give a numerical example

   a. **Rule 1**: If two quantities are equal, one can be substituted for the other

If a = b, and a = x, we can also write b = x

Example: From the definitions class:

$$KE = \frac{1}{2}mv^2 \qquad \text{and} \qquad m = \frac{w}{g}$$

Therefore:

$$KE = \frac{1}{2}\left(\frac{w}{g}v^2\right) \qquad \text{or} \qquad KE = \frac{wv^2}{2g}$$

b. **Rule 2**: If a quantity is subtracted from its equal, the result is zero
If a = b, then a - b = 0

To isolate the unknown:

$$X + 4 = 36$$
$$X + 4 - 4 = 36 - 4$$
$$X = 32$$

c. **Rule 3:** If a quantity is divided by its equal, the result is one
If a = b, then a/b = 1

Example:

$$d = \bar{v}t$$
$$\frac{d}{t} = \frac{\bar{v}t}{t}$$
$$\frac{d}{t} = \bar{v}(1)$$

d. **Rule 4:** Adding (or subtracting, multiplying, dividing) the same amount to equal quantities results in two new quantities that are still equal

If a = b, then a + c = b + c

Example: If two cars have the same weight (e.g., a = 3200 lbs and b = 3200 lbs), then a = b, and adding the same weight to each (a driver whose weight is given by c = 160 lbs) will produce occupied cars whose weights are the same:

$$a = b$$
$$a + c = b + c$$
$$3200\,lb = 3200\,lb$$
$$3200\,lb + 160\,lb = 3200\,lb + 160\,lb$$
$$3360\,lb = 3360\,lb$$

e. **Rule 5**: Adding (or subtracting) 0 to a quantity does not change its value

   a + 0 = a   and   a - 0 = a

f. **Rule 6**: Multiplying (or dividing) a quantity by 1 does not change its value

   (a)(1) = a   and   a/1 = a

g. **Rule 7**: The order of multiplying (or adding) two numbers is immaterial

   ab = ba   and   a + b = b + a

   Example:

   (3)(7) = 21 and (7)(3) = 21. Likewise, 3 + 7 = 10 and 7 + 3 = 10

h. **Rule 8:** The order of equality is immaterial

   If a = b   then   b = a

   Example: If, in an original equation, the unknown quantity is on the right-hand side, this rule allows us to place it on the more familiar left-hand side

   If ab = x and we know that a = 3 and b = 5, then (3)(5) = x, or x = (3)(5) = 15

i. **Rule 9 :** The product of the sum is the sum of the products

   a(b + c) = ab + ac

   Example: If a = 3, b = 4, and c = 5, we can write:

$$\begin{aligned} a(b+c) &= (3)(4+5) \\ &= (3)(9) \\ &= 27 \end{aligned}$$

But we also have:

$$\begin{aligned} ab+ac &= (3)(4)+(3)(5) \\ &= 12+15 \\ &= 27 \end{aligned}$$

j. **Rule 10:** The quotient of a sum is the sum of its quotients

$$\frac{a+b}{c}=\frac{a}{c}+\frac{b}{c}$$

Example: If a = 4, b = 8, and c = 2, we have:

$$\frac{a+b}{c}=\frac{4+8}{2}=\frac{12}{2}=6$$
$$\frac{a}{c}+\frac{b}{c}=\frac{4}{2}+\frac{8}{2}=2+4=6$$

Note: It <u>is not true</u> that:

$$\frac{a}{b+c}=\frac{a}{b}+\frac{a}{c}$$

6. These various rules can be applied to an equation where the unknown quantity is not all by itself. For example, if, in the equation, a known quantity is added to the unknown quantity, we can subtract the known quantity from both sides

   Example: The equation from basic physics that relates the acceleration of an object to it's change in velocity is given by:

$$a=\frac{V_e - V_i}{t}$$

   a. Apply the rules of algebra to this equation to find the final velocity if we know the acceleration, time and initial velocity

      Solution: We want to manipulate the equation so that the unknown quantity, Ve, is all by itself on one side of the equation. To do that, we can first get rid of the t in the denominator by multiplying both sides of the equation by the same quantity, t, and using the fact that equals divided by equals produces 1

$$a = \frac{V_e - V_i}{t}$$

$$at = \frac{V_e - V_i}{t} t$$

$$at = \frac{V_e - V_i}{t} t = (V_e - V_i)(1)$$

$$at = V_e - V_i$$

b. We now need to get rid of the V_i that is with the V_e. We can do that by adding V_i to both sides of the equation
(Side 34)

$$at = V_e - V_i$$
$$at + V_i = V_e - V_i + V_i$$
$$at + V_i = V_e + 0$$
$$at + V_i = V_e$$

We can now swap the two sides of the equation to get the unknown, V_e all by itself:

$$V_e = at + V_i$$
$$V_e = V_i + at$$

F. Solving an Equation for One Unknown

1. Procedure
   a. Addition and subtraction are inverse operations

x + 3 = 8

$$x + 3 = 8$$
$$-3 = 8 - 3$$
$$x = 5$$

5 + y = 13

$$5 + y = 13$$
$$-5 \quad = 13 - 5$$
$$y = 8$$

6 + a =

$$
\begin{aligned}
6 + a &= 18 \\
-6 \quad &= 18 - 6 \\
a &= 12
\end{aligned}
$$

x - 10 = 2

$$
\begin{aligned}
x - 10 &= 2 \\
+10 &= 2 + 10 \\
x &= 12
\end{aligned}
$$

y - 3 = 14

$$
\begin{aligned}
y - 3 &= 14 \\
+3 &= 14 + 3 \\
y \quad &= 17
\end{aligned}
$$

2. Multiplication and division are inverse operation

3x = 12

$$
\begin{aligned}
3x &= 12 \\
\frac{3x}{3} &= \frac{12}{3} \\
x &= 4
\end{aligned}
$$

4y = 16

$$
\begin{aligned}
4y &= 16 \\
\frac{4y}{4} &= \frac{16}{4} \\
y &= 4
\end{aligned}
$$

16b=32

$$
\begin{aligned}
16b &= 32 \\
\left(\frac{16b}{1}\right)\left(\frac{1}{16}\right) &= \left(\frac{32}{1}\right)\left(\frac{1}{16}\right) \\
b &= 2
\end{aligned}
$$

$6x = 30$

$$6x = 30$$
$$\frac{6x}{6} = \frac{30}{6}$$
$$x = 5$$

$\frac{x}{3} = 12$

$$\frac{x}{3}(3) = 12(3)$$
$$x = 36$$

$\frac{y}{4} = 10$

$$\frac{y}{4}(4) = 10(4)$$
$$y = 40$$

3. Negative numbers

   a. In the equations we will be using, there will be negative numbers, such as negative acceleration (deceleration)
   b. Number line -10....-5....0....5....10
   c. Multiplication of negative numbers
      1) Multiplication of positive numbers will result in a positive answer

         Example: 5(3) = 15

      2) Multiplication of a positive number and a negative number will result in a negative answer

         Example: 5(-3) = -15

      3) Multiplication of a negative number and a positive number will result in a negative answer

         Example: -6(6) = -36

      4) Multiplication of a negative number and a negative number will result in a positive answer

         Example: -5(-5) = 25

   d. The following examples will be completed with the class
      1) (5 + 3)(2) + 6(5 - 8)(3) =

         (8)(2) + 6(-3)(3) =

16 + (-54) = -38

2) 3(x - 26) - 30 = Where x = 12

$$3(x - 26) - 30 =$$
$$3(12 - 26) - 30 =$$
$$3(-14) - 30 =$$
$$-42 - 30 = -72$$

4. The use of parentheses

   a. To replace a multiplication sign

      Example: The equation 2 x 4 will be expressed as 2(4)

      The equation 2 x “X” will be expressed as 2X

   b. To “force” an expression to be considered as a single number or group of numbers exempt from the Fundamental Order of Operations
   c. The following examples will be completed with the class

      1) 3(x – 26) – 30 = Where x = 12

$$3(x - 26) - 30 =$$
$$3(12 - 26) - 30 =$$
$$3(-14) - 30 =$$
$$-42 - 30 = -72$$

      2) Where a = 7

$$2(a + b) + 3a - \frac{b}{2} =$$

$$2(a+b)+3a-\frac{b}{2}=$$
$$2(7+2)+3(7)-\frac{2}{2}=$$
$$2(9)+3(7)-\frac{2}{2}=$$
$$18+21-1=$$
$$39-1=38$$

d. Nested Parentheses are often used in complex equations. Always work "from the inside-out" by performing the operations within each basic group first

1) The following example will be completed with the class

$$6(\frac{(8-2)}{3})-10=$$

$$6(\frac{(8-2)}{3})-10=$$
$$6(\frac{6}{3})-10=$$
$$6(2)-10=$$
$$12-10=2$$

5. Repeated Multiplying of a Factor. Base, Exponent and Power

a. Base: The number being used as a repeated factor
b. Exponent: The number which indicates how many times the base is to be repeated
c. Power: The answer obtained

Base $^{\text{Exponent}}$ = Power

d. Complete the following example with the class

- $5^2 =$

Solution: (5)(5) =

Answer: 25

e. Square Root: The root of a number as determined by a radical sign. The root power is determined by the number to the left and above the root sign. To determine the root of a number we will utilize the calculator

Square Root - $\sqrt{25}$

$$\sqrt{(25+6)} =$$
$$\sqrt{31} = 5.56$$

1)

2)

$$\sqrt{5^2 + (25)(3)} =$$
$$\sqrt{25 + (25)(3)} =$$
$$\sqrt{25 + 75} =$$
$$\sqrt{100} = 10$$

3)

$$\sqrt{0^2 + (25)(3)} =$$
$$\sqrt{0 + 75} =$$
$$\sqrt{75} = 8.66$$

4)

$$\sqrt{0^2 - (25)(-3)} =$$
$$\sqrt{0 - (-75)} =$$
$$\sqrt{0 + 75} =$$
$$\sqrt{75} = 8.66$$

5)

$$\sqrt{0^2 - (-25.32)(50)} =$$
$$\sqrt{0 - (-1266)} =$$
$$\sqrt{0 + 1266} =$$
$$\sqrt{1266} = 35.58$$

10. Decimals and Fractions

    a. For the calculations from the equations the Los Angeles Police Department is using, there will be no use of fractions. All measurements, or fraction of a foot, will be converted to a whole number and decimal equivalent to the fraction

    Example:

    4 1/2 feet is the same as

    4' 6" is the same as

    4.5'

    b. To convert inches to feet you have to divide the inches by 12 (number of inches in a foot)

    Example: $9'' = \frac{9}{12} = .75'$

    c. To convert back to inches you multiply the decimal amount by 12. The product will not be exact

    Example: $.75\,(12'') = 9''$

11. Percent Conversions

    a. Changing Percent to Decimal

    To change a percent value to a decimal value, divide the percent value by 100

    Example:

$$35\% = \frac{35}{100} = .35$$

    b. Changing a Decimal to Percent

    To change a decimal value to a percent value, multiply the decimal value by 100

Example:

$$.35 = .35(100) = 35\%$$

G. CLOSING: Reinforce key leaning points

1. The basic Order of Operations must be used in order to use the equations you are going to learn in this class. If they are not used, the wrong answer will result

2. Pay special attention to negative numbers as they play an important part in the resulting answer

3. Knowledge of algebraic equation manipulation techniques will help to rearrange equations to isolate the unknown

Day 2

IV. MATH REVIEW AND QUIZ (1 Hr.)

A. Provide students with opportunity to ask questions about Math review covered the previous day

1. Provide basic overiview of what was covered during Topic 3.0 review

2. Hand out Math Quiz Number 1

3. Grade a return quiz

V. EVIDENCE DOCUMENTATION (3 Hr.)

A. Topic 4.0 - Introduction and Orientation

1. Brief overview of goals and objectives

a. Review of importance of evidence documentation

B. Methods of Measuring and Documenting Physical Evidence

1. Tools for measurement

a. Pacing – estimating a distance by “walking it off”. The goal is to take steps that are three feet (one yard) long in order to calculate the distance

1) This method is very inaccurate because it is difficult to be consistent with each step
2) Length of pace needs to be checked

a) Those with shorter legs may have to exaggerate their normal step
b) Those with longer legs may have to shorten their normal step

b. Rollermeter – a wheeled device that measures distance as it is rolled on a surface
1) More accurate than pacing over long distances
2) Still not the most accurate because some distance can be added through the bouncing of the rollermeter on rough surfaces
3) Must frequently be tested for accuracy
4) Know the increments of measure
a) Tenths of feet
b) Inches

c. Tape measures
1) Accurate when used properly
2) Difficult to use over very long distances
3) When using as a base line or reference line, ensuring the tape measure is at 90 degrees to the base curb is critical
4) Different types available
a) Steel
b) Cloth
c) Increments of inches or feet

2. The four steps of preservation of non-recoverable physical evidence: Identify, measure, record and photograph

a. Identify the evidence
1) Attempt to identify which tire left the tire mark or which vehicle and part of that vehicle left the gouge or scrape mark
2) Identify how each tire mark was left (locked wheel, yaw, post-impact scrub, print, etc.)
3) Match damage to vehicle undercarriage or suspension to gouge and scrape marks

b. Measure the evidence
1) Using an approved method of measurement, locate the position of the evidence on the surface
2) Distinguish where changes of direction are located identifying pre and post impact tire marks separately
3) <u>Always</u> record a starting point and an ending point for each piece of evidence. Yes, even if the evidence is only 4 inches long

4) At rest positions of vehicles is important evidence: Measure all four tires for Class I reporting situations

c. Record the measurements
   1) Keep field notes neat and uniform for ease of transfer to “Physical Evidence” section “f” of your T/C report
   2) Use reporting format taught in the Basic CI class
   3) Identify method of measurement used
      a) Coordinate method: 90 degrees from two curb lines
      b) Reference line
      c) Reference points

d. Photograph the evidence
   1) Photograph the scene as it was when you arrived
   2) Mark evidence with chalk, lumber crayon, paint
   3) Re-photograph the evidence

VI. SKID DOCUMENTATION FIELD PROBLEM (4 Hr.)

A. Brief overview of goals and objectives

1. Review field deployment procedures
   a. Safety brief

2. Students will respond to the intersection where the instructor has previously laid down tire marks on the roadway

3. The field project is worth 20 points toward the final grade

4. Students will:

   a. In small groups, measure the intersection and physical evidence with the tools provided
   b. Complete their own basic field sketch and field notes to be used upon return to the classroom

5. In the classroom the students will:

   a. Diagram the intersection and physical evidence, to scale, on the front of the paper
   b. Briefly describe and document the location of the physical evidence on the top half of the back of the paper
   c. On the bottom half of the back of the paper, describe the components of the evidence, justifying the direction of travel of the vehicle and the type of tire mark(s) documented

6. Using the proper tools and methods of documentation helps produce consistency and confidence in reporting and court testimony

B. Reinforce key learning points

1. Properly identifying and documenting the various types of physical evidence encountered at the scene of a traffic collision is necessary to complete a speed analysis

2. Photography is an integral part of evidence documentation that cannot be overlooked

Day 3

VII. DRAG FACTOR AND GRADE (2 Hr.)

A. Topic 5.0 - Introduction and Orientation

1. Students will attempt to provide the definitions for the following terms:

a. ACCELERATION (a)

1) Rate of change of velocity with respect to time
2) Acceleration may be either a positive value (acceleration), or a negative value (deceleration)
3) The equation used to determine the acceleration rate of a vehicle is: $a = fg$

b. GRAVITY (g)

1) The force that pulls all things to the ground
2) The acceleration force of gravity is 32.2 fps^2

c. BRAKING EFFICIENCY (B_e)

1) A given vehicle's ability to retard its forward velocity
2) The number of wheel groups marking divided by the total number of wheel groups

d. COEFFICIENT OF FRICTION or MU (f or μ)

1) A number, expressed as a decimal, representing the resistance of an object sliding on a level surface

e. GRADE (G)

1) The change in elevation in a specified direction along the centerline of a roadway or the path of a vehicle
2) Grade is positive (+) if the surface rises in the specified direction and negative (-) if it falls in that direction

f. DRAG FACTOR or RESULTANT COEFFICIENT OF FRICTION (f_r)

1) A number, expressed as a decimal, representing the coefficient of friction, plus or minus the grade, times the braking efficiency
2) Expressed as a mathematical equation:

$$f_r = B_e(f \pm G)$$

g. SPEED (S)

1) The rate of progress, usually without regard to direction
2) Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in miles per hour (mph) for this class

h. VELOCITY (v)

1) The rate of change of distance with respect to time
2) Can be expressed in any value of motion (miles per hour, meters per second, etc). Expressed in feet per second for this class

B. Methods of Determining the Coefficient of Friction

1. Three basic ways to determine the coefficient of friction for a given roadway

a. The most accurate method is to conduct test skids
    1) **DISTRIBUTE**: Safety Guidelines and instruct students to review and follow the guidelines
    2) Best scenario is to duplicate the conditions of the collision by:
        a) If possible, using the vehicle involved in the collision
        b) Conducting the test skids on the same roadway near the AOI
        c) Conducting the test skids as soon after the collision as possible to duplicate the weather and roadway conditions

    3) Procedure for conducting test skids
        a) Completely block off the roadway
        b) Keep safety first in mind

c) Drive the vehicle at a steady rate. This speed can be documented by using a radar or laser device or the speedometer
d) After skidding the vehicle to a stop, measure the skid distance. The distance can be documented by using a bumper gun or spotters
e) When the speed of the vehicle and skid distance have been determined, place the data into the following formula:

$$f = \frac{S^2}{30d}$$

f) The result is the coefficient of friction for the roadway
g) To ensure an accurate result is obtained, there should be a minimum of three tests completed

b. Another method that can be used is a drag sled

1) A drag sled uses a section of tire filled with concrete, which is pulled along the surface. A scale is used to determine the amount of force needed to pull the sled
2) Procedures for using a drag sled
   a) Weigh the sled with the same scale used during the pull phase
   b) Pull the sled across the surface noting the amount of force needed to keep the sled in motion
   c) Enter this data into the following equation:

$$f = \frac{F}{w}$$

   d) Drag sled areas of caution
      (1) When the sled is pulled across the surface, the scale must be pulled horizontal to the surface. Any angle in the direction of the pulling force will skew the result
      (2) Do not record the highest force needed to pull the sled. The force will be at its highest level just before the sled begins to slide across the surface. This is because it takes more force to break the static resistance of the tire to the surface than it does to keep the sled moving once it has begun to slide

c. The final method to determine the coefficient of friction of a roadway is to use published tables
1) Refer to the chart in the Student Manual

2) The chart's components are:
    a) Descriptions of different road surfaces
    b) Pavement condition (dry or wet)
    c) Vehicle speed range

3) Students will locate the range of coefficient of frictions for the following examples
    a) Portland Cement, Traveled, Dry 45 miles per hour:
        Answer: 0.60 - 0.75

    b) Asphalt, New Sharp, Raining, 25 miles per hour
        Answer: 0.50 - 0.80

2. Factors effecting the coefficient of friction

    a. Roadway surface: Asphalt, concrete, dirt, gravel, etc.
    b. Tires
        1) Passenger cars use a soft compound to help with the comfort of the ride
        2) Commercial truck tires are made with a much harder compound to help with tire wear and durability
        3) Do not apply the published tables provided in this class to vehicles with commercial grade tires

    c. Grade
        1) Upgrade (+) or downgrade (-)
        2) Superelevation or banking
        3) Roadway crown

    d. Weather

    e. Other factors that are present, but that are so minute that we do not account for them
        1) Higher speeds
        2) Wind
        3) Vehicle weight
        4) Tire size

3. How braking efficiency can affect the stopping ability of a vehicle

    a. Worn brakes can cause the brake system to not apply the pressure needed to properly stop the vehicle

    b. Low brake fluid causes the brake calipers to travel an insufficient distance to squeeze the brake pads properly
    c. Brakes that are out of adjustment will cause longer stopping distance

d. Brakes on an overloaded vehicle cannot stop the vehicle that is over the weight specifications for the system
e. A loss of hydraulic or air pressure cannot properly apply pressure to the brake system
f. Brake fade is caused during high speed driving and causes loss of brakes due to extreme heat in the brake pads and rotors

4. Other considerations

a. Pedestrians that are sliding or tumbling on the roadway also have coefficient of frictions
b. Down motorcycle – gouging of the pavement or sliding
c. Sheet metal sliding on the roadway during a rollover must be considered and has a coefficient of friction as well

D. Determining Roadway Grade

1. Ask the students if they have had to determine the grade of a roadway surface during a collision investigation

2. Have the students describe in detail the methods and tools that can be used to determine the roadway grade

a. 100” string, line level and tape measure method

1) Attach the line level to one end of the 100” string

2) Hold the end of the string opposite the line level on the ground

3) Pull the string tight and level the string using the line level

4) Measure 90 degrees from the level string to the roadway surface. This measurement is equal to the percentage of grade of the street

5) Have the students explain why the measurement to the ground is equal to the percent grade of the roadway using the following
example:

You measure 12” from the level string to the roadway surface. The grade equals 12 percent. Why?

$$G = \frac{Rise}{Run}$$

$$G = \frac{12}{100}$$

$$G = .12 \text{ or } 12 \text{ percent}$$

b. Tape measures and properly built block wall method

1) Locate a block wall that has been properly built with level joints

2) Measure a distance of 100” on one of the joints

3) Take two measurements to the ground, one at each end of the 100” span

4) Because one end of the 100” span is not at the ground, subtract the smaller of the two measurements from the larger

5) The result is equal to the grade of the roadway, also in percent

6) The same equation applies

c. Blue Blitz template method

1) Draw a vertical line on a notebook or clip board. This line must be 90 degrees to the bottom edge

2) Drill a small hole in the notebook or clip board near the top of the line

3) Hang the Blue Blitz temple next to the notebook or clip board by inserting a pen or pencil into the “pivot” hole on the template and the hole in the notebook or clip board

4) Place the bottom edge of the notebook or clip board on the roadway surface

5) Allow the Blue Blitz template to swing freely until it is still

6) Clamp the Blue Blitz template to the notebook or clip board with your hand ensuring that it cannot move

7) The grade of the roadway can be read where the vertical line on the notebook or clip board crosses the number line at the bottom of the Blue Blitz template

3. The grade should be written as a positive (+) or negative (-) depending on the direction the vehicle was traveling, up or down the grade

VIII. SPEED COMPUTATION (6 Hr.)

A. Topic 6.0 - Introduction and Orientation

1. Introduction of material

    a. Speed calculation from physical evidence
    b. Initial velocity on single surface
    c. Minimum velocity over multiple surfaces
    d. Radius of a curve lecture
    e. Calculating the radius of a curve
    f. Time and distance analysis
    g. Time and distance calculations

B. Speed Calculation from Physical Evidence

1. Refer to the Equation Sheet located in the front of the Student Manual

2. The equation sheet is divided into three sections

    a. The left section is the variable to be calculated
    b. The center section is a list of the variables that are known
    c. The right section is the equation to be used

3. This equation sheet can be used during the class and for all tests. Although you will get to know some of the equations by heart, we do not expect you to memorize them

4. Converting Speed to Velocity (Miles Per Hour to Feet Per Second)

    a. Both of the terms “Speed” and “Velocity” are variables that describe a change of position with respect to time. Any unit of motion can be used to describe the terms (miles per hour, feet per second, etc.)
    b. For this class, we will use the term “Speed” to describe motion in units of “Miles Per Hour” (MPH) and the term “Velocity” to describe motion in units of “Feet Per Second” (FPS)
    c. To convert speed (MPH) to velocity (FPS) use this equation: (Slides 4 & 5)

$$v = S(1.47)$$

        1) The conversion factor of 1.47 is widely used in the accident investigation field. It is derived from the following:

$$1\ \text{fps} = 1\ \text{mph}$$

$$1\ \text{fps} = \frac{1\ \text{mile (in feet)}}{1\ \text{hour (in seconds)}}$$

$$1\ \text{fps} = \frac{5280\ \text{feet}}{3600\ \text{seconds}}$$

$$1\ \text{fps} = 1.47\ (\text{mile per hour})$$

2) Examples:

10 mph (1.47) = 14.70 fps

30 mph (1.47) = 44.10 fps

80 mph (1.47) = 117.60 fps

100 mph (1.47) = 147 fps

5. Converting Velocity to Speed (feet per second to miles per hour)

   a. To convert velocity (FPS) to speed (MPH), use this equation:

$$S = \frac{V}{1.47}$$

   b. Examples:

$$\frac{22.05\ \text{fps}}{1.47} = 15\ \text{mph}$$

$$\frac{110.25\ \text{fps}}{1.47} = 75\ \text{mph}$$

$$\frac{66.15\ \text{fps}}{1.47} = 45\ \text{mph}$$

$$\frac{33\ \text{fps}}{1.47} = 22\ \text{mph}$$

6. Minimum Initial Velocity (v_i) on a single surface

   a. The objective is to determine the minimum initial velocity, or, the velocity at the start of the skid, of a vehicle, where the distance of the skid and acceleration factor are known
   b. The equation used is:

$$v_i = \sqrt{{v_e}^2 - 2ad}$$

c. The variables in the equation are:

1) v_i – Initial velocity in feet per second
2) v_e – End velocity in feet per second
3) a – acceleration rate in feet per second squared
4) d – distance in feet

C. Initial Velocity on a Single Surface

1. Distribute scenarios 1 through 6 one at a time

2. Complete each scenario on the white board while the PowerPoint presentation is running

3. Scenario 1

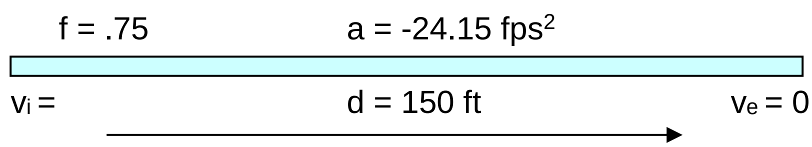
a. A vehicle slides to a stop on a roadway with a coefficient of friction of .75. The slide distance was 150 feet. What was the vehicle's initial velocity?
b. List the known variables

$$v_i = \underline{\qquad\qquad} \text{ fps}$$
$$v_e = 0 \text{ fps}$$
$$f = .75$$
$$a = \underline{\qquad\qquad} \text{ fps}$$
$$d = 150 \text{ feet}$$

c. Calculate the acceleration rate

$$a = fg$$
$$a = .75(32.2)$$
$$a = -24.15 \text{ fps}^2$$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-24.15)(150)}$$
$$v_i = \sqrt{0 - (-7245)}$$
$$v_i = \sqrt{7245}$$
$$v_i = 85.11 \text{ fps}$$

4. Scenario 2

   a. A vehicle slides to a stop on a roadway with a coefficient of friction of .60. The slide distance was 200 feet. What was the vehicle's initial speed?

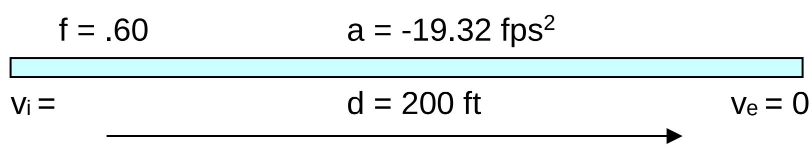
   b. List the known variables

$$v_i = \underline{\hspace{2cm}} \text{ fps}$$
$$v_e = 0 \text{ fps}$$
$$f = .60$$
$$a = \underline{\hspace{2cm}} \text{ fps}$$
$$d = 200 \text{ feet}$$

   c. Calculate the acceleration rate

$$a = fg$$
$$a = .60(32.2)$$
$$a = -19.32 \text{ fps}^2$$

   d. Break down components on diagram



   e. Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-19.32)(200)}$$
$$v_i = \sqrt{0 - (-7728)}$$
$$v_i = \sqrt{7728}$$
$$v_i = 87.90 \text{ fps}$$

   f. Convert the velocity to speed

$$S = \frac{v}{1.47}$$
$$S = \frac{87.90}{1.47}$$
$$S = 59.79 \text{ mph OR } 59 \text{ mph}$$

5. Scenario 3: Student will work problem on the board

   a. A vehicle slides to a stop on a roadway with a coefficient of friction of .70. The slide distance was 175 feet. What was the vehicle's initial speed?

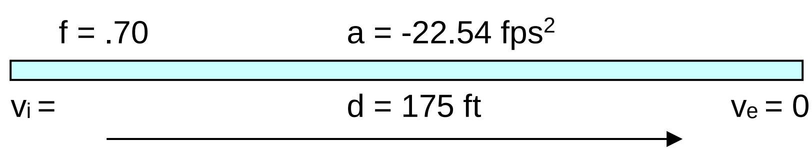
   b. List the known variables

$$v_i = \_\_\_\_\_\_\_\_ \text{ fps}$$
$$v_e = 0 \text{ fps}$$
$$f = .70$$
$$a = \_\_\_\_\_\_\_\_ \text{ fps}$$
$$d = 175 \text{ feet}$$

   c. Calculate the acceleration rate

$$a = fg$$
$$a = .70(32.2)$$
$$a = -22.54 \text{ fps}^2$$

   d. Break down components on diagram



   e. Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-22.54)(175)}$$
$$v_i = \sqrt{0 - (-7889)}$$
$$v_i = \sqrt{7889}$$
$$v_i = 88.82 \text{ fps}$$

   f. Convert the velocity to speed

$$S = \frac{v}{1.47}$$

$$S = \frac{88.82}{1.47}$$

$$S = 60.4 \text{ mph OR } 60 \text{ mph}$$

6. Scenario 4: Alternate method for calculating speed in miles per hour

   a. A vehicle slides to a stop on a roadway with a coefficient of friction of .70. The slide distance was 175 feet. What wa the vehicle's initial speed?

   b. The use of the equations that produce the initial velocity in feet per second

      1) This makes it easier to complete a time and distance analysis where using miles per hour is difficult
      2) This is to show that there are other methods of speed calculation out there. This is important to remember for court purposes
      3) The numbers used here are the same as in scenario #3
      4) The equation to calculate the speed in miles per hour with the information given is:

$$S = \sqrt{30df}$$

      5) The variables in this equation are:
         a) Speed in miles per hour
         b) 30 – A constant to make the equation work properly
         c) d – measured skid length
         d) f – Resultant coefficient of friction or drag factor

      6) Use of the equation
         a) List the known variables

$$S = \underline{\qquad\qquad} \text{ mph}$$

$$f = .70$$

$$d = 175 \text{ feet}$$

         b) Calculate the minimum speed

$$S = \sqrt{30df}$$

$$S = \sqrt{30(175)(.70)}$$

$$S = \sqrt{3675}$$

$$S = 60.62 \text{ mph OR } 60 \text{ mph}$$

7) As you can see, the difference between the two answers is 0.22 miles per hour, but after dropping off the result following the decimal, the speeds are the same

7. Scenario 5: Student work problem the board

a. A vehicle slides to a stop on a roadway with a coefficient of friction of .80 over a distance of 45 feet. What was the vehicle's initial velocity?
b. List the known variables

$v_i =$ ________ fps

$v_e = 0$ fps

$f = .80$

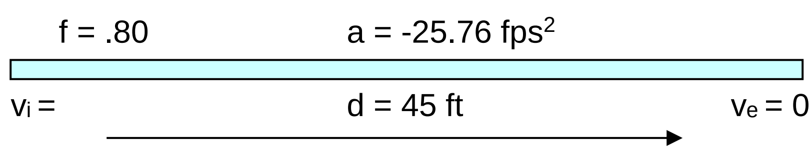
$a =$ ________ fps

$d = 45$ feet

c. Calculate the acceleration rate

$$a = fg$$
$$a = .80(32.2)$$
$$a = -25.76 \text{ fps}^2$$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-25.76)(45)}$$
$$v_i = \sqrt{0 - (-2318.4)}$$
$$v_i = \sqrt{2318.4}$$
$$v_i = 48.14 \text{ fps}$$

8. Scenario 6: Student work problem the board

a. A vehicle slides to a stop on a roadway with a coefficient of friction of .25 over a distance of 150 feet. What was the vehicle's initial speed?
b. List the known variables

$v_i =$ ________ fps

$v_e = 0$ fps

$f = .25$

$a =$ ________ fps

$d = 150$ feet

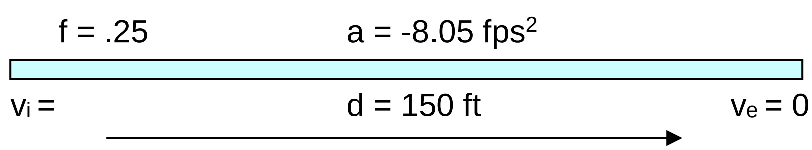
c. Calculate the acceleration rate

$a = fg$

$a = .25(32.2)$

$a = -8.05 \text{ fps}^2$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-8.05)(150)}$

$v_i = \sqrt{0 - (-2415)}$

$v_i = \sqrt{2415}$

$v_i = 49.14$ fps

f. Convert the velocity to speed

$S = \frac{v}{1.47}$

$S = \frac{88.82}{1.47}$

$S = 60.4$ mph OR 60 mph

D. Minimum Velocity over Multiple Surfaces

1. When a vehicle slides over two different surfaces, the surfaces must be analyzed separately. This is because each surface has its own coefficient of friction

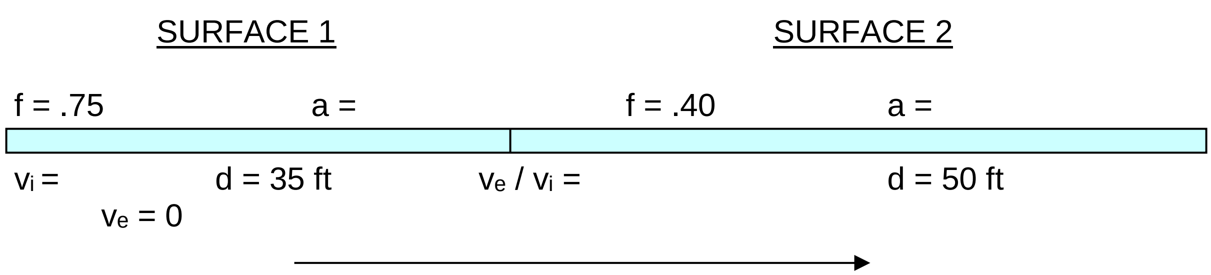
2. When using the minimum velocity equation, start calculating from the end of the skid and work backward to the beginning of the skid

3. Hand out scenario 7, 8 and 9

4. Complete each scenario on the white board while the PowerPoint presentation is running

5. Scenario 7

   a. A vehicle slides to a stop over two surfaces. The vehicle slides 35 feet with a coefficient of friction of friction of .75 on an asphalt surface. The vehicle then slides 50 feet with a coefficient of friction of .40 on the gravel shoulder. What is the vehicles speed when it started to slide?
   b. Break down the components on a diagram



   c. Start with Surface 2
      1) List the known variables

$$v_i = \_\_\_\_\_\_\_\_ \text{ fps}$$
$$v_e = 0 \text{ fps}$$
$$f = .40$$
$$a = \_\_\_\_\_\_\_\_ \text{ fps}$$
$$d = 50 \text{ feet}$$

      2) Calculate the acceleration rate

$$a = fg$$
$$a = .40(32.2)$$
$$a = -12.88 \text{ fps}^2$$

      3) Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-12.88)(50)}$$
$$v_i = \sqrt{0 - (-1288)}$$
$$v_i = \sqrt{1288}$$
$$v_i = 35.88 \text{ fps}$$

d. The initial velocity for Surface 2 now becomes the ending velocity for Surface 1

e. Complete calculations for Surface 1

1) List the known variables

$$v_i = \underline{\qquad\qquad} \text{ fps}$$
$$v_e = 35.88 \text{ fps}$$
$$f = .75$$
$$a = \underline{\qquad\qquad} \text{ fps}$$
$$d = 35 \text{ feet}$$

2) Calculate the acceleration rate

$$a = fg$$
$$a = .75(32.2)$$
$$a = -24.15 \text{ fps}^2$$

3) Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{35.88^2 - 2(-24.15)(35)}$$
$$v_i = \sqrt{1288 - (-1690.5)}$$
$$v_i = \sqrt{2978.5}$$
$$v_i = 54.57 \text{ fps}$$

4) Convert velocity to speed

$$S = \frac{v}{1.47}$$
$$S = \frac{54.57}{1.47}$$
$$S = 37.12 \text{ mph OR } 37 \text{ mph}$$

6. Scenario 8

a. A vehicle slides to a stop over two surfaces. The vehicle slides 55 feet with a coefficient of friction of friction of .80 on a concrete surface. The vehicle then slides 175 feet with a coefficient of friction of .55 into a dirt field. What is the vehicles speed when it started to slide?

b. Break down the components on a diagram

SURFACE 1 — SURFACE 2

f = .80 a = f = .55 a =

v_i = d = 55 ft v_e / v_i = d = 175 ft

v_e = 0

$\longrightarrow$

c. Start with Surface 2

1) List the known variables

$v_i = \_\_\_\_\_\_\_\_$ fps

$v_e = 0$ fps

$f = .55$

$a = \_\_\_\_\_\_\_\_$ fps

$d = 175$ feet

2) Calculate the acceleration rate

$a = fg$

$a = .55(32.2)$

$a = -17.71 \text{ fps}^2$

3) Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^2 - 2ad}$$

$$v_i = \sqrt{0^2 - 2(-17.71)(175)}$$

$$v_i = \sqrt{0 - (-6198.5)}$$

$$v_i = \sqrt{6198.5}$$

$$v_i = 78.73 \text{ fps}$$

d. The initial velocity for Surface 2 now becomes the ending velocity for Surface 1

e. Complete calculations for Surface 1

1) List the known variables

$v_i = \_\_\_\_\_\_\_\_$ fps

$v_e = 78.73$ fps

$f = .80$

$a = \_\_\_\_\_\_\_\_$ fps

$d = 55$ feet

2) Calculate the acceleration rate

$a = fg$

$a = .80(32.2)$

$a = -25.76 \text{ fps}^2$

3) Calculate the minimum initial velocity

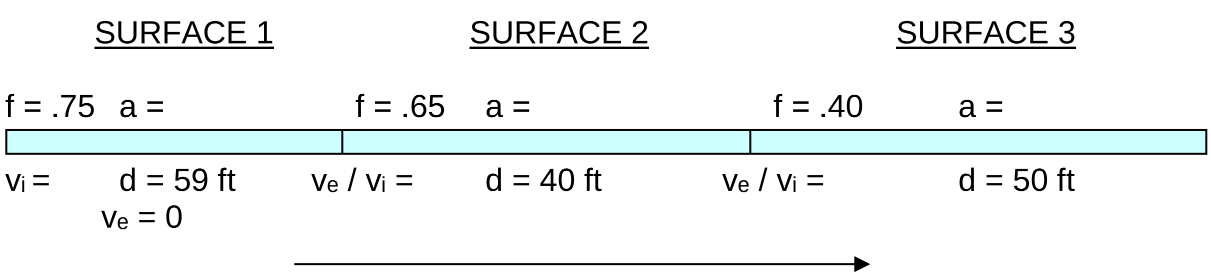
$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{78.73^2 - 2(-25.76)(55)}$$
$$v_i = \sqrt{6198.5 - (-2833.6)}$$
$$v_i = \sqrt{9032.1}$$
$$v_i = 95.03 \text{ fps}$$

4) Convert velocity to speed

$$S = \frac{v}{1.47}$$
$$S = \frac{95.03}{1.47}$$
$$S = 64.6 \text{ mph OR } 64 \text{ mph}$$

8. Scenario 9: Different students will work each surface problem on the board

   a. A vehicle slides to a stop over three surfaces. The vehicle slides 59 feet with a coefficient of friction of friction of .75 on an asphalt surface. The vehicle then slides 40 feet with a coefficient of friction of .65 on a concrete surface. The vehicle then slides 50 feet on the final grass surface with a coefficient of friction of .40. What is the vehicles speed when it started to slide?
   b. Break down the components on a diagram



   c. Start with Surface 3
      1) List the known variables

$$v_i = \underline{\qquad\quad} \text{ fps}$$
$$v_e = 0 \text{ fps}$$
$$f = .40$$
$$a = \underline{\qquad\quad} \text{ fps}$$
$$d = 50 \text{ feet}$$

      2) Calculate the acceleration rate

$a = fg$

$a = .40(32.2)$

$a = -12.88\ fps^2$

3) Calculate the minimum initial velocity

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-12.88)(50)}$

$v_i = \sqrt{0 - (-1288)}$

$v_i = \sqrt{1288}$

$v_i = 35.88\ fps$

4) The initial velocity for Surface 3 now becomes the ending velocity for Surface 2

d. Complete calculations for Surface 2

1) List the known variables

$v_i = \_\_\_\_\_\_\_\_\ fps$

$v_e = 35.88\ fps$

$f = .65$

$a = \_\_\_\_\_\_\_\_\ fps$

$d = 40\ feet$

2) Calculate the acceleration rate

$a = fg$

$a = .65(32.2)$

$a = -20.93\ fps^2$

3) Calculate the minimum initial velocity

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{35.88^2 - 2(-20.93)(40)}$

$v_i = \sqrt{1288 - (-1674.4)}$

$v_i = \sqrt{2962.4}$

$v_i = 54.42\ fps$

e. The initial velocity for Surface 2 now becomes the ending velocity for Surface 1

f. Complete calculations for Surface 1

1) List the known variables

$v_i = \_\_\_\_\_\_\_\_$ fps

$v_e = 54.42$ fps

$f = .75$

$a = \_\_\_\_\_\_\_\_$ fps

$d = 59$ feet

2) Calculate the acceleration rate

$a = fg$

$a = .75(32.2)$

$a = -24.15 \text{ fps}^2$

3) Calculate the minimum initial velocity

$v_i = \sqrt{v_e^{\,2} - 2ad}$

$v_i = \sqrt{54.42^2 - 2(-24.15)(59)}$

$v_i = \sqrt{2962.4 - (-2849.7)}$

$v_i = \sqrt{5812.1}$

$v_i = 76.23$ fps

4) Convert velocity to speed

$S = \frac{v}{1.47}$

$S = \frac{76.23}{1.47}$

$S = 51.8$ mph OR 51 mph

E. Radius of a Curve

1. Up to this point the radius of a curve equation was only used to calculate the radius of a corner for a scale diagram
2. Use of the equation as part of a process to calculate the speed of a vehicle that leaves a yaw mark during a high-speed turn
3. In order to calculate the speed of a vehicle that has left a yaw mark, the same measurements used to complete the Speed / Skid Chart are needed

   a. Chord of any length
   b. To use the Speed / Skid chart to determine the speed from a yaw mark, the chord has to be 50 feet in length <u>only</u>
   c. Middle ordinate
   d. Equation used

      $R = \frac{C^2}{8m} + \frac{m}{2}$

   e. Equation Variables
      1) C – Chord length

2) m – Middle ordinate length
3) 8 – Mathematical constant
4) 2 – Mathematical constant

4. Once the radius of the yaw nark has been calculated, the minimum speed can be calculated using the following equation
   (Slide 24)

$$v = \sqrt{Ra}$$

F. Calculating the Radius of a Curve
1. Hand out scenario 10 – 17, one at a time

2. Complete each scenario on the white board while the PowerPoint presentation is running

3. Scenario 10

   a. You have documented a yaw mark on the roadway that is 99 feet long. You measured a 3-inch middle ordinate from a 50-foot chord. What is the radius of the yaw mark?
   b. List the known variables
      $R = \_\_\_\_\_\_\_ \text{ feet}$
      $C = 50 \text{ feet}$
      $m = 3 \text{ inches}$
   c. Convert the middle ordinate from inches to feet
      $$\frac{3 \text{ inches}}{12 \text{ inches}} = .25 \text{ feet}$$
   d. Calculate the radius
      $$R = \frac{C^2}{8m} + \frac{m}{2}$$
      $$R = \frac{50^2}{8(.25)} + \frac{.25}{2}$$
      $$R = \frac{2500}{2} + \frac{.25}{2}$$
      $$R = 1250 + .12$$
      $$R = 1250.12 \text{ OR } 1250 \text{ feet}$$

4. Scenario 11

   a. You have documented a yaw mark on the roadway that is 65 feet long. You measured a 6-inch middle ordinate from a 50-foot chord. What is the radius of the yaw mark?

b. List the known variables

$R = \_\_\_\_\_\_\_ \text{ feet}$

$C = 50 \text{ feet}$

$m = 6 \text{ inches}$

c. Convert the middle ordinate from inches to feet

$$\frac{6 \text{ inches}}{12 \text{ inches}} = .50 \text{ feet}$$

d. Calculate the radius

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{50^2}{8(.5)} + \frac{.5}{2}$$

$$R = \frac{2500}{4} + \frac{.5}{2}$$

$$R = 625 + .25$$

$$R = 625.25 \text{ OR } 625 \text{ feet}$$

5. Scenario 12: A student will work the problem on the white board

a. You have documented a yaw mark on the roadway that is 55 feet long. You measured a 3-inch middle ordinate from a 30-foot chord. What is the radius of the yaw mark?

b. List the known variables

$R = \_\_\_\_\_\_\_ \text{ feet}$

$C = 30 \text{ feet}$

$m = 3 \text{ inches}$

c. Convert the middle ordinate from inches to feet

$$\frac{3 \text{ inches}}{12 \text{ inches}} = .25 \text{ feet}$$

d. Calculate the radius

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{30^2}{8(.25)} + \frac{.25}{2}$$

$$R = \frac{900}{2} + \frac{.25}{2}$$

$$R = 450 + .12$$

$$R = 450.12 \text{ OR } 450 \text{ feet}$$

6. Scenario 13: A student will work the problem on the white board

a. You have measured an intersection for a scale diagram. The corners of the intersection are the same size. You measured a 17-inch middle ordinate from a 12-foot chord. What are the radii of the corners?

b. List the known variables

$R = \_\_\_\_\_\_\_ \text{ feet}$

$C = 12 \text{ feet}$

$m = 17 \text{ inches}$

c. Convert the middle ordinate from inches to feet

$$\frac{17 \text{ inches}}{12 \text{ inches}} = 1.41 \text{ feet}$$

d. Calculate the radius

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{12^2}{8(1.41)} + \frac{1.41}{2}$$

$$R = \frac{144}{11.28} + \frac{1.41}{2}$$

$$R = 12.76 + .70$$

$$R = 13.46 \text{ OR } 13 \text{ feet}$$

7. Scenario 14

a. A vehicle left a 104-foot-long left front yaw mark on a roadway with a coefficient of friction of .60. The investigating officer calculated an 800-foot radius for the start of the yaw mark. What was the velocity of the vehicle?

b. List the known variables

$v = \_\_\_\_\_\_ \text{ fps}$

$R = 800 \text{ feet}$

$f = .60$

$a = \_\_\_\_\_\_ \text{ fps}^2$

c. Calculate the acceleration rate

$$a = fg$$

$$a = .60(32.2)$$

$$a = 19.32 \text{ fps}^2$$

d. Calculate the velocity of the vehicle

$$v = \sqrt{Ra}$$

$$v = \sqrt{800(19.32)}$$

$$v = \sqrt{15456}$$

$$v = 124.32 \text{ fps OR } 124 \text{ fps}$$

8. Scenario 15: A student will work problem on the white board

a. A vehicle left a 75-foot-long left front yaw mark on a roadway with a coefficient of friction of .70. The investigating officer calculated a 200-foot radius for the start of the yaw mark. What was the velocity of the vehicle?
b. List the known variables

$v = \_\_\_\_\_\_ \text{ fps}$

$R = 200 \text{ feet}$

$f = .70$

$a = \_\_\_\_\_\_ \text{ fps}^2$

c. Calculate the acceleration rate

$a = fg$

$a = .70(32.2)$

$a = 22.54 \text{ fps}^2$

d. Calculate the velocity of the vehicle

$v = \sqrt{Ra}$

$v = \sqrt{200(22.54)}$

$v = \sqrt{4508}$

$v = 67.14 \text{ fps OR } 67 \text{ fps}$

9. Scenario 16: A different student will work problem on the board

a. A vehicle left a 405-foot-long right front yaw mark on a roadway with a coefficient of friction of .60. The investigating officer measured a middle ordinate of 5 inches from a 50-foot chord. What was the velocity of the vehicle?
b. List the known variables

$R = \_\_\_\_\_\_ \text{ feet}$

$C = 50 \text{ feet}$

$m = 5 \text{ inches}$

$v = \_\_\_\_\_\_ \text{ fps}$

$f = .60$

$a = \_\_\_\_\_\_ \text{ fps}^2$

c. Convert middle ordinate from inches to feet

$\frac{5 \text{ inches}}{12 \text{ inches}} = .41 \text{ feet}$

d. Calculate the radius of the yaw mark

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{50^2}{8(.41)} + \frac{.41}{2}$$

$$R = \frac{2500}{3.28} + \frac{.41}{2}$$

$$R = 762.19 + .20$$

$$R = 762.39 \text{ feet OR } 762 \text{ feet}$$

e. Calculate the acceleration rate

$$a = fg$$

$$a = .60(32.2)$$

$$a = 19.32 \text{ fps}^2$$

f. Calculate the velocity of the vehicle

$$v = \sqrt{Ra}$$

$$v = \sqrt{762(19.32)}$$

$$v = \sqrt{14721.84}$$

$$v = 121.33 \text{ fps OR } 121 \text{ fps}$$

10. Scenario 17: A different student will work the problem on the board

a. A vehicle left a 233-foot-long right front yaw mark on a roadway with a coefficient of friction of .70. The investigating officer measured a middle ordinate of 4 inches from a 50-foot chord. A 2% downgrade was also measured parallel to the striations of the yaw mark. What was the velocity of the vehicle?

b. List the known variables

$R =$ ______ feet

$C = 50$ feet

$m = 5$ inches

$v =$ ______ fps

$f = .60$

$a =$ ______ fps^2

$G = -.02$

$f_r =$ ______

c. Convert middle ordinate from inches to feet

$$\frac{4 \text{ inches}}{12 \text{ inches}} = .33 \text{ feet}$$

d. Calculate the radius of the yaw mark

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{50^2}{8(.33)} + \frac{.33}{2}$$

$$R = \frac{2500}{2.64} + \frac{.33}{2}$$

$$R = 946.96 + .16$$

$$R = 947.12 \text{ feet OR } 947 \text{ feet}$$

e. Calculate the Resultant coefficient of friction or Drag factor

$$f_r = B_e(\mu \pm G)$$

$$f_r = \frac{4}{4}(.70 - .02)$$

$$f_r = 1(.68)$$

$$f_r = .68$$

f. Calculate the acceleration rate

$$a = fg$$

$$a = .68(32.2)$$

$$a = 21.89 \text{ fps}^2$$

g. Calculate the velocity of the vehicle

$$v = \sqrt{Ra}$$

$$v = \sqrt{947.12(21.89)}$$

$$v = \sqrt{20732.45}$$

$$v = 143.98 \text{ fps OR } 143 \text{ fps}$$

G. Time and Distance Analyses

1. Time & Distance analyses are valuable in establishing the position of each driver at the time they first observed some stimulus that caused them to slam on the brakes. This stimulus is not necessarily the other vehicle involved in the collision

2. In many cases, this can also help establish which driver had the best chance to avoid the collision

3. Also, knowing the position of the drivers at the time they reacted to a stimulus can help in establishing the driver's sight lines

4. Perception and reaction time

   a. The time a person takes to perceive a hazard, decide what to do, and then carry out that response

b. Studies have determined that the average perception / reaction time is 1.5 seconds
c. Perception / reaction time can be affected by numerous factors
    1) Age
    2) Experience
    3) Sobriety
    4) Physical disability
    5) Fatigue
    6) Level of attentiveness

d. Perception time
    1) Defined as the general process of detecting some object or situation and comprehending that object or situations significance
    2) The average perception time is .75 of a second

e. Reaction Time

    1) Defined as the time required from perception to the start of vehicle control
    2) The average Reaction time is .75 of a second

f. Braking Distance

    1) The distance the vehicle travels from the time the brakes are applied to the time the vehicle stops or there is a collision
    2) The measured skid distances

g. Total Stopping Distance
    1) The distance traveled during three phases
        a) Perception
        b) Reaction
        c) Braking
    2) Used to establish which driver had the “final opportunity to avoid” the collision

h. Constant velocity

    1) The rate of motion of an object that has no acceleration
    2) The equation to calculate constant velocity is:

$$\bar{v} = \frac{d}{t}$$

    3) Used during a time / distance analysis where a constant velocity for the vehicle is assumed to determine the position of a vehicle at the time the driver perceived a hazard. This

velocity is the speed calculated for the vehicle at the start of the skids

Day 4

IX. SPEED COMPUTATION - CONTD **(1 Hr.)**

A. Time and Distance Calculations

1. Hand out scenarios 18 - 28, one at a time

2. Complete each scenario on the white board while the PowerPoint presentation is running

3. Scenario 18

a. A vehicle is traveling a constant velocity of 80 feet per second. What would be the distance traveled during a perception time of .75 of a second?
b. **ASK**: What equation is used to calculate the distance. The equation has not yet been provided, however, it can be written with the algebraic manipulations learned earlier in the class and with the equation given on slide 40
c. Re-write the constant velocity equation to isolate the distance term "d"

$$\bar{v} = \frac{d}{t}$$

$$\bar{v}t = \frac{d}{t}(t)$$

$$d = \bar{v}t$$

d. List the known variables

$$\bar{v} = 80 \text{ fps}$$

$$t_p = .75 \text{ sec}$$

e. Calculate the distance

$$d = \bar{v}t_p$$

$$d = 80(.75)$$

$$d = 60 \text{ feet}$$

4. Scenario 19: A student will work the problem on the board

a. A vehicle is traveling a constant velocity of 65 feet per second. What would be the distance traveled during a perception time of .75 of a second?
b. List the known variables

$\bar{v} = 65 \text{ fps}$

$t_p = .75 \text{ sec}$

c. Calculate the distance

$d = \bar{v} t_p$

$d = 65(.75)$

$d = 48.75 \text{ feet}$

5. Scenario 20: A student will work the problem on the board

   a. A vehicle is traveling a constant velocity of 80 feet per second. What would be the distance traveled during a reaction time of .75 of a second?

   b. List the known variables

   $\bar{v} = 80 \text{ fps}$

   $t_r = .75 \text{ sec}$

   c. Calculate the distance

   $d = \bar{v} t_r$

   $d = 80(.75)$

   $d = 60 \text{ feet}$

6. Scenario 21: A student will work the problem on the board

   a. A vehicle is traveling a constant velocity of 80 feet per second. What would be the distance traveled during perception and reaction time?

   b. List the known variables

   $\bar{v} = 80 \text{ fps}$

   $t_{p+r} = 1.5 \text{ sec}$

   c. Calculate the distance

   $d = \bar{v} t_{p+r}$

   $d = 80(1.5)$

   $d = 120 \text{ feet}$

7. Scenario 22: A student will work the problem on the board

   a. A vehicle is traveling a constant speed of 45 miles per hour. What would be the distance traveled during perception and reaction time?

   b. List the known variables

   $S = 45 \text{ mph}$

   $\bar{v} = \underline{\qquad} \text{ fps}$

   $t_{p+r} = 1.5 \text{ sec}$

   c. Convert speed in mile per hour to velocity in feet per second

$v = S(1.47)$

$v = 45(1.47)$

$v = 66.15 \text{ fps}$

d. Calculate the distance

$d = \bar{v}t_{p+r}$

$d = 66.15(1.5)$

$d = 99.22 \text{ feet}$

8. Scenario 23: A different student will work each step on the board

   a. A vehicle slides to a stop on a roadway with a coefficient of friction of .70 over a distance of 180 feet
   b. **ASK**: What is the distance traveled during the driver's reaction time?
      1) List the known variables

         $v_i =$ ________ fps

         $v_e = 0 \text{ fps}$

         $f = .70$

         $a =$ _________ fps

         $d_b = 180 \text{ feet}$

         $d_r =$ _________ feet

         $t_r = .75 \text{ sec}$

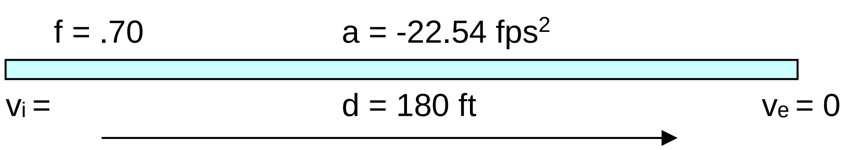
      3) Calculate the acceleration rate

         $a = fg$

         $a = .70(32.2)$

         $a = -22.54 \text{ fps}^2$

      4) Break down components on diagram



      5) Calculate the minimum initial velocity

         $v_i = \sqrt{v_e{}^2 - 2ad}$

         $v_i = \sqrt{0^2 - 2(-22.54)(180)}$

         $v_i = \sqrt{0 - (-8114.4)}$

         $v_i = \sqrt{8114.4}$

         $v_i = 90.07 \text{ fps}$

      6) Calculate the distance traveled during perception

$$d = \bar{v}t$$
$$d = 90.07(.75)$$
$$d = 67.55 \text{ feet}$$

c. **ASK**: What was the distance traveled during reaction and braking?

1) List the known variables

$$d_r = 67.55 \text{ feet}$$
$$d_b = 180 \text{ feet}$$

2) Calculate the total distance

$$d_t = d_r + d_b$$
$$d_t = 67.55 + 180$$
$$d_t = 247.5 \text{ feet}$$

9. Scenario 24: A different student will work each step on the board

a. A vehicle slides to a stop on a roadway with a coefficient of friction of .55 over a distance of 105 feet. What is the vehicle's **total stopping distance**?

b. List the known variables

$v_i =$ ________ fps

$v_e = 0$ fps

$f = .55$

$a =$ ________ fps

$d_b = 105$ feet

$d_p =$ ________ feet

$d_r =$ ________ feet

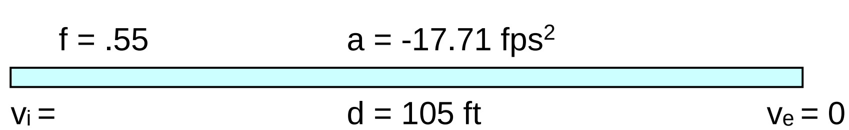
$t_p = .75$ sec

$t_r = .75$ sec

c. Calculate the acceleration rate

$$a = fg$$
$$a = .55(32.2)$$
$$a = -17.71 \text{ fps}^2$$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-17.71)(105)}$$
$$v_i = \sqrt{0 - (-3719.1)}$$
$$v_i = \sqrt{3719.1}$$
$$v_i = 60.98 \text{ fps}$$

f. Calculate the distance traveled during perception

$$d_p = \bar{v}t$$
$$d_p = 60.98(.75)$$
$$d_p = 45.73 \text{ feet}$$

g. Calculate the distance traveled during reaction

$$d_r = \bar{v}t$$
$$d_r = 60.98(.75)$$
$$d_r = 45.73 \text{ feet}$$

h. Calculate the total stopping distance

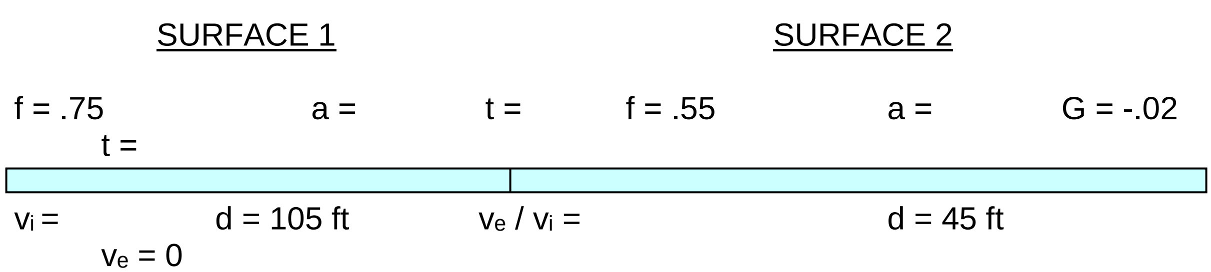
$$d_t = d_p + d_r + d_b$$
$$d_t = 45.73 + 45.73 + 105$$
$$d_t = 196.46 \text{ feet}$$

10. Scenario 25: A different student will work each step on the board

a. A vehicle slides to a stop over two surfaces leaving 4 wheel locked independent tire marks. The vehicle slides 105 feet on the first surface with a coefficient of friction of .75, then slides to a stop over the second surface for 45 feet with a coefficient of friction of .55 and a 2% downgrade

b. **ASK**: What is the total stopping distance?

   1) Break down the components on a diagram



2) Start with Surface 2
3) List the known variables

$v_i =$ ________ fps

$v_e = 0$ fps

$f = .55$

$f_r =$ ________

$B_e = 1$

$G = -.02$

$a =$ ________ fps

$d = 45$ feet

4) Calculate the Drag factor or resultant coefficient of friction

$f_r = B_e(\mu \pm G)$

$f_r = 1(.55 - .02)$

$f_r = 1(.53)$

$f_r = .53$

5) Calculate the acceleration rate

$a = fg$

$a = .55(32.2)$

$a = -17.06 \text{ fps}^2$

6) Calculate the minimum initial velocity at the start of surface 2

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-17.06)(45)}$

$v_i = \sqrt{0 - (-1535.4)}$

$v_i = \sqrt{1535.4}$

$v_i = 39.18$ fps

7) The initial velocity for Surface 2 now becomes the ending velocity for Surface 1
8) Complete calculations for Surface 1
   a) List the known variables

   $v_i =$ ________ fps

   $v_e = 39.18$ fps

   $f = .75$

   $a =$ ________ fps

   $d = 105$ feet

   b) Calculate the acceleration rate

   $a = fg$

   $a = .75(32.2)$

   $a = -24.15 \text{ fps}^2$

c) Calculate the minimum initial velocity

$$v_i = \sqrt{v_e^{\,2} - 2ad}$$
$$v_i = \sqrt{35.88^2 - 2(-24.15)(105)}$$
$$v_i = \sqrt{1535.4 - (-5071.5)}$$
$$v_i = \sqrt{6606.9}$$
$$v_i = 81.28 \text{ fps}$$

d) Calculate the distance traveled during perception / reaction

(1) List the known variables

$d_{p+r} =$ ________ feet

$\bar{v} = 81.28$ fps

$t = 1.5$ sec

(2) Calculate the perception / reaction distance

$$d_{p+r} = \bar{v}t$$
$$d_{p+r} = 81.28(1.5)$$
$$d_{p+r} = 121.92 \text{ feet}$$

e) Calculate the total stopping distance

(1) List the known variables

$d_{p+r} = 121.92$ feet

$d_b = 150$ feet

(2) Calculate the total stopping distance

$$d_t = d_{p+r} + d_b$$
$$d_t = 121.92 + 150$$
$$d_t = 271.92 \text{ feet}$$

c. **ASK:** How long did it take for the driver to perceive the hazard and bring the vehicle to a stop?

1) Calculate the time it took the vehicle to slide over surface 2

a) List the known variables

$a = -17.06$ fps^2

$v_i = 39.18$ fps

$v_e = 0$ fps

b) Calculate the time

$$t - \frac{v_e - v_i}{a}$$
$$t = \frac{0 - 39.18}{-17.06}$$
$$t = \frac{-39.18}{-18.06}$$
$$t = 2.16 \text{ sec}$$

2) Calculate the time it took the vehicle to slide over surface 1
   a) List the known variables
   $$a = -24.15 \text{ fps}^2$$
   $$v_i = 81.28 \text{ fps}$$
   $$v_e = 39.18 \text{ fps}$$
   b) Calculate the time
   $$t - \frac{v_e - v_i}{a}$$
   $$t = \frac{39.18 - 81.28}{-24.15}$$
   $$t = \frac{-42.10}{-24.15}$$
   $$t = 1.74 \text{ sec}$$

3) Calculate the total stopping time
   a) List the known variables
   $$t_{p+r} = 1.5 \text{ sec}$$
   $$t_{b-1} = 1.74 \text{ sec}$$
   $$t_{b-2} = 2.16 \text{ sec}$$
   b) Calculate the total time
   $$t_t = t_{p+r} + t_{b-1} + t_{b-2}$$
   $$t_t = 1.5 + 1.74 + 2.16$$
   $$t_t = 5.4 \text{ sec}$$

11. Scenario 26: A student will work the problem on the board

   a. A vehicle slides to a stop on a roadway with a coefficient of friction of .70 over a distance of 150 feet. How long did it take to skid the 150 feet?
   b. List the known variables

$v_i = \_\_\_\_\_\_\_\_$ fps

$v_e = 0$ fps

$f = .70$

$a = \_\_\_\_\_\_\_\_\_$ fps

$d = 150$ feet

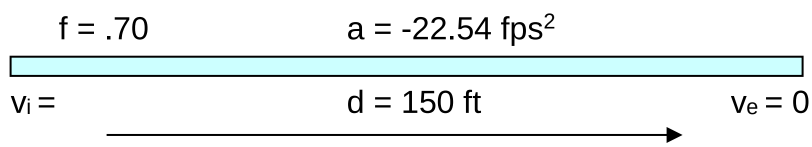
c. Calculate the acceleration rate

$a = fg$

$a = .7(32.2)$

$a = -22.52 \text{ fps}^2$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$v_i = \sqrt{v_e{}^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-22.54)(150)}$

$v_i = \sqrt{0 - (-6762)}$

$v_i = \sqrt{6762}$

$v_i = 82.23$ fps

f. Calculate the skid time

$t = \frac{v_e - v_i}{a}$

$t = \frac{0 - 82.83}{-22.54}$

$t = \frac{-82.83}{-22.54}$

$t = 3.6$ sec

12. Scenario 27: A student will work problem on the board

a. A vehicle slides to a stop on a roadway with a coefficient of friction of .70 over a distance of 60 feet. How long did it take to skid the 60 feet?
b. List the known variables

$v_i = \underline{\hspace{2cm}}$ fps

$v_e = 0$ fps

$f = .70$

$a = \underline{\hspace{2cm}}$ fps

$d = 60$ feet

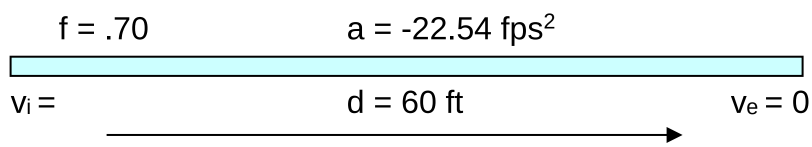
c. Calculate the acceleration rate

$a = fg$

$a = .7(32.2)$

$a = -22.52 \text{ fps}^2$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-22.54)(60)}$

$v_i = \sqrt{0 - (-2704.8)}$

$v_i = \sqrt{2704.8}$

$v_i = 52$ fps

f. Calculate the skid time

$t = \frac{v_e - v_i}{a}$

$t = \frac{0 - 52}{-22.54}$

$t = \frac{-52}{-22.54}$

$t = 2.3$ sec

13. Scenario 28: A student will work the problem on the board
    a. Find the “Total Stopping Time”, in seconds; it took a vehicle to slide to a stop. The vehicle slides 560 feet on loose gravel with a .40 coefficient of friction
    b. List the known variables

$v_i =$ ________ fps

$v_e = 0$ fps

$f = .70$

$a =$ ________ fps

$d = 60$ feet

$t_{skid} =$ ________ sec

$t_{p+r} = 1.5$ sec

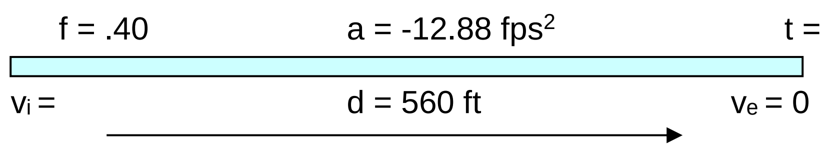
c. Calculate the acceleration rate

$a = fg$

$a = .4(32.2)$

$a = -12.88 \text{ fps}^2$

d. Break down components on diagram



e. Calculate the minimum initial velocity

$v_i = \sqrt{v_e^2 - 2ad}$

$v_i = \sqrt{0^2 - 2(-12.88)(560)}$

$v_i = \sqrt{0 - (-14425.6)}$

$v_i = \sqrt{14425.6}$

$v_i = 120.1 \text{ fps}$

f. Calculate the skid time

$t_{skid} = \frac{v_e - v_i}{a}$

$t_{skid} = \frac{0 - 120.1}{-12.88}$

$t_{skid} = \frac{-120.1}{-12.88}$

$t_{skid} = 9.32 \text{ sec}$

g. Calculate the total stopping time

$t_{total} = t_{p+r} + t_{skid}$

$t_{total} = 1.5 + 9.32$

$t_{total} = 10.8 \text{ sec}$

I. Reinforce the key learning points

1. When using calculations to establish the minimum speed of a vehicle, the calculations and results shall be recorded on a 556 Supplemental as a standalone report

2. Be careful when deciding upon variables. The must be justification for the numbers used in the equations in front of a jury

3. Base all variables on physical evidence

4. Never add pre-impact skids to post-impact skids to establish the speed of a vehicle

X. SKID TESTING & DRAG SLED FIELD PROJECT (7 Hr.)

A. SPEED COMPUTATION FIELD PROJECTS

1. Brief overview of goals and objectives

    a. Drag sled and skid marking
    b. Skid measuring
    c. Scaled diagrams of skid marks

B. Drag Sled and Skid Marking

1. **DISTRIBUTE**: Safety Guidelines and instruct students to review and follow the guidelines

2. Students will meet at specified location with the Skid Test Data handout

3. Drag sled demonstration and tests

    a. **DEMONSTRATE**: How the drag sled works by first weighing the sled with the assistance of one of the students
    b. The drag sled should be pulled on the surface being tested, with the scale horizontal to the ground
    c. Pulling the sled by the scale at an angle to the ground can induce error in the final result
    d. Record the required pull force on different surfaces such as dirt, asphalt, concrete, etc. and record on the handout

4. Skid testing

    a. Ensure the street to be used for testing is guarded at each end to stop all traffic during each test

b. One at a time, students will drive a vehicle and accelerate to a pre-determined speed
c. Half the students will have 25 mph and the other half 35 mph as their speed
d. They will then slam on the brakes and bring the vehicle to a stop. An instructor shall accompany the students during the tests
e. An instructor will verify the speed of the vehicle with a radar device from a safe location
f. Once the vehicle is stopped and the gear shift is in a parked position, mark the rest location of the tires with chalk
g. The student will then drive the vehicle to the starting point
h. Once the vehicle has cleared, the students will measure the length of the skids laid down by the vehicle
i. Record the speed of the vehicle (verified by radar) and the skid length for each test on the Skid Test Data handout
j. Complete as many tests as there are students wishing to participate as drivers
k. The following details should be pointed out
    1) Smears indicating the vehicles direction of travel
    2) Any buildup of rubber and tar on raised surfaces in the roadway indicating direction of travel for the vehicle
    3) How to measure the wheelbase of the vehicle and match to the tire marks
        a) The wheelbase is the distance between the front and rear axle on the vehicle
        b) Measure the distance between the front and rear axles on one side of the vehicle
        c) Measure the distance between the end of the rear tire mark and the end of the front tire mark on one side of the set of tire marks laid down by the vehicle
        d) The measurements from the vehicle and the tire marks should be the same
    4) How to measure the track width of the vehicle
        a) The track width is the distance between the center of the left side tire tread and the center of the right-side tire tread
        b) Measure the distance between the centers of the tread on either the front or rear tires of the vehicle
        c) Measure the distance between the centers of the front or rear tire marks left on the roadway by the skidding vehicle
        d) The measurements from the vehicle and tire marks should be the same
    5) How to match the number of striations on the tire marks to the tread pattern on the vehicle

a) Skid mark striations are left by the tread of the skidding tire
b) Count the number of treads on the tires of the vehicle
c) Count the number of striations in the tire mark
d) The number of tread and striations should match

6) How to compare the width of the tire mark to the width of the tire
   a) The width of the tire is measured from shoulder to shoulder on the tread face of the tire
   b) Measure the tread width on the vehicle
   c) Measure the width of the tire mark
   d) The width of the tire tread and the width of the tire mark should be very close. The front tire mark may be slightly wider due to over-deflection, and the rear tire mark may be slightly narrower due to under-deflection

C. Skid Measuring

1. The skids which will be used in this section will be made by an instructor before the class

2. The students shall measure the intersection, roadway and tire marks
   a. Break the students into groups of three or four
   b. Each group shall be provided with the necessary measuring tools (measure-meter, tape measures, etc.)
   c. Each group shall document the measurements of the intersection and tire marks on a basic field sketch

3. Once the students have collected the measurements of the intersection and tire marks, they shall return to the classroom to complete the project

4. Completing a scale diagram of the intersection or roadway
   a. On a blank sheet of paper complete a scale diagram of the intersection
   b. Use traffic template and compass

5. Plotting the tire marks on the diagram

   a. On the completed scale diagram, plot the tire marks with the measurements obtained at the scene
   b. Draw the tire marks on the diagram with the traffic template

6. Calculating a co-efficient of friction for the roadway using the skid test data collected during the skid testing

a. With the equations learned in the speed computation part of the course, calculate the co-efficient of friction for the roadway from the testing
b. First, use the drag sled data to calculate the coefficient of friction
c. Second, calculate the coefficient of friction for the roadway using the skid test data
d. Average the skid test results for the final coefficient of friction to be used in the speed calculations (Section 8)

7. Documenting the type of tire marks and justifying their conclusion with the characteristics of those tire marks

   a. On the back side of the paper, identify the type of tire marks measured (4-wheel locked overlapping, 4 wheel locked independent, etc.)
   b. Justify the type of tire marks chosen with the characteristics of those tire marks seen in the field

8. Documenting the direction of travel of the vehicle and justifying their conclusion with physical evidence

   a. Identify the direction of travel for the vehicle that left the tire marks
   b. Justify the direction of travel chosen with physical evidence seen in the tire marks in the field (tar smears, start light and end abruptly and straight across from each other, etc.)

9. Calculating a minimum speed for the vehicle

   a. Using the coefficient of friction calculated from the skid tests and the length of the tire marks measured, calculate a minimum speed for the vehicle that left the tire marks
   b. Use the equations learned in the speed calculation portion of the class

D. Reinforce the key learning points

1. Accurately identifying the type of tire marks left at the scene of a collision is very important

2. Accurately measuring the length and location of the tire marks is equally important

3. Tire marks that are not identified properly, or are not measured and documented properly, may result in an error in the calculation of a minimum speed for the vehicle leaving the tire marks

4. Matching the tire marks to the vehicle is important for court testimony

Day 5

X. CASE STUDIES (4 Hr.)

A. Brief overview of training goals and objectives

1. Practical application of the material they have learned thus far in the course

2. Analysis of scenarios to determine different collision related issues

3. Presentation case study solutions to the rest of the class

4. Defense of solutions presented as if in court by answering questions posed by the instructors

B. Case Studies

1. Case Study A

a. You respond to the scene of a collision involving two vehicles. One of the vehicles has clearly failed to stop for a stop sign because it left 65 feet of pre-impact 4-wheel locked independent tire marks. The tire marks start before the limit line and continue to the area of impact
b. You conduct test skids in the intersection:

TEST	SKID DISTANCE	RADAR SPEED
1	45 FEET	30 MPH
2	48 FEET	30 MPH
3	49 FEET	31 MPH

c. What was the minimum speed of the vehicle at the start of the tire marks?

b. Determine the coefficient of friction using the test data and the following formula

$$f = \frac{S^2}{30d}$$

1) Test #1

$$f = \frac{S^2}{30d}$$
$$f = \frac{30^2}{30(45)}$$
$$f = \frac{900}{1350}$$
$$f = .666$$

2) Test #2

$$f = \frac{S^2}{30d}$$
$$f = \frac{30^2}{30(48)}$$
$$f = \frac{900}{1440}$$
$$f = .625$$

3) Test #3

$$f = \frac{S^2}{30d}$$
$$f = \frac{31^2}{30(49)}$$
$$f = \frac{961}{1470}$$
$$f = .653$$

4) Average the results by adding the results and dividing by 3

$$f_a = \frac{f_1 + f_2 + f_3}{3}$$
$$f_a = \frac{(.666) + (.625) + (.653)}{3}$$
$$f_a = \frac{1.9444}{3}$$
$$f_a = .64$$

5) Determine the acceleration rate

$$a = fg$$
$$a = .65(32.2)$$
$$a = -20.60\ fps^2$$

6) Determine the initial velocity of the velocity

$$v_i = \sqrt{v_e^{\ 2} - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-20.60)(65)}$$
$$v_i = \sqrt{0 - (-2678)}$$
$$v_i = \sqrt{2678}$$
$$v_i = 51.74\ fps$$

7) Convert the initial velocity in feet per second to miles per hour

$$S = \frac{v}{1.47}$$
$$S = \frac{51.74}{1.47}$$
$$S = 35.19\ \text{ OR }\ 35\ mph$$

2. Case Study B

   a. You are investigating a collision in which a vehicle skids off the roadway onto a dirt shoulder and collides with a parked vehicle. Your investigation revealed that the vehicle left four wheel locked independent tire marks for 62 feet on the street and 21 feet on the dirt shoulder prior to impact. The street is asphalt and was level and dry with a coefficient of friction of 0.75. The dirt was also level and had a coefficient of friction of 0.40

   b. What was the speed of the vehicle at the start of the skids?

   c. Determine the acceleration rates for the surfaces

DIRT: f = 0.40

$$a = fg$$
$$a = .40(32.2)$$
$$a = -12.88\ fps^2$$

STREET: f = 0.75

$$a = fg$$
$$a = .75(32.2)$$
$$a = -24.15\ fps^2$$

   d. Start at the end of the tire marks. Determine the velocity of the vehicle at the transition between the street and the dirt

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-12.88)(21)}$$
$$v_i = \sqrt{0 - (-540.96)}$$
$$v_i = \sqrt{540.96}$$
$$v_i = 23.25 \text{ fps}$$

e. The initial velocity on the dirt becomes the end velocity for the street. Calculate the minimum speed of the vehicle at the start of the tire marks

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{23.25^2 - 2(-24.15)(62)}$$
$$v_i = \sqrt{540.96 - (-2994.6)}$$
$$v_i = \sqrt{3535.56}$$
$$v_i = 59.46 \text{ fps}$$

f. Convert the velocity in feet per second to miles per hour

$$S = \frac{v}{1.47}$$
$$S = \frac{59.46}{1.47}$$
$$S = 40.44 \text{ mph OR } 40 \text{ mph}$$

g. Each group will answer the following questions as if they were in court:

1) What type of tire marks were documented?
   a) Four wheel locked independent tire marks
2) How did you know the wheels were locked?
   a) The striations were parallel to the direction of travel
3) What are striations?
   a) Lines within the tire marks left by the tread pattern of the tire
4) How do you know the tire marks were left by my client's car and not a different car?
   a) The tire marks lead right up to the impact point and ended under the vehicle's tires at their at rest position
   b) The following are other methods to match the tire marks to a particular vehicle

(1) Counting the tread pattern which matched the number of striations in the marks

(2) Measuring the track width on the vehicle which matched the width between the right and left side tire marks

(3) Measuring the width of the individual tire marks which matched the width of the tires on the vehicle

(4) Measuring the vehicle's wheel base which matched the tire marks ending locations on the roadway (between front and rear on one side of the vehicle or the other)

5) What did the tire marks look like in the dirt?

a) A furrow was plowed as the tires slid in the soft material. Dirt was thrown to the sides during the slide and a pile of dirt was located at the end of the marks in front of the tire positions

3. Case Study C

a. A vehicle attempts to negotiate a curve in the roadway. The passenger claims the driver was traveling 50 miles per hour. The vehicle left 165 feet of two-wheel right side yaw marks. A 100-foot chord was laid at the beginning of the tire mark resulting in an 8 inch middle ordinate measurement. The roadway surface was asphalt that was dry, level and well-traveled. Test skids were not conducted

b. What was the minimum speed of the vehicle at the start of the yaw marks?

c. Determine the radius of the yaw mark

$$R = \frac{C^2}{8m} + \frac{m}{2}$$

$$R = \frac{100^2}{8(.66)} + \frac{.66}{2}$$

$$R = \frac{10000}{5.28} + \frac{.66}{2}$$

$$R = 1893.93 + .33$$

$$R = 1894.26 \text{ feet OR } 1894 \text{ feet}$$

d. Calculate the acceleration rate range. The coefficient of friction used is taken from the chart: 0.55 to 0.70 for speeds over 30 mph

Low coefficient: f = 0.55 High coefficient: f = 0.70

$$a = fg \qquad a = fg$$
$$a = .55(32.2) \qquad a = .70(32.2)$$
$$a = 17.71 \text{ fps}^2 \qquad a = 22.54 \text{ fps}^2$$

e. Calculate a range of minimum velocities for the vehicle

Low coefficient: f = 0.55

$$v = \sqrt{Ra}$$
$$v = \sqrt{1894(17.71)}$$
$$v = \sqrt{33542.74}$$
$$v = 183.14 \text{ fps}$$

High coefficient: f = 0.70

$$v = \sqrt{Ra}$$
$$v = \sqrt{1894(22.54)}$$
$$v = \sqrt{42690.76}$$
$$v = 206.61 \text{ fps}$$

f. Convert the velocities in feet per second to miles per hour

Low coefficient: f = 0.55

$$S = \frac{v}{1.47}$$
$$S = \frac{183.14}{1.47}$$
$$S = 124.58 \text{ mph OR } 124 \text{ mph}$$

High coefficient: f = 0.70

$$S = \frac{v}{1.47}$$
$$S = \frac{206.61}{1.47}$$
$$S = 140.55 \text{ mph OR } 140 \text{ mph}$$

g. One of the groups will answer the following questions as if they were in court:
  1) Officers, do you really think that my client was driving between 124 and 140 miles per hour? He was driving a Porsche, but still – over 120 miles per hour?
    a) If the group's answer is "no", ask "Then why are we even here in court?"
    b) If the group's answer is "yes", ask the following questions:
      (1) What type of tire marks did you base the analysis on?
        (a) Yaw Marks
      (2) How do you know they were yaw marks? What did they look like that led you to believe they were yaw marks?
        (a) The striations were perpendicular to the direction of travel and the rear tire was tracking outside the path of the front tire
      (3) Did my clients Porsche have an ABS?

(a) Yes (Instructor may provide this information to students if they don't know it)

(4) How long were the tire marks?

(a) 165 feet

(5) Have you heard of the "Slide To Stop" equation where speed is equal to the square root of 30 times the coefficient of friction times the skid distance?

(a) Yes

(6) What if you are mistaken, and the skids are really ABS marks. You know a car can turn during heavy braking with an ABS, right?

(a) Yes

(7) Can you calculate, on the board for the jury, the speed my client was really traveling using the "Slide To Stop" equation?

(a) Yes

Low coefficient: f = 0.55	High coefficient: f = 0.70
$S = \sqrt{30df}$	$S = \sqrt{30df}$
$S = \sqrt{30(165)(.55)}$	$S = \sqrt{30(165)(.70)}$
$S = \sqrt{2722.5}$	$S = \sqrt{3465}$
$S = 52\text{ mph}$	$S = 58\text{ mph}$

(8) So which is it, Officers? 124 to 140 miles per hour, or 52 to 58 miles per hour?

(a) (No response from the officers is required. The officers return to their seats; end of court testimony questions)

h. The above listed questions represent what usually occurs in court. The defense attorney's tasks are as follows:

1) Ensure they are interpreting the physical evidence properly
2) Defend their interpretation with knowledge of evidence characteristics

4. Case Study D

a. You have been asked by a detective to provide the minimum speed of a vehicle involved in a collision that occurred three weeks ago. The collision occurred when a eastbound vehicle turned left in front of a westbound vehicle at an intersection

b. The I/O at the scene documented the skid marks left by the westbound vehicle:

c. <u>PHYSICAL EVIDENCE</u>
   1) V-2 laid down the following pre-impact four wheel locked overlapping tire marks:
   2) Left side was located:

Starting and 24' S/N curb of 3rd Street & 56' E/E curb of Cochran Avenue
Ending 16' S/N curb of 3rd Street & 08' W/E curb of Cochran Avenue.

   3) Right side was located:

Starting and 18' S/N curb of 3rd Street & 57' E/E curb of Cochran Avenue
Ending 11' S/N curb of 3rd Street & 08' W/E curb of Cochran Avenue.

   4) V-2 also laid down the following post-impact tire scrubs:

Left front was located:

Starting and 16' S/N curb of 3rd Street & 08' W/E curb of Cochran Avenue
Ending 10' S/N curb of 3rd Street & 13' W/E curb of Cochran Avenue.

Right front was located:

Starting and 11' S/N curb of 3rd Street & 08' W/E curb of Cochran Avenue
Ending 04' S/N curb of 3rd Street & 13' W/E curb of Cochran Avenue.

d. The I/O was unable to complete skid tests at the scene. The roadway is new Portland cement. A witness stated that the westbound vehicle was traveling at high rate of speed, approximately 45 mph. The intersection and the roadway approaching was level and dry

e. What was the westbound vehicle's minimum speed at the start of the skids?

f. Plot the tire marks on a diagram of some sort to determine the skid length

   1) Note: this cannot be solved by subtracting the measurements to determine the length because the tire marks are not parallel to the north curb line

g. Determine a range for the coefficient of friction of the roadway using the table:

Low coefficient: f = 0.70

$$a = fg$$
$$a = .70(32.2)$$
$$a = -22.54 \text{ fps}^2$$

High coefficient: f = 1.00

$$a = fg$$
$$a = 1.0(32.2)$$
$$a = -32.20 \text{ fps}^2$$

h. Determine the range of velocity for the vehicle:
   1) Note: The skid distance used should only be <u>55 feet</u> because the type of tire mark documented. The students MUST subtract 10 feet from the total skid length

Low coefficient: f = 0.70

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-22.54)(55)}$$
$$v_i = \sqrt{0 - (-2479.40)}$$
$$v_i = \sqrt{2479.40}$$
$$v_i = 49.79 \text{ fps}$$

High coefficient: f = 1.00

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-32.20)(55)}$$
$$v_i = \sqrt{0 - (-3542)}$$
$$v_i = \sqrt{3542}$$
$$v_i = 59.51 \text{ fps}$$

i. Convert the velocity in feet per second to miles per hour

Low coefficient: f = 0.70 High coefficient: f = 1.00

$$S = \frac{v}{1.47}$$
$$S = \frac{49.79}{1.47}$$
$$S = 33.87 \text{ mph OR } 33 \text{ mph}$$
$$S = \frac{v}{1.47}$$
$$S = \frac{59.51}{1.47}$$
$$S = 40.48 \text{ mph OR } 40 \text{ mph}$$

j. One of the groups will answer the following questions as if they were in court:
   1) How long were the tire marks?
      a) 65 feet

2) What skid distance did you use in the calculations?
   a) If the students answer “55 feet”, skip down to #3
   b) If the students answer 65 feet, ask: what type of tire marks were documented?
      (1) 4 wheel locked overlapping tire marks
3) What are the characteristics of the 4-wheel locked overlapping tire marks?
4) Same as 4-wheel locked independent except, the investigator cannot tell where each tire mark starts, independent of the other
5) When you have a set of 4 wheel locked overlapping tire marks, what must be done to the total length of the tire marks prior to using them for any speed analysis (Skid Chart or Equations)
   a) A deduction for the measured wheelbase, or an average wheelbase distance of 10’, MUST be deducted from the total skid length
5) Why did you only use 55’ for the skid length?
   a) Because the tire marks are 4 wheel locked overlapping tire marks. This means that the investigator could not determine where the four tire marks started independent of one another. When this occurs, a deduction for the measured wheelbase, or an average wheelbase distance of 10’, must be deducted from the total skid length

5. Case Study E

   a. You are investigating a collision in which a drunk westbound driver has struck and killed a pedestrian, crossing the roadway northbound in a crosswalk
   b. The skid marks have been documented and drawn to scale on the provided diagram. They are identified as 4 wheel locked independent tire marks. A witness stated that the pedestrian was in the center of the crosswalk when the vehicle struck him/her
   c. Test skids were conducted through the crosswalk in the westbound #1 lane:

TEST	SKID DISTANCE	RADAR SPEED
1	42’ 6”	35 MPH
2	41’ 0”	35 MPH
3	43’ 7”	36 MPH

The roadway has a downgrade for westbound traffic. You measured 5" to the roadway surface from a level 100" string

d. What was the westbound vehicle's minimum speed at the start of the skids?
   1) Determine the average tire mark length

$$d_a = \frac{RF + LF + RR + LR}{4}$$
$$d_a = \frac{69 + 79 + 82 + 84}{4}$$
$$d_a = \frac{314}{4}$$
$$d_a = 78.5$$

   2) Determine the coefficient of friction using the test data and the following formula

$$f = \frac{S^2}{30d}$$

      a) Test #1

$$f = \frac{S^2}{30d}$$
$$f = \frac{35^2}{30(42.5)}$$
$$f = \frac{1225}{1275}$$
$$f = .96$$

      b) Test #2

$$f = \frac{S^2}{30d}$$
$$f = \frac{35^2}{30(41)}$$
$$f = \frac{1225}{1230}$$
$$f = .99$$

      c) Test #3

$$f = \frac{S^2}{30d}$$
$$f = \frac{36^2}{30(43.58)}$$
$$f = \frac{1296}{1307.4}$$
$$f = .99$$

3) Average the results by adding the results and dividing by 3

$$f_a = \frac{f_1 + f_2 + f_3}{3}$$
$$f_a = \frac{(.96) + (.99) + (.99)}{3}$$
$$f_a = \frac{2.94}{3}$$
$$f_a = .98$$

4) Determine the acceleration rate

$$a = fg$$
$$a = .98(32.2)$$
$$a = -29.94 \text{ fps}^2$$

5) Determine the initial velocity of the velocity

$$v_i = \sqrt{{v_e}^2 - 2ad}$$
$$v_i = \sqrt{0^2 - 2(-29.94)(78.5)}$$
$$v_i = \sqrt{0 - (-4700.58)}$$
$$v_i = \sqrt{4700.58}$$
$$v_i = 68.56 \text{ fps}$$

6) Convert the initial velocity in feet per second to miles per hour

$$S = \frac{v}{1.47}$$
$$S = \frac{68.56}{1.47}$$
$$S = 46.63 \text{ OR } 46 \text{ mph}$$

e. Approximately how fast was the vehicle traveling when it struck the pedestrian? (a different group will answer this question)
   1) Determine the distance the vehicle skidded prior to colliding with the pedestrian by measuring the distance on the diagram. This distance should be approximately 53 feet
   2) Determine the approximate speed at the time of impact using the calculated initial velocity, the acceleration rate and the distance traveled:

$$v_e = \sqrt{v_i^2 + 2ad}$$
$$v_e = \sqrt{68.56^2 + 2(-29.94)(53)}$$
$$v_e = \sqrt{4700.58 + (-3173.64)}$$
$$v_e = \sqrt{1526.94}$$
$$v_e = 39.07 \text{ fps}$$

3) Convert the end velocity in feet per second to miles per hour

$$S = \frac{v}{1.47}$$
$$S = \frac{39.07}{1.47}$$
$$S = 26.57 \text{ mph OR } 26 \text{ mph}$$

f. If the pedestrian were crossing the street at a constant velocity of 4 feet per second, where was the pedestrian at the time the car started to skid? (a different group will answer this question)

1) Calculate the time it took the vehicle to skid to the impact point using the calculated velocity at the start of the skid, the calculated velocity at the time of impact and the acceleration rate:

$$t = \frac{v_e - v_i}{a}$$
$$t = \frac{39.07 - 68.56}{-29.94}$$
$$t = \frac{-29.49}{-29.94}$$
$$t = .98 \text{ sec}$$

2) Calculate the position of the pedestrian, 0.98 seconds prior to impact

$$d = \bar{v}t$$
$$d = 4(.98)$$
$$d = 3.98 \text{ feet S of AOI}$$

d. This case study is difficult. It is a quite common one, especially when taken further to calculate where both the vehicle and pedestrian were when the driver of the vehicle perceived a hazard

6. Case Study F

a. Vehicle A was eastbound on 12th Street at a constant speed of 15 miles per hour. Vehicle B was northbound on Wall Street and laid down 19 feet of pre-impact 4 wheel locked independent tire marks terminating at the AOI. Vehicle B was traveling 5 miles per hour at the time of impact. The intersection has a coefficient of friction of 0.70
b. Both of the parties claimed they had the green light. There were no independent witnesses to the collision
c. Use 1.5 seconds for Party B's perception / reaction time
   1) Who ran the red light?
   2) Determine the speed of Vehicle B at the start of the skids
   3) Convert the 5 mile per hour impact speed to feet per second

$$v = S(1.47)$$
$$v = 5(1.47)$$
$$v = 7.35 \text{ fps}$$

   4) Calculate the acceleration rate

$$a = fg$$
$$a = .70(32.2)$$
$$a = -22.54 \text{ fps}^2$$

   5) Calculate the initial velocity

$$v_i = \sqrt{v_e^2 - 2ad}$$
$$v_i = \sqrt{7.35^2 - 2(-22.54)(19)}$$
$$v_i = \sqrt{54.02 - (-856.52)}$$
$$v_i = \sqrt{910.54}$$
$$v_i = 30.17 \text{ fps}$$

   6) Calculate the distance Vehicle B traveled during perception / reaction

$$d = \bar{v}t$$
$$d = 30.17(1.5)$$
$$d = 45.25 \text{ feet}$$

   7) Calculate the time it took Vehicle B to skid the 19 feet to impact

$$t = \frac{v_e - v_i}{a}$$
$$t = \frac{7.35 - 30.17}{-29.94}$$
$$t = \frac{-22.82}{-22.54}$$
$$t = 1.01 \text{ sec}$$

   8) Calculate the total stopping time

$$t_s = t_{p+r} + t_b$$
$$t_s = 1.5 + 1.01$$
$$t_s = 2.51 \text{ sec}$$

9) Calculate total stopping time

$$d_s = d_{p+r} + d_b$$
$$d_s = 45.25 + 19$$
$$d_s = 64.25 \text{ feet}$$

10) Plot Vehicle B on the provided diagram, 64 feet south of the AOI. This is the position of Vehicle B at the time the driver perceived a hazard
11) Position Vehicle A at its position at the time the driver of Vehicle B perceived a hazard using Vehicle A's total stopping time (the time it took Vehicle B to reach the AOI) and Vehicle B's constant velocity of 15 mph

12) Convert Vehicle B's constant velocity to feet per second

$$v = S(1.47)$$
$$v = 15(1.47)$$
$$v = 22.05 \text{ fps}$$

13) Calculate the distance Vehicle B traveled in the 2.5 seconds prior to impact

$$d = \bar{v}t$$
$$d = 22.05(2.5)$$
$$d = 55.12 \text{ feet}$$

14) Plot Vehicle A's position on the diagram at the time the driver of Vehicle B perceived a hazard. Vehicle A was 55 feet west of the AOI
15) Draw a line from the approximate position of the driver at the time the driver perceived a hazard
    a) Can he see Vehicle A? NO! vehicle A is obscured by the building on the southwest corner of the intersection
16) So what did the driver of Vehicle A react to? Was it the red light in front of him? Without a witness or confession from Party A, we will never know. The answer to the question is that it is indeterminate as to who ran the light

C. CLOSING: Reinforce key learning points

1. Using the equations provided, you can:

    a. Calculate the minimum speed of vehicles

b. Establish the position of vehicles and parties at different times during the collision sequence:
    1) AOI
    2) Time of perception
    3) Reaction

2. All variables used in the equations must be based on defendable physical evidence

3. The officer must know how to explain the basis for the variables used in each equation in a way that a jury can understand

XI. COURSE REVIEW AND FINAL EXAM (4 Hr.)

A. Course Review

1. Provide student with brief overview

2. Provide students an opportunity to ask questions for clarification

B. Final Exam

1. **DISTRIBUTE**: Final exam

2. Have students complete the exam

3. Collect the exam

4. Grade exam

5. Go over answers to the exam questions with the class