T H E R E <u>I S</u> S A F E T Y I N N U M B E R S

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For

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PREFACE

This material has been designed particularly for Supervisory Personnel to emphasize the basic concepts of the applicable laws of physics and related formulas insofar as they pertain to certain situations which may arise from day to day in the safe operation of motor vehicles. In addition, it has been the endeavor to illustrate certain examples in such a manner as they may be useful as the need arises long after the details of class presentation have been forgotten.

Certainly the influence of Mr. Leslie H. Appel, who for many years conducted lectures in this field and whose lectures I was privileged to attend and participate in, is responsible for my confidence in undertaking this assignment. Too, I am indebted to him for a critical review of the material included.

In addition, my appreciation to Mr. George F. Goehler for the opportunity to undertake the assignment, for had he not been inspired to initiate a project which includes this material, such opportunity would not have been possible.

David D. Canning

THERE IS SAFETY IN NUMBERS

It has been stated that there are only three basic causes of Motor Vehicle Accidents. They include defective highways--about 6%, defective vehicles--8%, and the remaining, namely human deficiencies, 86%. Of the 86%, the generally accepted categories include inattention--36%, following too closely--15%, taking or failing to yield right of way--33%, and physical deficiencies about 2%.

With respect to highway deficiencies, there is a never-ending program to provide safer roadways.

In the effort to reduce accidents caused by defective equipment, some twenty states have inaugurated programs of compulsory vehicle inspection. Here in California, the Highway Patrol will place in effect in March, 1965, rules and regulations relating to the safety of trucks and buses.

In connection with the largest category, namely human deficiencies, many states have or will step up their programs for licensing and/or driver education. The series of examples and illustrations which follow are designed to relate some of the causes of accidents due to human deficiencies to the laws of motion in so far as vehicles are involved.

LAWS OF MOTION

Applicability of the laws of motion in so far as Motor Vehicles are involved, relate directly to Newton's three Laws of Motion. Substantially they are as follows:

1. Every body remains in its condition of rest or uniform motion in a straight line except as it is acted upon by a force greater than the opposing force.

2. The rate at which the momentum of a body changes is proportional to the impressed force causing the change, and this change takes place in the direction in which the force is applied.

3. For every action there is an equal and opposite reaction.

In the first law we see that a resultant force is necessary to give the body acceleration. The resistance of the body to change its motion is called inertia.

The second law expresses the first law in mathematical form, ie., Force equals mass times acceleration or $F = Ma$, and $a = \frac{F}{M}$.

The third law refers to the action of one body on another, and the equal and opposite reaction. For example, if a bus strikes a fixed object, it can only exert as much force on the object as the object is able to exert on the bus.

Other terms relating to the illustrations to follow include those identified with work and energy as follows:

Force - Force is determined as the push or pull acting upon a body.

Friction - When a body slides over another body, a force acts upon it which resists its motion. It is related to the force necessary to slide one body over another and the weight of the sliding body. Thus coefficient of friction designated $f = \frac{F}{W}$ where (W) weight is the gravitational (g) pull of the earth exerted on the mass of a body (M). W then equals Mg or $M = \frac{W}{g}$.

Gravity - Gravity (g) is acceleration due to the gravitational pull of the earth and equals approximately 32.16 feet per second per second.

Work - Work is force acting through space or distance and may be expressed as FS.

Kinetic Energy - Kinetic Energy is the capacity of a moving body for doing work and equals $\frac{Wv^2}{2g}$ where (v) velocity is in feet per second. Since work done in stopping a vehicle must be equal to overcoming its Kinetic Energy, it follows that work FS = KE Kinetic Energy, or $\frac{Wv^2}{2g}$.

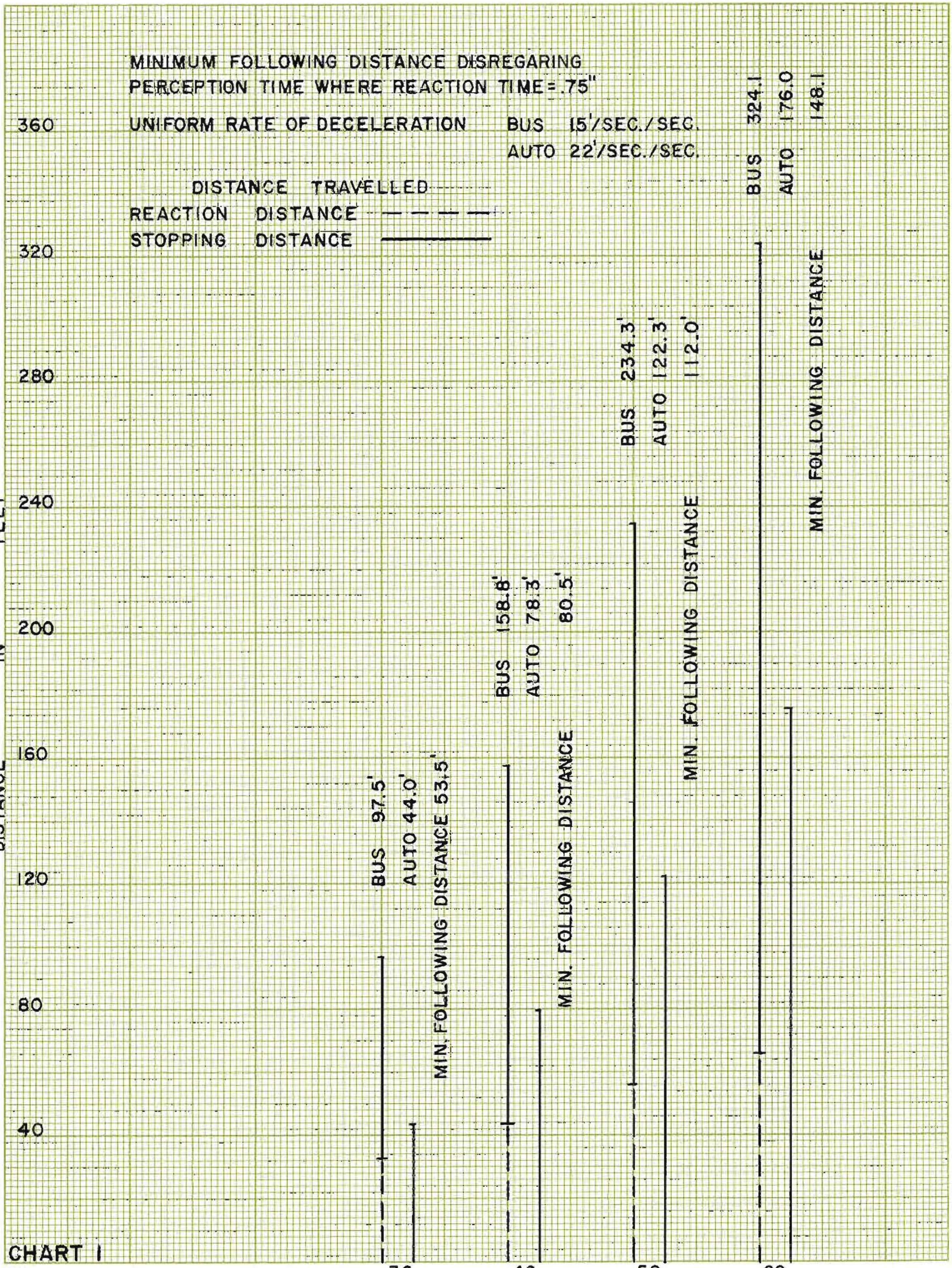
Linear Motion Equations - Linear Motion equations, to which reference will be made in the illustrations to follow, are based on Newton's first law of motion as defined above. They are set forth in the Appendix.

The first of the series of illustrations has to do with following too closely, namely:

Rear-End Collision

Under the heading of Human Deficiencies, following too closely is included as one of the major factors contributing to Motor Vehicle accidents. Although it is generally accepted that to insure minimum safe following distance one car length should be allowed for each 10 miles per hour of speed, ie. at 30 miles per hour, allow 3 car lengths this is not necessarily the minimum standard since several factors enter into what governs minimum safe following distance. They include (a) reaction time of the following driver (b) rate of deceleration of the vehicle being followed (c) rate of deceleration of the following vehicle and (d) speed or velocity. Some authorities advocate that perception time or a combination of perception time and reaction time should also be included. However, in the illustration to follow, perception time is ignored. (See Chart I)

Chart I illustrates typical situations where a bus is following an auto and is required to make an emergency stop in order to avoid a rear-end collision. Reaction time is assumed at .75 seconds, uniform rate of deceleration for the bus, 15'/Sec^2; and for the auto, 22'/Sec^2. First, in order to convert miles per hour to feet per second, miles per hour are multiplied by 1.467. At 30 miles per hour, the vehicles are traveling 44'/Sec which results in a reaction distance of 33'.



MINIMUM FOLLOWING DISTANCE DISREGARING
PERCEPTION TIME WHERE REACTION TIME = .75"
UNIFORM RATE OF DECELERATION BUS 15'/SEC./SEC.
AUTO 22'/SEC./SEC.
DISTANCE TRAVELLED
REACTION DISTANCE
STOPPING DISTANCE
BUS 97.5'
AUTO 44.0'
MIN. FOLLOWING DISTANCE 53.5'
BUS 158.8'
AUTO 78.3'
80.5'
MIN. FOLLOWING DISTANCE
BUS 234.3'
AUTO 122.3'
112.0'
MIN. FOLLOWING DISTANCE
BUS 324.1
AUTO 176.0
148.1
MIN. FOLLOWING DISTANCE
360
320
280
240
200
160
120
80
40
DISTANCE IN FEET
30
40
50
60
SPEED IN M.P.H.

CHART I

By application of formula $d = \frac{v^2}{2a}$, it can be calculated that the bus can stop in 64.5 feet or a total minimum following distance of 97.5 feet. Since the driver of the car being followed has no reaction distance (in other words he has already applied his brakes), application of the formula for stopping distance indicates that he could stop in 44 feet. This would result in a minimum safe following distance of 53.5 feet (97.5' - 44'). Under the rule of one car length for each 10 miles per hour, the minimum, assuming one car length equals 20 feet, would be 60 feet. Therefore, at 30 miles per hour, there would be a safety margin of 6.5 feet. By the same a analysis, the following results: At 40 mph, there would be no margin; at 50 mph, the rule would fall 12' short; at 60 mph, the minimum safe following distance would be short by 28 feet.

Effect of Emergency Stop on Passengers

Tests have been made which indicate that in order to avoid the possibility of injury to passengers, uniform rate of deceleration should not exceed 11'/Sec^2. Chart II illustrates graphically the distance traveled during the decrease in speed for each 10 mph from an initial speed of 30 mph, under emergency conditions, with a uniform rate of deceleration of 15'/Sec^2. In addition, there is shown the effect of reducing the braking effortdduring the period from 10 mph to stop. The formula used in making the calculations is is $d = \frac{v_2^2 - v_1^2}{2a}$. The calculations show that: in braking from 30 mph to 20 mph, distance traveled equals 35.8'; from 20 mph to 10 mph, distance traveled equals 21.5'; and from 10 mph to stop, distance traveled equals 7.2'. The severe braking effort from 10 mph to stop in only 7.2' is the major contributing factor to falling passengers, whiplash, etc. Also there is shown the more severe braking effect from 5 mph to stop (less than 2 feet) which occurs principally after starting up, adversely affecting standees. As shown by

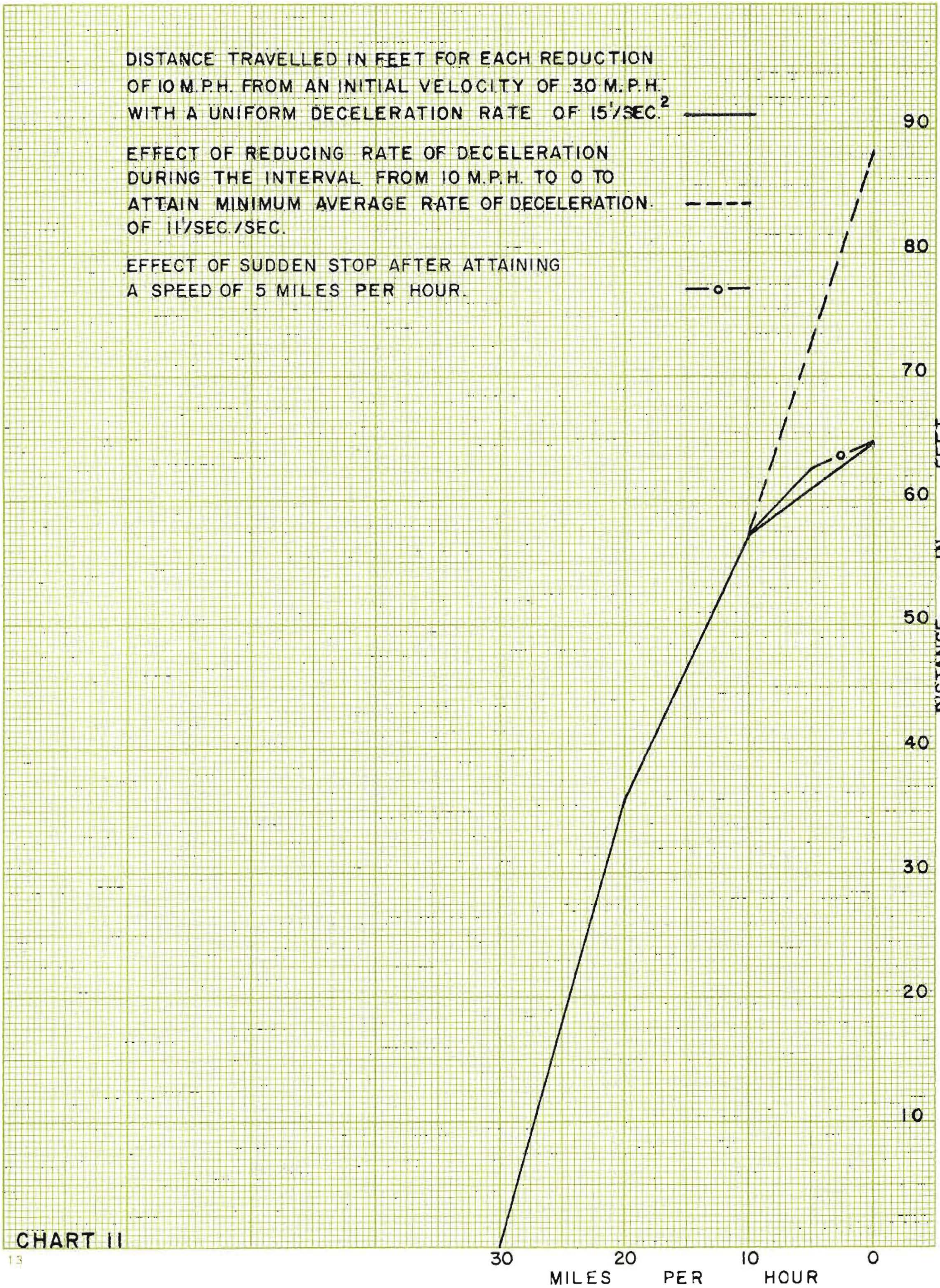

DISTANCE TRAVELLED IN FEET FOR EACH REDUCTION
OF 10 M.P.H. FROM AN INITIAL VELOCITY OF 30 M.P.H.
WITH A UNIFORM DECELERATION RATE OF 15'/SEC.^{2}
EFFECT OF REDUCING RATE OF DECELERATION
DURING THE INTERVAL FROM 10 M.P.H. TO 0 TO
ATTAIN MINIMUM AVERAGE RATE OF DECELERATION
OF 11'/SEC./SEC.
EFFECT OF SUDDEN STOP AFTER ATTAINING
A SPEED OF 5 MILES PER HOUR.
90
80
70
60
50
40
30
20
10
DISTANCE IN FEET
30
20
10
0
MILES PER HOUR

CHART II

the dotted line, this can be compensated for somewhat--particularly-- if the braking effort is reduced when decelerating from 10 mph to stop. The minimum average deceleration rate of $11'/Sec^2$, would require a total stopping distance of 88 feet. Therefore, in order to attain an average rate of $11'/Sec^2$, it would be necessary in braking from 10 mph to stop to reduce the rate of deceleration to $3.5'/Sec^2$. In view of these findings, the safe following distance set forth in Chart I does not apply particularly when a standing passenger load is involved.

Inattention

Although following too closely might well be classed in the category of inattention, it has been said that accidents caused by inattention are due largely to failure to make proper use of the eyes. A particularly costly example of this is failure to insure that the front door of the bus is clear before closing. Others include failure to observe cars pulling from the curb, a driver preparing to alight from the left side, pedestrians leaving the curb, failure to observe speed signs particularly on curves, the setting of traffic lights, and many others. Clearest seeing takes place in only a small portion of the visual field. With respect to peripheral vision, tests have shown that in some instances the field is limited to as little as 20 degrees. Even with good peripheral vision, clear vision does not prevail. Therefore, according to at least one theory, if accidents resulting from instances such as outlined above are to be avoided, there must be a continual shifting of the eyes.

In the category of inattention, three illustrations are included. They are (1) determining the speed of a vehicle which leaves the highway, (2) relationships of pedestrian traffic to vehicular traffic, and (3) overtaking and passing.

Speed of a Vehicle Leaving the Highway

In instances where vehicles leave the highway, particularly on curves where speed warnings are ignored, it is possible under certain conditions to calculate the speed of the vehicle. For purpose of illustration, the following assumptions are made:

Height of embankment - 21'
Distance of point of landing from highway - 100'

In order to determine the speed of the vehicle as it left the highway, it is necessary to apply the law of falling bodies. Objects fall to the ground because the earth exerts a pull on them. This pull is called the force of gravity identified by the letter (g). As previously stated, (g) by measurement has been determined at 32+'/Sec^2. Gravitational pull is always the same whether or not the object is dropped or has horizontal velocity before it commences falling. The law of falling bodies illustrated graphically on Chart III is the basis for determining the speed in the example set forth above. Since the initial velocity remains constant throughout the fall of the object, horizontal distance traveled for each second of fall is always the same. Application of the formula $d = \frac{gt^2}{2}$, indicates that the object will perform as follows:

	FALL	TRAVEL HORIZONTALLY
During the 1st second	16'	50'
For 2 seconds	64'	100'
For 3 seconds	144'	150'
For 4 seconds	256'	200'
For 5 seconds	400'	250'

LAW OF FALLING BODIES

WHERE d = VERTICAL DISTANCE IN FEET

g = ACCELERATION DUE TO GRAVITY

t = TIME IN SECONDS

$$d = \frac{gt^2}{2}$$

ASSUME INITIAL VELOCITY 50'/SEC. AND HEIGHT 400'

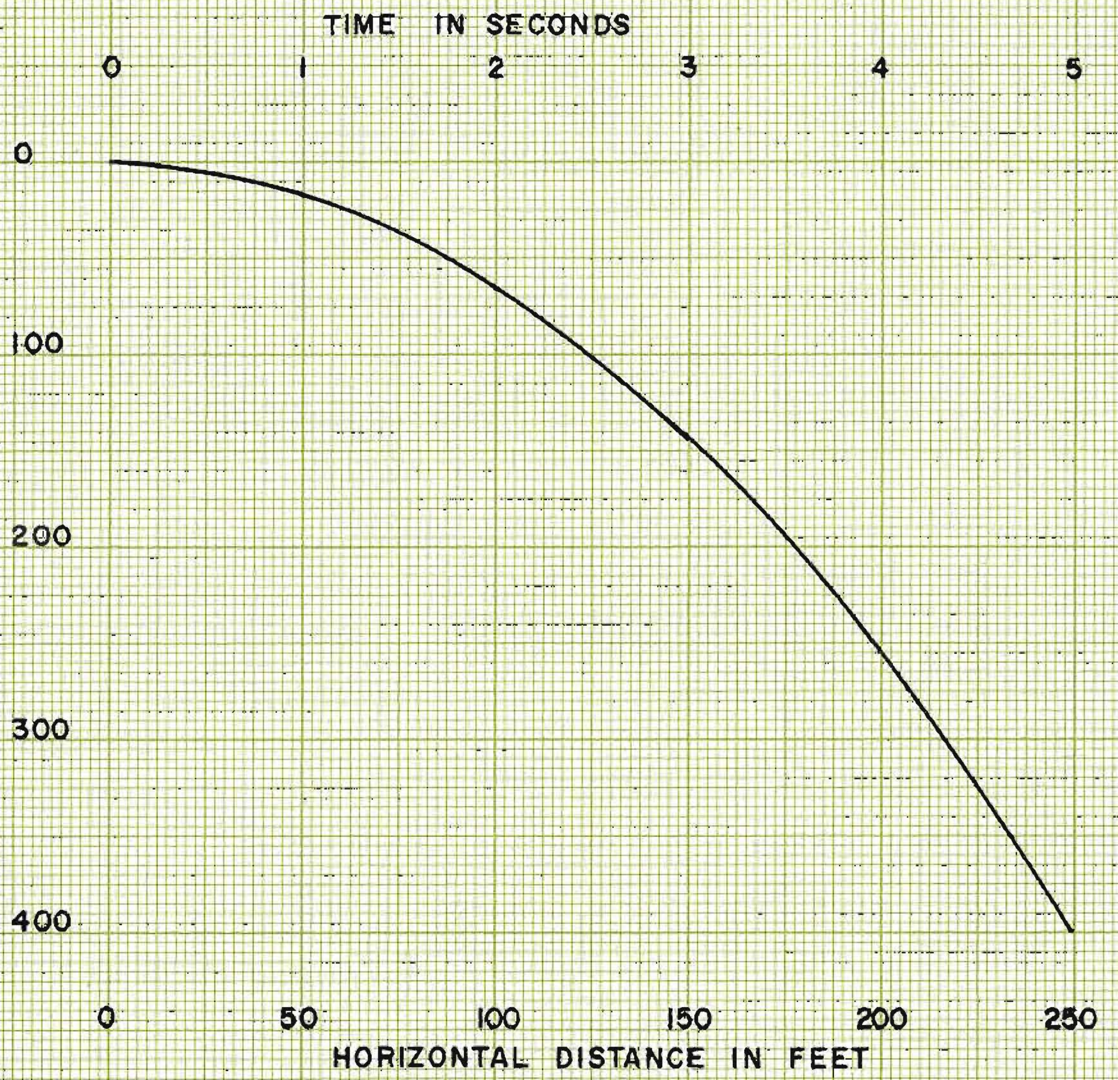


CHART III

Since it is necessary to isolate the time it took the vehicle to fall 21 feet, it is necessary to convert the formula $g = \frac{dt^2}{2}$ to time. This becomes, then, $t = \sqrt{\frac{2d}{g}}$. Time for the vehicle to fall 21 feet -- $t = \sqrt{\frac{42}{32}} = 1.14''$. During the time it took the vehicle to fall 21', it also traveled horizontally 100 feet. Speed, by application of the formula $v = \frac{d}{t} = \frac{100'}{1.14''} = 88'/\text{Sec} = 60$ mph. Therefore, under the assumptions made, the vehicle was traveling 60 mph when it left the highway.

Pedestrian Versus Vehicle

Failure to look ahead and to govern speed accordingly, particularly when a pedestrian starts to cross the street from in front of a parked car, can result in a pedestrian collision. Walking speeds of pedestrians crossing a street, generally speaking, vary from 3.5 to 4.5 feet per second. For the purpose of this illustration, a walking speed of 4'/Sec will be used. Other assumptions are as follows:

Width of Street - 60'
Speed of approaching bus - 30 mph
Distance from curblane - 8.5'
Width of bus - 8.5'
Rate of deceleration - $15'/\text{Sec}^2$

The question to be answered is, "How far away from point of possible contact must the driver observe the pedestrian to avoid collision?" The example is illustrated by Chart IV. First the pedestrian must have negotiated at least 17' of the crossing in order to clear the left front corner of the bus. Time to negotiate 17' equals $t = \frac{d}{v} = \frac{17'}{4} = 4.25$ Seconds. From Chart I it was determined that under emergency stopping conditions, the total distance required to stop at 30 mph, including reaction time, is 97.5'. The time required to stop

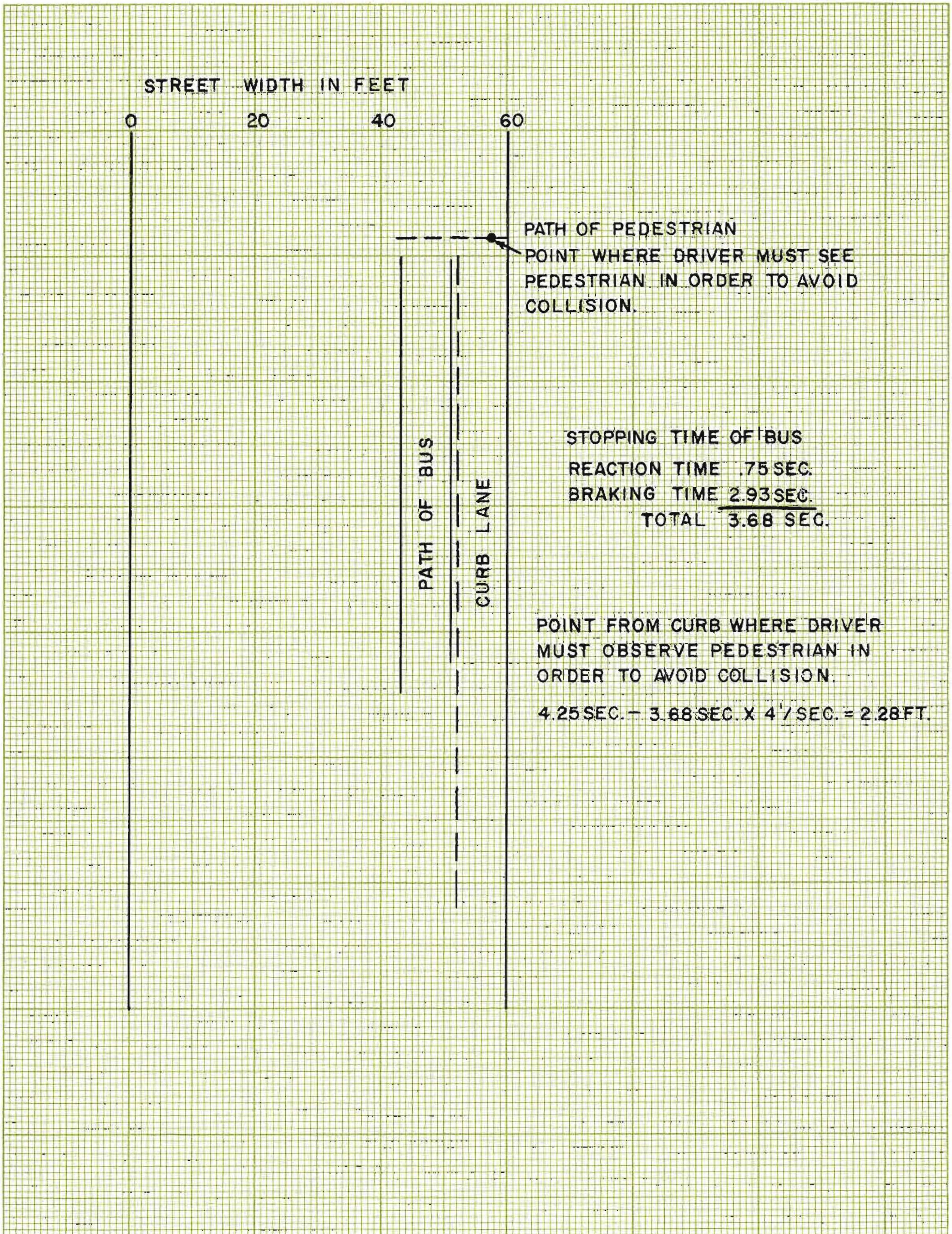

STREET WIDTH IN FEET
0
20
40
60
PATH OF PEDESTRIAN
POINT WHERE DRIVER MUST SEE PEDESTRIAN IN ORDER TO AVOID COLLISION.
PATH OF BUS
CURB LANE
STOPPING TIME OF BUS
REACTION TIME .75 SEC.
BRAKING TIME 2.93 SEC.
TOTAL 3.68 SEC.
POINT FROM CURB WHERE DRIVER MUST OBSERVE PEDESTRIAN IN ORDER TO AVOID COLLISION.
4.25 SEC. − 3.68 SEC. X 4'/SEC. = 2.28 FT.

CHART IV

can be determined from the formula $t = \frac{d}{v}$ for reaction time, and $t = \frac{v}{a}$ for braking time = as follows:

Reaction $t = \frac{d}{v} = \frac{33}{44} = .75$ seconds

Braking $t = \frac{v}{a} = \frac{44}{15} = 2.93$ seconds

Total Stopping Time 3.68 seconds

Since the time for the pedestrian to clear the left front corner of the bus is 4.25 seconds and the driver has only 3.68 seconds in which to stop, the pedestrian must be at least 2.28 feet from the curb when the driver reacts if he is to avoid a collision. This is calculated by 4.25" - 3.68" x 4'/Sec = 2.28'. If for example, the pedestrian steps out from between parked cars, he then has only 8.5' to negotiate to be in the clear. This distance can be negotiated in $\frac{8.5'}{4'/Sec}$ or 2.15 seconds. This means that the driver has only 2.15 seconds in which to avoid a collision. If reaction time is .75 Sec., this leaves a braking time of only 2.15" - .75" or 1.4 Seconds. Further, speed could be no greater than v = at, or 15'/Sec x 1.4"= 21'/Sec or 14.42 mph at the time the pedestrian stepped from between the parked cars if a collision is to be avoided.

To put it another way, the driver must see everything going on ahead of his vehicle whether it be a pedestrian, a car pulling from the curb, etc. within the distance in which he can react and stop.

Overtaking and Passing

Accidents resulting from overtaking and passing are usually associated with head-on collisions--particularly on a two-lane highway. In situations such as this, inattention can well include judgement. Factors involved include judgement of time, speed of opposing vehicles, acceleration characteristics of the passing vehicle, and speed of the vehicle being overtaken.

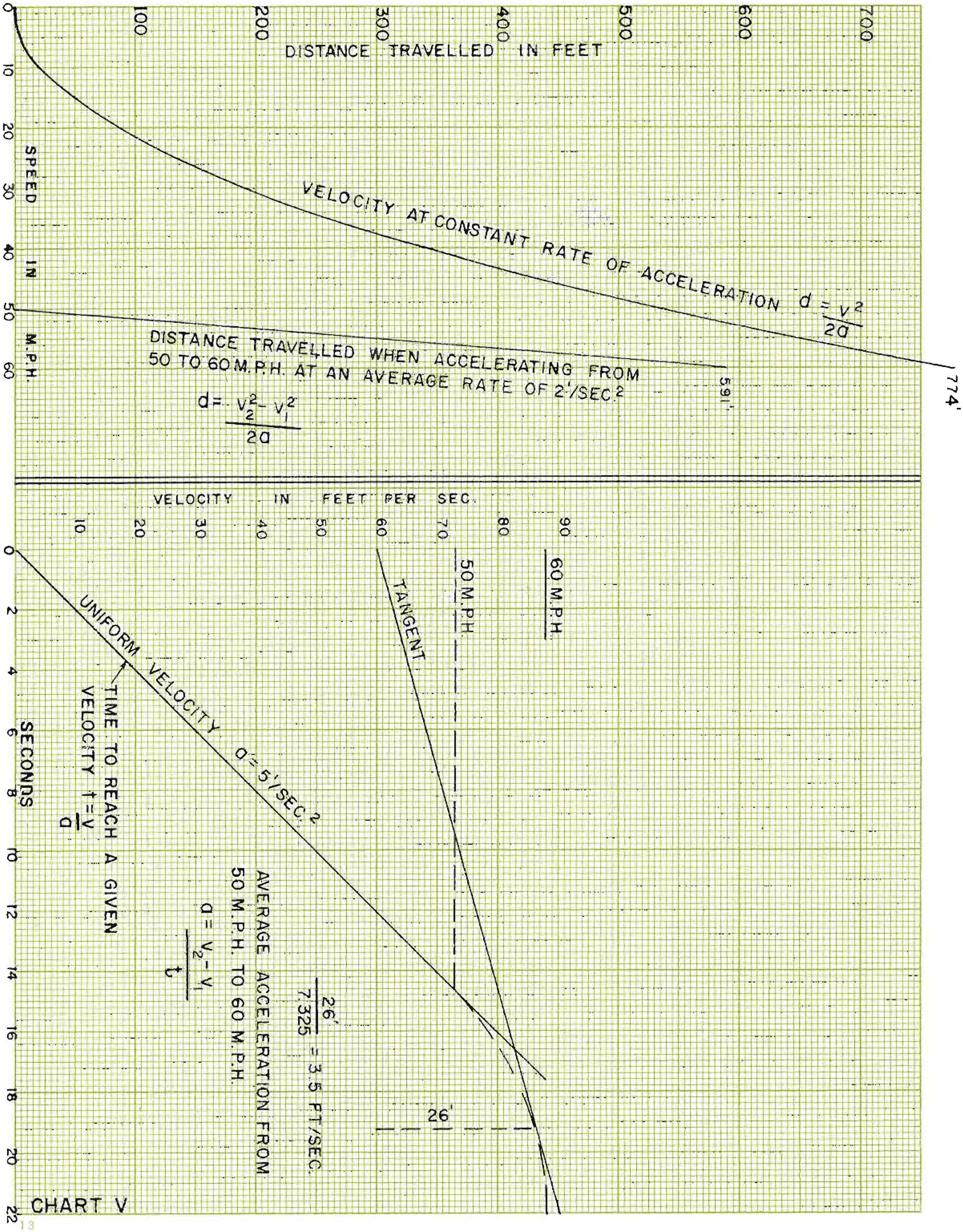
The probability of overtaking and passing safely can apply equally well on multiple-lane highways. The only difference being that the driver can remain in the passing lane in the event the hole ahead closes.

Acceleration

Before illustrating an example of overtaking and passing, it is proper that some of the characteristics of acceleration be examined. While acceleration is usually considered uniform; nevertheless, after attaining certain speeds, acceleration tends to decrease.

Definition: Acceleration is the change in velocity during an interval of time divided by the duration of that interval.

This, if a bus starting from a standstill acquires a velocity of 5'/Sec. by the end of one second, gains an additional 5'/Sec during the second, etc., it is said to have a pick up of $5'/Sec^2$. The lefthand side of Chart V illustrates the distance traveled when accelerating at a uniform rate of $5'/Sec^2$. Immediately to the right in the same block, there is shown the distance traveled when accelerating from 50 mph to 60 mph at an average rate of $2'/Sec^2$. The right hand portion of Chart V shows the time required to reach a given velocity, on the basis of uniform rate of acceleration, and is indicated by the solid diagonal line. The dotted curve line shows what is likely to take place after reaching a given speed, and demonstrates a tailing off when accelerating from 50 mph to 60 mph. Even during this period of time, acceleration is not uniform. In the illustration (not drawn to scale) after 4.5 seconds, the rate of acceleration is $3.5'/Sec^2$. But during the remaining 3 seconds, it drops from $3.5'/Sec^2$ to zero.


DISTANCE TRAVELLED IN FEET
SPEED IN M.P.H.
VELOCITY AT CONSTANT RATE OF ACCELERATION $d = \frac{v^2}{2a}$
774'
DISTANCE TRAVELLED WHEN ACCELERATING FROM 50 TO 60 M.P.H. AT AN AVERAGE RATE OF 2'/SEC.²
$d = \frac{V_2^2 - V_1^2}{2a}$
591'
VELOCITY IN FEET PER SEC.
SECONDS
TANGENT
50 M.P.H.
60 M.P.H.
UNIFORM VELOCITY $a = 5'/SEC.^2$
TIME TO REACH A GIVEN VELOCITY $t = \frac{V}{a}$
AVERAGE ACCELERATION FROM 50 M.P.H. TO 60 M.P.H.
$a = \frac{V_2 - V_1}{t}$
$\frac{26'}{7.325} = 3.5$ FT/SEC.
26'
CHART V

Example of Overtaking and Passing

The various distances involved in overtaking and passing are depicted on Chart VI and are based on the following assumptions:

Initial and constant speed of car being overtaken.	50 mph
Length of car.	20 ft.
Maximum rate of deceleration of car.	22'/Sec^2
Initial speed of overtaking bus.	50 mph
Maximum speed of overtaking bus.	60 mph
Length of bus.	40 ft.
Average acceleration of bus from 50 to 60 mph. . .	2'/Sec^2
Speed of opposing vehicle.	65 mph

The distance required to accelerate from 50 to 60 mph is determined from the formula $d = \frac{v_2^2 - v_1^2}{2a} = \frac{88^2 - 73.35^2}{4} = 591'$

Length of Bus	40'
Front of bus from zero (rear of bus).	631'

The time for bus to accelerate from 50 mph to 60 mph equals

$t = \frac{v_2 - v_1}{a} = \frac{88 - 73.35}{2} = 7.325$ seconds

Distance traveled by auto while bus is accelerating from 50 mph to 60 mph equals $d = vt = 73.35'/\text{Sec} \times 7.325\ \text{Sec} \doteq 537'$

Location of front of car from zero at time bus started accelerating length of bus	40'
From Chart I -- following distance	112'
Length of Car.	20'
Location of front of car from zero when bus reaches speed of 60 mph.	709'

The distance the bus must overcome at 60 mph to overtake, pass, and return to original lane is the sum of 709' - 631' or 78'; plus the minimum stopping distance of car at 50 mph--122'; plus length of the bus--40'; or a total distance to be overcome of 240'. The time to overcome is calculated from the formula $t = \frac{d}{v_2 - v_1} = 16.38$ Seconds, where v_2 is speed of bus and v_1 is speed of car.

The distance, then that the bus must move to pick up the 240 feet is d = at = 88'/Sec x 16.38 seconds = 1,441 feet. The distance the bus traveled in accelerating to 60 mph (591') plus the length of the bus (40') equals 631 feet. The total distance involved, then, equals 1441' + 631' or 2,072 feet. The length of time required to overtake and pass equals 7.325 seconds plus 16.38 seconds = 23.7 seconds. The sight distance, then required to avoid a head-on collision with an opposing vehicle traveling at 65 mph is the distance the bus traveled in overtaking (2072') plus the distance opposing vehicle traveled in 23.7 seconds at 65 mph equals d = vt = 95.35'/Sec x 23.7 seconds equals 2,260'. This makes the total sight distance 4,332 feet or approximately .8 mile. It is significant that this example of overtaking and passing results in a time saving of less than 4 seconds.

Failure to Yield Right of Way

Failure to yield right of way is usually associated with intersection accidents. Here, again, the following factors are involved; sight distance, reaction time, velocity, and rates of deceleration. Consider the following situations:

Bus "B" is traveling at 30 mph five feet from center line of a 60 foot street. Bus is 40 feet long. Bus has a maximum rate of deceleration of 15'/Sec^2. Drivers reaction time is .75 second. Auto "A", 20 feet long, is approaching from the left at 30 mph traveling five feet from the center of an 80-foot street. Auto has a maximum rate of deceleration of 22'/Sec^2, and driver has a reaction time of .75 second. The driver of bus has a sight distance indicated by S. The front of the bus is 84 feet from a point 5 feet south of the east-west center line when he observes auto approaching 76 feet distant from a point 5 feet east of the center line of the north-south street.

The following questions are raised:

1. Can the bus driver avoid hitting the auto provided the auto maintains its speed of 30 mph?

2. (a) Will a collision occur if both vehicles simultaneously make emergency stops?
   (b) At what speed would bus strike the auto?
   (c) What would be the maximum speed of bus in order to avoid striking auto provided auto makes an emergency stop?

Question 1

Referring to Chart VII, it is evident, first, that auto would have to travel 96 feet in order to avoid being struck (76' + 20'). Since Auto is traveling 30 mph (44'/Sec), it will take Auto $t = \frac{d}{v} = \frac{96}{44}$ or 2.18 seconds to clear the possible point of impact. Thus it is evident that the bus driver has 2.18 seconds to react and slow down his bus in order to avoid striking the auto. The question, then, is how far will the bus travel during the 2.18 seconds. Since reaction time is .75 second, the driver has 2.18 seconds minus .75 seconds or 1.43 seconds to slow down his bus. The formula $v_2 = v_1 - at = 44 - 15 \times 1.43 = 22.55$'/Sec. indicates that the bus has slowed down to 22.55'/Sec at the end of 1.43 seconds. The formula $d = \frac{v_1^2 - v_2^2}{2a} = \frac{1936 - 508.5}{30}$ equals 47.6 feet which is the distance the bus traveled slowing down in 1.43". To this distance the reaction distance, 44'/Sec x .75 seconds equals 33 feet, indicates that the bus traveled 80.6 feet during 2.18 seconds. Since distance available was 84 feet, the bus missed striking the auto by 3.4 feet.

Question 2a

From Chart I, it is evident that the auto would stop with its front end one foot westerly of the path of the bus as shown on Chart VIII. This is determined as follows:

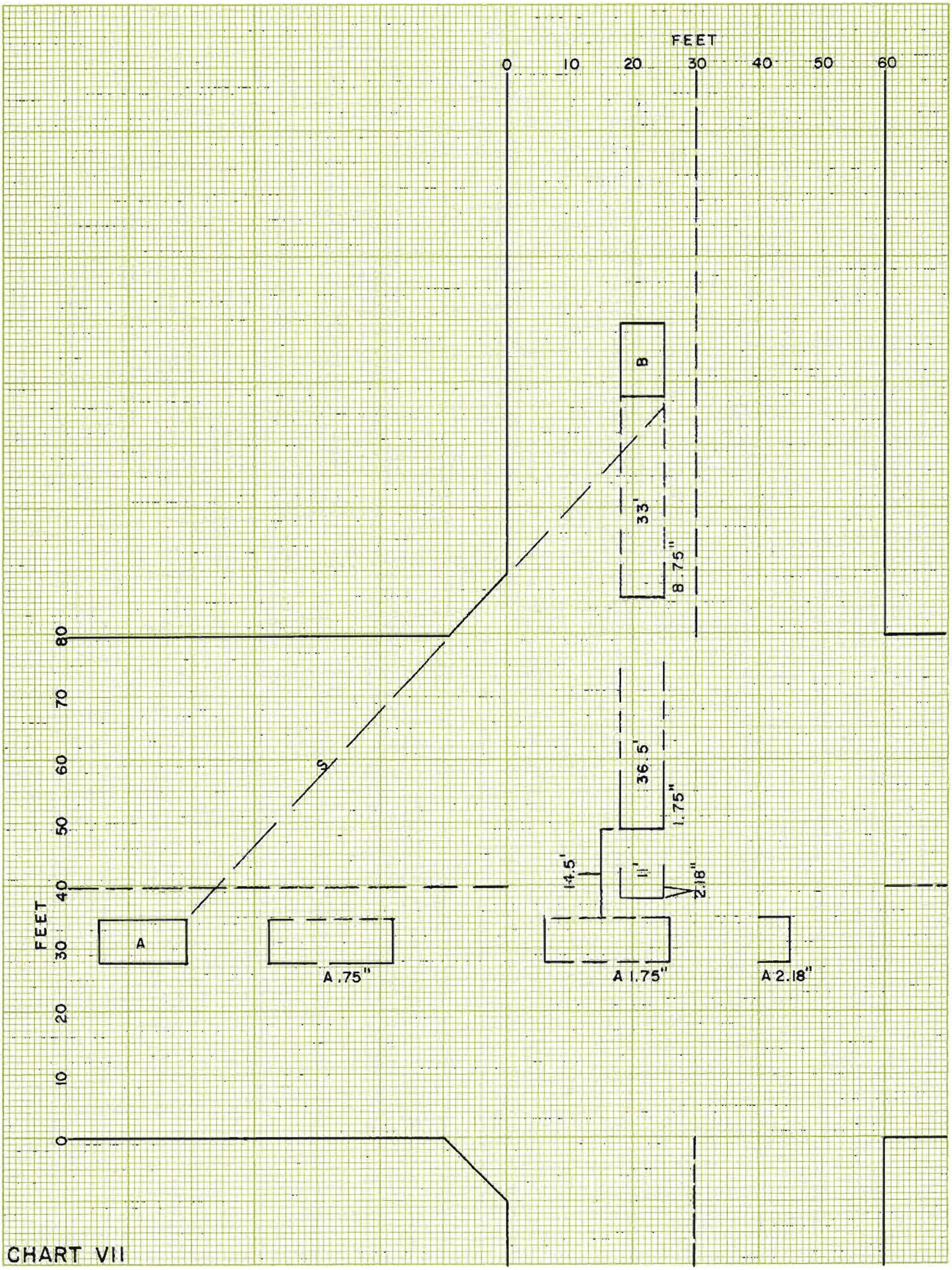
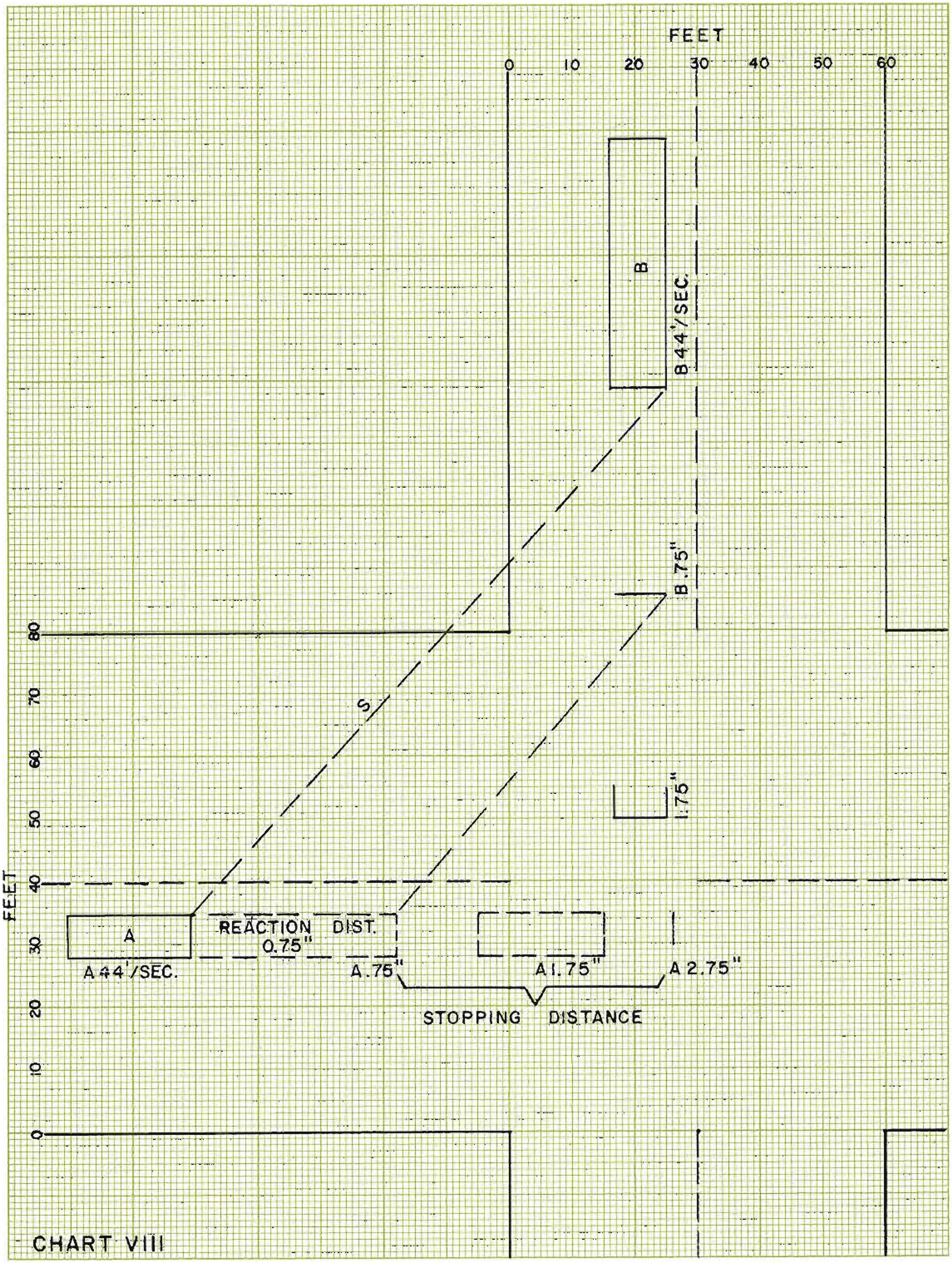

FEET
0
10
20
30
40
50
60
B
33'
B .75"
80
70
60
50
40
30
20
10
0
FEET
S
36.5'
1.75"
14.5'
11'
2.18"
A
A .75"
A 1.75"
A 2.18"

CHART VII


FEET
0
10
20
30
40
50
60
B
B 44'/SEC.
B .75"
S
1.75"
80
70
60
50
40
30
20
10
0
FEET
A
A 44'/SEC.
REACTION DIST.
0.75"
A .75"
A 1.75"
A 2.75"
STOPPING DISTANCE
CHART VIII

Reaction distance is 33 feet; plus stopping distance, $\frac{v_2^2}{2a} = \frac{1936}{44} = 44$ feet or a total of 77 feet. The bus, however, has a total stopping distance of 97.5' including reaction distance of 33 feet plus stopping distance of $\frac{v_2^2}{2a} = \frac{1936}{30} = 64.5$ feet. Since the maximum available distance is 84 feet, the bus would be 13.5 feet short of avoiding the collision.

Question 2b

The speed at which the bus would strike the auto can be determined as follows: Since the bus has only 84 feet in which to stop, the actual braking distance is 84' - 33' or 51'. In the formula $d = \frac{v_2^2 - v_1^2}{2a}$, v_1 can be isolated and $v_1 = \sqrt{v_2^2 - 2ad} = \sqrt{1936 - 1530} = \sqrt{406} = 20'/\text{Sec} = 13.7$ mph.

Question 2c

The maximum speed that bus could be traveling in order to avoid striking auto is determined from the formula $v_2^2 = 2ad$. However, in order to apply the formula, reaction distance must also be taken into consideration. This can only be done if the initial speed of the bus is known. Since reaction time is .75 second, reaction distance, d, equals .75"v. Therefore stopping distance equals 84' - .75"v. Substituting $v_2^2 = 2a\,(84' - .75''v)$ or $v_2^2 = 2520 - 22.5v$. v is isolated by the use of a quadratic equation in which $v_2^2 + 22.5v = 2520$.

The steps are as follows:

(1) $v_2^2 + 22.5v + 126.5625 = 2520 + 126.5625$

(2) $v_2^2 + 22.5v + 126.5625 = 2646.5625$

(3) $(v_2 + 11.25)^2 = 2646.5625$

(4) $v_2 + 11.25 = \sqrt{2646.5625}$

(5) $v_2 + 11.25 = 51.4445$

$v_2 = 51.4445 - 11.25 = 40.1945'/\text{Sec}$ or 27.6 mph

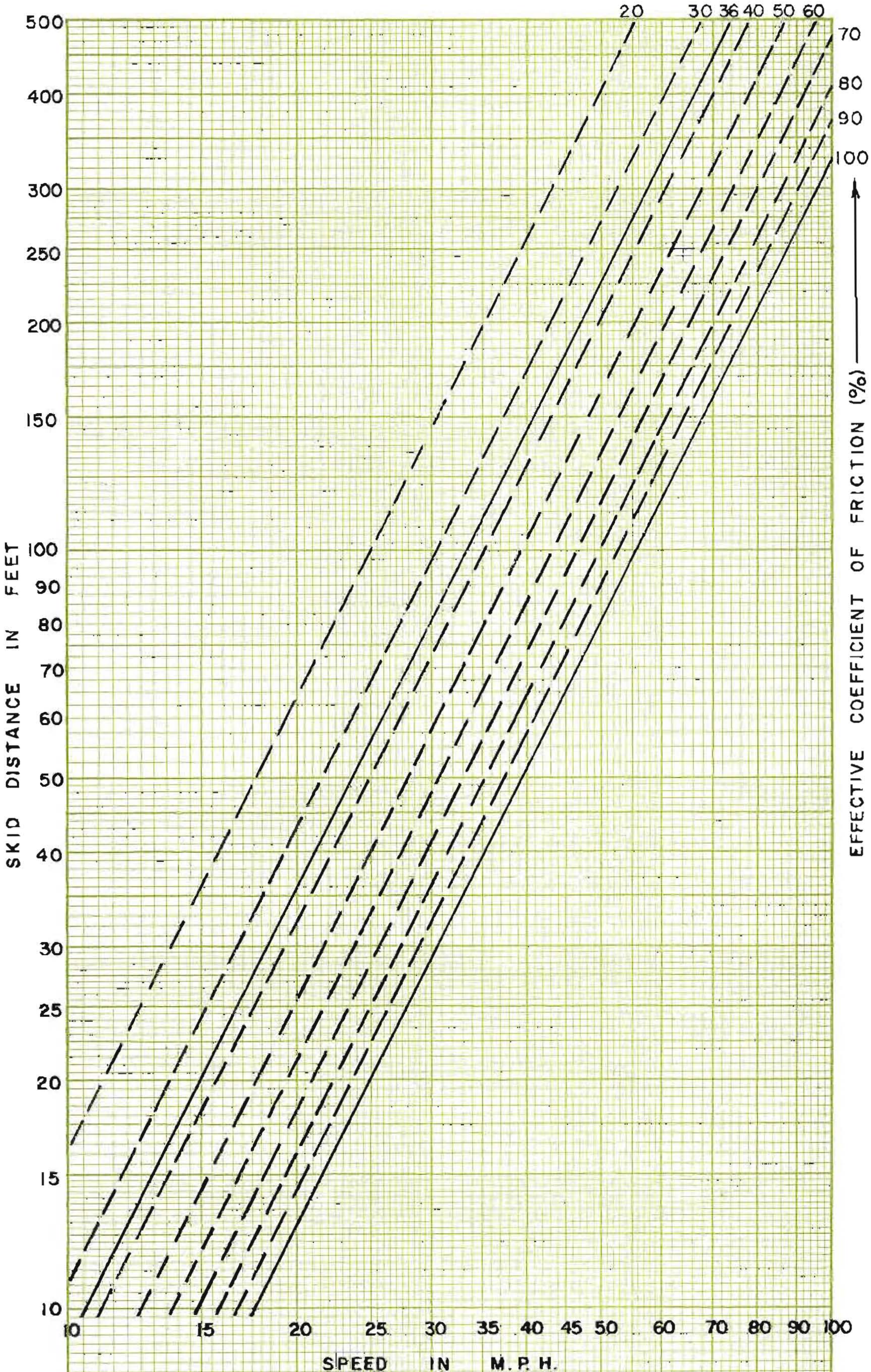
Proof:

Stopping,	$d = \frac{v_2^2}{2a} = \frac{1615.6}{30}$	=	53.85 feet
Reaction,	d = 40.1945'/Sec x .75"	=	30.15 feet
	Total Distance	=	84.00 feet

Estimating Speed From Skidmarks

When a vehicle skids or slides, the only force which acts upon it to retard its motion is the force of friction. The coefficient of friction (f) is defined as the ratio between the force (F) necessary to slide the vehicle over the surface and the weight (W) of the vehicle. Therefore, $f = \frac{F}{W}$. Force is the push or pull acting upon a body which causes it to accelerate in the direction of the force (Newton's 2nd Law of Motion). This acceleration is directly proportional to the force applied. For example, $\frac{F}{F_1} = \frac{a}{a_1}$. In the event of a body in free fall, the force acting would be its weight (W), and the acceleration or rate of change of motion would be that due to gravity (g)-- See Chart III. Substituting (W) for (F_1) and (g) for (a_1) the proportion above becomes $\frac{F}{W} = \frac{a}{g}$. From which F becomes $\frac{Wa}{g}$. Suppose that a vehicle of weight (W) is at rest on a horizontal surface and that a steady horizontal force (F) is exerted on it through a distance, d. The work performed on it in moving the vehicle is then Fd. If there is no friction, F causes the vehicle to accelerate uniformily; in accordance $F = \frac{Wa}{g}$. Since the uniform laws of motion show that $d = \frac{v^2}{2a}$, the Kinetic Energy acquired by the vehicle can be obtained by substitution of equal values. Thus $Fd = \frac{Wa}{g} \times \frac{v^2}{2a}$ or $\frac{Wv^2}{2g}$. However, since friction is involved, the coefficient of friction (f) must be introduced into the formula Fd which then becomes Ffd. Substituting W, the weight of the vehicle, for F, the equation then becomes $Wfd = \frac{Wv^2}{2g}$ or $fd = \frac{v^2}{2g}$. By transposition, $v^2 = fd2g$, and $v = \sqrt{fd2g}$. Since 2g is always constant, $v = 8.02 \sqrt{fd}$. In the event grades are involved, $v = 8.02 \sqrt{fd - p}$ where p equals percent of grade.

For example, if a vehicle skids 48 feet on level pavement known to have a coefficient of friction of .7, the minimum speed is $v = 8.02 \sqrt{48 \times .7} = 8.02 \times 5.8 = 46.5'$/Sec or 31.9 mph. By use of Logarithmic Scales, it is possible to plot mph under various coefficients of friction and length of skid. On Chart IX, by locating where the length of skid crosses the dotted lines horizontally and reading down, mph may be determined.



SKID-SPEED CHART

CHART IX

APPENDIX

Glossary Of Terms

a	Acceleration - or Deceleration
d	Distance in Feet
f	Coefficient of Friction
g	Gravity (32.16 Feet per second per second)
p	Percent of Grade
t	Time in seconds
v	Velocity in Feet
v_1	Initial Velocity
v_2	Final Velocity
F	Force
KE	Kinetic Energy $= \frac{Wv^2}{2g}$
M	Pounds Mass
W	Weight in Pounds
mph	Miles Per Hour
$\sqrt{}$	Square Root
'	Feet
"	Seconds
Sec	Seconds
'/Sec	Feet Per Second
'/Sec^2	Feet Per Second Squared

APPENDIX

Formulas

UNIFORM AND UNIFORMLY VARYING MOTION

$$a = \frac{v_2 - v_1}{t} ; \frac{v_2}{t} ; \frac{v_2^2}{2d}$$

$$d = vt ; \frac{v_1 + v_2}{2}(t) ; v_2 t - \frac{at^2}{2} ; v_1 t + \frac{at^2}{2} ; \frac{at^2}{2} ; \frac{v_2^2 - v_1^2}{2a} ; \frac{v_2^2}{2a}$$

$$t = \frac{d}{v} ; \frac{2d}{v_1 + v_2} ; \frac{2d}{v_2} ; \frac{v_2 - v_1}{a} ; \frac{v_2}{a}$$

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

$$v_1 = v_2 - at ; at$$

$$v_2 = v_1 + at ; at$$

STOPPING DISTANCE

$$a = \frac{v_2^2}{2d} ; \frac{v_1^2 - v_2^2}{2d}$$

$$d = \frac{v_2^2}{2a} ; \frac{v_1^2 - v_2^2}{2a}$$

$$t = \frac{2d}{v_2} ; \frac{v_2}{a}$$

DECELERATION

$$v_2 = v_1 - at$$

Conversion Factors

mph = '/Sec x .6818

ft/Sec = mph x 1.467

mph	'/Sec	'/Sec²	mph	'/Sec	'/Sec²
5	7.34	53.88	35	51.35	2636.82
10	14.67	215.21	40	58.68	3443.34
15	22.00	484.00	45	66.00	4356.00
20	29.34	860.84	50	73.35	5380.22
25	36.68	1345.42	55	80.69	6510.88
30	44.00	1936.00	60	88.00	7744.00