SIMULATING NO-PASSING ZONE VIOLATIONS ON A VERTICAL CURVE OF A TWO-LANE RURAL ROAD

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SIMULATING NO-PASSING ZONE VIOLATIONS ON A VERTICAL CURVE OF A TWO-LANE RURAL ROAD

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ABSTRACT

A unique simulation was developed to evaluate the performance of a system designed specifically to detect and warn no-passing zone violations on vertical curves of two-lane rural roads.

After the system architecture and the system design were developed, a special software program was written in order to test the system functions and assess the system performance. Many roadway, vehicle, and driver's-related parameters were introduced in this simulation to reflect as close as possible what is occurring in the real world. More than 19500 violation runs were made for the basic scenario to reflect and calibrate the actual conditions of the parameters involved.

The simulation was used also as a tool to conduct a system evaluation by applying it for both "with" and "without" the warning system cases. The simulation outcome for "without the warning system" case was very close to the actual real-world condition (1.41 Vs. 0.71 crash per year). The simulation runs of "with the warning system" case showed also that the system could virtually eliminate all head-on collisions, should the violators obey the early warning messages displayed.

1. INTRODUCTION

A new safety application, as part of ITS Advanced Rural Transportation System (ARTS), has been deployed on a two-lane rural road (Route 114), in Southwest Virginia. The route has a rolling geometry of several vertical curves and is subject to significant head-on accidents. During the period 1994-2000, the road experienced 11 crashes that resulted in 12 fatalities and 29 injuries. All these accidents were a result of two main conditions:

1- **Illegal passing maneuvers** crossing solid yellow centerline, and
2- A short passing sight distance due to the **road vertical profile**.

The main objective of this research, supported by Virginia Department of Transportation VDOT, is to design, install, test, and evaluate a video detection-based warning system on one vertical crest curve, capable of performing the following two main functions:

1. Detect vehicles that attempt to violate the no-passing zone.
2. Warn the violating drivers in order to discourage them from continuing their risky maneuvers.

Figure 1 gives an overview of the physical architecture of the system. The main elements are a series of video detection cameras, “DO NOT PASS” warning message signs and enforcement cameras. The intent of this paper is to discuss only the simulation of the overall system. The system architecture and design is discussed in another paper “Deploying an ITS Detection and Warning System for No-Passing Zones on Two-Lane Rural Roads”.

2. ROLE OF SIMULATION

A computer simulation was developed to represent the violation problem under study in order to achieve the following three purposes:

1- Understand better the violation problem on vertical curves of two-lane rural roads; in terms of how it occurs and what are the main factors affecting crash occurrences.
2- Get some estimation on how the system would perform under varying conditions.
3- After system validation, “what if “ tests could be used to assess the sensitivity of the outcome due to some limited modification of one or more parameter.

3. CODE STRUCTURE

A special simulation code was written in MATLAB of The MathWorks to represent the no-passing zone violations. The simulation is a microscopic, stochastic, and period scanning tool. The simulation code consists of many program files that could be grouped into the following:

1- Input Module
2- Violation Generator
3- Road Profile Module
4- Main Analysis programs
5- Support Analysis Modules
6- Crash Outcome Analysis program
7- Report Module

4. DEFINING THE INPUT PARAMETERS

The system parameters may be classified into three groups, which are related to the three transportation system components:

1- Roadway-related parameters.
2- Vehicle-related parameters.
3- Driver-related parameters.

4.1 Roadway Related Parameters

4.1.1 Road Profile

The road profile is expressed as a series of 50-feet segments based on the coordinates and elevation readings of the road centerline plans. Figure 2(a) depicts the X and Z readings, and Figure 2(b) shows the plan configuration of the 2-lane road. The road segment put under detection is d =2100 feet long.

The two traffic directions are treated separately in the kinematical analysis. Therefore, the exact location of every vehicle going eastbound or westbound at a certain moment of time “t” will be referred to the origin point of the vehicle direction (see Figure 2).

During the course of an illegal passing, a crash physically occurs when the distance AC is zero, which could be expressed as follow:

distance AC = 0 → d - (xA + xC) = 0 → xA + xC = d .

Where, xA and xC are the abscissas of vehicles A and C respectively.

4.2 Vehicle-Related Parameters

The vehicle classes and their shares out of the total traffic mix were determined based on a field traffic classification survey conducted during two representative weeks in September 2000.The vehicle classes and shares are:

1- Light vehicles (LV) such as passenger cars (83%)
2- Medium vehicles (MV) such as pick-up trucks, vans and SUVs (14%)
3- Heavy vehicles (HV) such as trucks and buses (3%)

Figure 2 shows the three vehicles contributing to a potential crash scene. The vehicles are defined as follow:

1- A is the passing vehicle violator who tries to pass illegally vehicle B ahead,
2- B is the passed vehicle, and
3- C is the vehicle coming in the opposing direction.

Violator vehicle A could belong either to light or to medium classes as was observed in the violation field survey, whereas B and C will belong to either category of the 3 vehicle classes. A random uniform distribution is used when assigning vehicles in the violation simulation.

4.2.1 Vehicle Length

The standard length for passenger car is 19 feet and 30 feet for single unit truck (AASHTO Green Book)(*1*). Medium vehicles length is considered 24 feet.

4.2.2 Vehicle Height

A study conducted by Fitzpatrick et al. (*2*) reviewed the driver eye and vehicle heights for use in geometric design. The recommended values for the drivers' eye height are 3.6, 4.3 and 7.6 feet for light, medium and heavy vehicles respectively. For vehicle classes, recommended heights are 4.3, 5.1 and 8.9 feet respectively.

4.2.3 Vehicle Location

Each of the three vehicles involved need to be located initially as simulation starts at time = 0. The initial time (t =0) will be considered as the moment when vehicle B enters the detection area followed by vehicle A.

Location of vehicle A: According to the conducted field surveys, it was found that violations were taking place during low traffic flow (mostly at level of service C or better). At time = 0 the volume and speeds are selected randomly from their associated distributions. Therefore, we can determine the mean of desired spacing between vehicles A and B using the basic traffic flow model:

$$q = ku_B \rightarrow d_d = \frac{1}{k} = \frac{u_B}{q} \quad = \text{Mean desired spacing}$$

Where: q = traffic volume per unit time

u_B = The vehicle speed

k = traffic density (inverse of average spacing)

However, vehicle A driver, as a potential violator, seeks to narrow the distance with vehicle B before he/she starts the passing maneuver. This distance between the two vehicles should be greater than or equal to the minimum spacing determined by the Pitts car-following model (Halati) (*3*):

$$d_{AB} = L + 10 + ku_A + bk(u_B - u_A)^2 \quad \text{(In feet)} \qquad \text{where:}$$

d_{AB} = space headway between the lead vehicle B and the follower A from front bumper to front bumper.

L = lead vehicle (B) length.

u_A & u_B = speed of vehicles A and B respectively.

b= calibration constant defined as 0.1 (when $u_A > u_B$) or 0 otherwise.

k = driver sensitivity factor for the follower vehicle A that can range from 1.6 for timid driver to 0.3 for aggressive drivers.

Having all parameters at time = 0, a minimum distance dAB_{min} could be then calculated for the aggressive violator:

$$d_{AB\min} = L + 10 + 0.3u_A + 0.03(u_B - u_A)^2$$

As a conclusion, the violating vehicle A location at time = 0 is randomly selected between the mean desired spacing d_d and the minimum headway $d_{AB\min}$.

Location of vehicle C: Similarly for vehicle C, a mean desired spacing was calculated based on random headway based on the density-flow relationship for the traffic flow in the opposite direction of vehicles A & B. Since vehicle C could be located either inside or outside the detection area, the spacing segment from which the location of vehicle C was randomly selected was equally extended between inside and outside the detection area.

Based on above, the assumptions result in the following chain of implications:

1- At time = 0, vehicles A and C drivers cannot see each other. If vehicles A and C drivers can see each other, Driver A would not start the illegal maneuver.
2- This would implement the two vehicles A and C would be initially located on the two sides of the vertical curve.
3- Violations are simulated for those taking place in the upgrade side of the detection area. The system has no impact on the passing maneuvers taking place before vehicle B reaches the detection area where A in that case has enough sight distance to decide whether or not to pass vehicle B.

4.2.4 Vehicle Speed

Initial speed for each vehicle is randomly distributed following the normal probability density function associated with the vehicle class and direction of travel, with the intent to replicate the observed data from the field.

However, we may visualize the development of speed of the three vehicles while simulating the passing maneuver as follow:

- Vehicle B speed remains constant throughout the entire maneuver.
- Vehicle C speed remains constant till the moment when vehicles C and A are revealed to each other. It is assumed in this latter case that the driver of vehicle C would intuitively try to reduce his/her speed to avoid a probable collision with A.
- Vehicle A speed varies depending on the acceleration or deceleration rates introduced during the passing maneuver.

4.2.5 Acceleration Rate

Acceleration is considered only for the violating vehicle A. Research has demonstrated that overtaking acceleration is typically 65 percent of the maximum acceleration for a vehicle under "unhurried" circumstances (ITE 1992) (*4*). However, because of the illegal nature of the maneuver that is being considered, it is assumed that the driver of vehicle A is "hurried" and thus accelerates at the maximum acceleration rate while overtaking vehicle B. The same source above provides an approximate equation for acceleration on a grade:

$$a_{GV} = a_{LV} - \frac{GxG_g}{100}$$

Where, a_{GV} = Max acceleration rate on grade

a_{LV} = Max acceleration rate on level

G = gradient

Gg = acceleration of gravity ($9.8\text{m/sec}^2 = 32.2\text{ ft/ sec}^2$)

To establish models for the relationship between the maximum acceleration at level grade and speed for light and medium vehicles, we have applied a proposed model validated through a paper issued by (Rakha et al.) (*5*). Typical model input parameters for light and medium vehicles such as engine power, vehicle mass, vehicle altitude and frontal area, have been introduced and typical maximum acceleration–speed relationship were established for both light and medium vehicle types as follow:

For light vehicles:

$$a_A = 3.281(3.1 - 0.0069u_A)\ldots when: u_A \le 43.5mph$$

$$a_A = 3.281(4.9 - 0.0483u_A)\ldots when: u_A > 43.5mph$$

For medium vehicles:
$$a_A = 3.281(2.8 - 0.0076u_A)\ldots when: u_A \le 52.8mph$$
$$a_A = 3.281(5.23 - 0.0536u_A)\ldots when: u_A > 52.8ph$$

Where: a_A = Maximum acceleration for vehicle A (in ft/ sec²)

u_A = Vehicle A speed (mph)

4.2.6 Deceleration

Deceleration is considered constant. A research conducted by Fambro et al (*6*) provides some controlled braking performance data of direct application to deceleration modeling. "Steady state" approximations to these data show wide variations among drivers, ranging from **-0.46 g** to **-0.70 g.**

Regardless of the vehicle class, the means and standard deviations of –0.45g and 0.09g are adopted to simulate the braking deceleration for vehicle A (expected deceleration), and –0.55g and 0.07g respectively for vehicle C (unexpected deceleration).

4.3 Driver-Related Parameters

4.3.1 No-Passing Zone Violation Rate

The simulation generates violations based on the rates observed during field surveys, in which illegal takeovers were committed with short passing sight distance in both directions. The field observation resulted in 3.4 violations per 10,000 vehicles in the eastbound direction and 0.8 violations per 10,000 vehicles in the westbound direction. These violation rates correspond approximately to about 720 and 170 violations committed with no enough passing sight distance per year in the eastbound and westbound directions, respectively.

4.3.2 Visibility Between Vehicles A and C

The process which determines whether a clear line-of-vision is established between the two vehicles A and C, is based on the fact that, no physical obstacle should interrupt the line of sight between the eye of one vehicle driver and the top of the other vehicle. The process adopted to establish whether vehicles can observe one another consists of the following steps (see Figure 3):

1- Assess the horizontal location of vehicle A and C at time t
2- Using the road vertical profile data, estimate the elevation of vehicles A and C using interpolation.
3- Knowing the type of both vehicles, determine the altitude of the eye of vehicle A driver (Et), and the top of vehicle C (Tt).
4- Establish the line-of-sight between E and T.
5- Along the line ET, locate a series of points at 50-feet increment starting from E towards T.
6- Determine the elevations of the series of points identified in step 5, (dotted lines in the figure) along the line of sight between points Et and Tt.
7- Referring to the road profile, compute the roadway elevations along the series of points identified in step 5.
8- Compare the altitude of the points along the line-of-sight, and the altitude of the road having same vertical projection.
9- A clear line-of-sight will be established at time instant t, if the altitudes of **all the points**, along the line of sight ET, are higher than those of the road profile, which have the same vertical projection.
10- In the case that the condition of step 9 is not satisfied by at least in one point, it is assumed that vehicles A and C cannot establish a visual contact at time instant t.
11- Repeat the entire process in the subsequent time step t +1 (next deci-second).

Figure 3 represents two cases of line-of-sight: Interrupted in case 1 and clear in case 2.

4.3.3 Human Factor Parameters

In a microscopic simulation, the driver is governed by a complex environment in which numerous analytical factors intervene in shaping the overall performance of the road-driver-vehicle system. The examination of such human performance requires - like any other human behavior – consideration of individual differences. For instance (*7*), when measuring braking response, two drivers could react differently under identical environmental conditions, and the same driver could act differently under different environmental conditions as well (normal driving versus intoxicated driving conditions). The following human factor variables are considered:

4.3.4 Perception-Reaction Time (PRT)

A literature review by Lerner et al. (*8*) includes a summary of brake PRT from a wide variety of studies. The perception/reaction times in the simulation are considered as random normally distributed parameter with a mean and a standard deviation of 0.54 and 0.1 second for the violating vehicle 'A' which is considered "expected" as the violator committing the illegal pass is aware of the risky consequences. However, the PRT of vehicle 'C' traveling in the opposing direction is taken as "surprised" because the driver is unaware of the vehicle violation. The mean and the standard deviation of PRT adopted for vehicle C are 1.31 and 0.61 seconds respectively.

4.3.5 Reading Time Allowance

Allowance must be made for reading the sign message before a driver begins to act in response to the information. Dudek (*9*) indicated that 85 percent of drivers **familiar** with the road and signs read a 13-word message (excluding prepositions) with 6 message units in 6.7 seconds (about 0.5 second per word or 1.1 second per message unit).

The short word sign **"DO NOT PASS"** proposed as a warning sign consists of two short words and one message unit. In addition, Route 114 is a local road that serves local commuters. Therefore, we may consider the road commuters as familiar drivers, which could – according to Dudek's study- read and comprehend the sign in 1 to 1.1 seconds. Consequently, an average of one-second reading time is assumed in simulating the time lag as illustrated in the following section.

4.3.6 Time Lag Components

A time lag accounts for the period of time starting from the moment when the vehicle crosses the double yellow line. This time lag could vary depending on the following two cases:

Case 1: the violating car perceives the warning message before an opposing vehicle is seen. In this case the time lag accounts for:

1- Verification process, that is the time required to verify a violation, and
2- Displaying warning message, that is the time required displaying the message.

For a video and transmission speed of 30 images per second, the central processor would require 0.1 seconds to receive three consecutive images for analysis. If a violation is verified, the system promptly closes the circuit and activates the warning message virtually at a zero time lag. However, to be conservative we may account for another 0.1 second for image analysis and the warning display time lag. Consequently, the total time lag amounts for 0.2 seconds for the two time lag components (1+2) described above.

The other time lags to consider are:

3- Reading: a time lag of one second is assumed as illustrated above.
4- Perception/ Reaction time lag: As discussed earlier, it is considered randomly distributed with a mean and standard deviation of 1.31 and 0.61 seconds respectively for the "surprised" vehicle C, and 0.54 and 0.1 second for the "expected" vehicle A.

Case 2: The opposing vehicle is seen before reading stage. The time lag in this case accounts for the response time only. That is, we are going to consider time lag component 4 only for both vehicles A and C.

4.3.7 Driver's Conditions

In general, alcohol lengthens driver reaction times and cognitive processing times. In our case, driving under influence (DUI) plays a major role in determining the value of some parameters such as the time lag components described above. The simulation will take into consideration two types of vehicle A driver's condition:

1- Regular driving condition.
2- Driving under the influence (DUI).

NHTSA issued a research entitled " Driver Characteristics and Impairment at Various BAC" (*10*). It was found that alcohol significantly impaired performance on some measures for all examined Blood Alcohol Content BAC from 0.02% to 0.10%, and the magnitude of the impairment increased with increasing BAC.

Because no data were available on the alcohol levels of drivers driving along the study section of Route 114, a number of assumptions were made, as follow:

3- Twenty percent of the violators were assumed to drive under the alcohol influence. This assumption is based on the accidents data, which showed that 20% of the crashes involved alcohol.
4- When simulating violations, drivers of vehicles B and C were assumed to operate under normal conditions.
5- For impaired drivers, 0.5 second was added to the driver's time lag components of Reading and PRT.

5. SIMULATION METHODOLOGY

Figures 4 and 5 depict the logic behind the simulation of the system functions without and with the proposed detection and warning system. The logic consists of tracking the three vehicles, as follows:

Direction 1: deals mainly with vehicles A and B sequence of events attempting to start and complete the takeover maneuver.

Direction 2: deals with vehicle C, the vehicle approaching in the opposing direction.

Time: is introduced in every kinematical equation describing the location, speed and acceleration of the various vehicles.

As the flowcharts also show, the outcome of the takeover maneuver could be either a safe passing or an unavoidable crash depending on vehicle A driver's reaction and action decision.

5.1 "Without" Warning System Case

The kind of parameters introduced in the simulation and the sequence of processes approximate to large extent what is happening in reality. Therefore, we expect that the simulation outcome of the "without" case should reflect the current situation to an acceptable degree of realism.

Figure4 depicts the simulation flowchart for passing "without" the warning system. After the speeds and the locations of the three vehicles are randomly generated, we examine the passing threshold. A loop was created to represent the process of continuous monitoring of the opposite direction of the violating driver, as long as the driver of vehicle A is in the passing phase. This loop updates the different parameters every 0.1 second until an opposing vehicle C is seen or the passing maneuver is completed.

Once the vehicles see each other, random PRT time lag periods for both vehicles start, after which vehicle C decelerates whereas vehicle A could accelerate or decelerate depending on the action that the violator would take. Different scenarios of those possible actions will be discussed in details in a coming section.

5.2 "With" Warning System Case

Generally, the " with warning system" case follows the same logic as the "without case". However, it is more complicated because the drivers would act differently depending on which event might occur first: vehicles A and C see each other or the violation is detected.

For the first situation when A and C see each other, both start their PRT time lag at the same moment similar to the without case. For the second situation when the system detects the violation and warns the driver of vehicle A, only vehicle A starts its time lag period. This period consists of reading time in addition to the PRT. Meanwhile, vehicle C is unaware of the violation. It will keep its speedy motion until it sees vehicle A after which it starts its PRT followed by the deceleration action.

Whether a line of sight is established or warning is displayed, vehicle A could brake or accelerate depending on the action taken by the violator. Similar to the "without" case, different action scenarios of the possible actions will be analyzed. Figure 5 depicts the simulation flowchart for passing "with" warning system case.

5.3 Post Perception Action

Based on the above, two perception situations could be specified and exposed to driver A while in the left lane violating the solid yellow line:

1- Either perceiving the fact that a car C is coming in the opposite direction, and he/she must do something to avoid collision. Or,
2- Perceiving the fact that he/she was "caught" by the detection system and he/she must obey and discontinue the violation.

While the first situation might take place in both "with" and "without" warning system cases, the second could happen only when the system is installed and put in service, that is in the "with" case.

Here we should have a little pause to visualize what kind of decision or action the driver A may take in either situation. An unlimited number of "logical" actions may occur, arising principally from the uncertainty in human behavior. Different individuals would perform different actions when exposed to different physical and psychological conditions (surprise, fear, anxiety, drinking problem, life pressures, etc).

For the sake of simplifying such complex situations, we will assume in this simulation the following scenarios:

- **Vehicle B will remain in its lane at constant speed**. This assumption is similar to what AASHTO's "green book" assumes when it models the passing sight distance. Here, we assume that vehicle B driver will stay neutral towards the illegal passing maneuver of A.
- **Driver C will decelerate when Vehicles A and C are revealed to each other without leaving the lane**. This assumption is partially valid in our case because of the lack of shoulder.
- **For driver A action, we may distinguish two situations:**

Situation 1: **The two opposing vehicles A&C see each other:** This event could take place in both the "with" and "without" case analysis. Driver A could choose to make one of three assumed actions, perceived by him as the appropriate one, to avoid a possible collision with C. These three actions are:

1- **Make a complete stop**. Driver A will decelerate assuming that a full stop would be most likely achievable before he collides with C. In this case the conditions to avoid a crash are:
distance AC >0→ d – (xAt + xCt) > 0 at time t when
uAt = 0 and uCt = 0.

Where: xAt, xCt = the locations of vehicles A and C at time t
uAt, uCt = the velocities of vehicles A and C at time t
d = the length of the road link under detection

2- **Set back and move to the right lane**. Here driver A assumes that he/she has enough time to start decelerating while making a lane change to the right behind vehicle B in order to avoid collision with vehicle C. To observe such a happy outcome, the following conditions must be fulfilled:

xAt < xBt - ES at time t when
xAt + xCt = d

Where: ES = **emergency headway** that vehicle A needs to have behind vehicle B to avoid collision with it.

Referring to the Microscopic Traffic SIMulator (MITSIM) developed by Yang and Koutsopoulos (*11*), under the "emergency regime", the following vehicle A uses an appropriate deceleration rate to avoid collision with leading vehicle B. The model suggested to fulfill such requirement is:

$a_A = \min\{\overline{a}_A; a_B - 0.5(u_A - u_B)^2 / g\}$ $u_A > u_B$ Where:

a_A, a_B = Acceleration (deceleration when negative) rates of vehicles A&B
$\overline{a}_A$ = Normal deceleration rate of vehicle A
u_A, u_B = Speed of vehicles A and B
g = Clearing distance separating vehicles A and B

Figure 6,a depicts the positions of the three vehicles at time t when A and C are about to collide.
As B is traveling at constant speed, it has zero acceleration. Considering that emergency braking of vehicle A would result in a more aggressive deceleration, we may find:

$$a_A = -0.5(u_A - u_B)^2 / g$$

$$\rightarrow g = -0.5(u_A - u_B)^2 / a_A = -1.076(\Delta u)^2 / a_A$$ (**g** in feet, **u** in mph)

The case described above fits when vehicles A and C see each other after A starts the violation at a higher speed than B, but before it overtakes B.
Another case could happen when vehicles A and C see each other after A starts the violation and overtakes B. In this case A should decelerate to a speed less than B, then try to merge behind B before it hits vehicle C. Here we are going to assume that such maneuver can succeed if, at the moment of merging, the speed of A is less at least by 5mph than B and the minimum emergency distance Ed is 10 feet.
Finally, Es the headway required to avoid crash between A and B is given by
Es = Ed + LB where LB = length of vehicle B.

3- **Continue the passing maneuver in an attempt to avoid collision with vehicle C.** Driver A will insist to overpass B by continuing accelerating under the assumption that he/she is capable to complete a safe passing before he collides with the decelerating vehicle C. In order to accomplish that, driver A will overtake vehicle B by a minimum emergency distance ET before he/she makes his/her fast lane change to the right ahead of vehicle B (see Figure 6,b). To observe such a scenario, the following conditions are to be fulfilled:

$$xAt > xBt + ET \quad \text{at time t when}$$
$$xAt + xCt = d$$

Where:

ET = the minimum headway that A needs to have ahead of B to make safe lane change.

As the speed of vehicle A is higher than that of B, ET could be estimated by the following simple equation:

$ET = gmin + LA$

where:

gmin = minimum distance set for A to make safe merging ahead of B, taken equal to 10 feet.

LA = length of vehicle A.

<u>Situation 2:</u> Driver A perceives that his/her violation was detected by the system.

This situation could happen only in the "With" case. The A driver can take also any of the three actions described above.

6. SIMULATION RUNS

Every violation in any simulation run output consists of a series of matrices describing the time-dependent parameters while the violation process is in progress. Some of the main parameters are the location and speed of the three vehicles A, B and C, the acceleration and deceleration of vehicles A and C, and the visibility and detection status for vehicles A and C.

All these parameters (and others of less important role) are updated every 0.1 second throughout the simulation period of one violation, which is considered to last 25 seconds. One simulation run performs 890 violations, which are the real-world estimated annual number of violations on the project site having short passing distance in both directions. Twenty-two runs were made to represent a total of 22 years of system analysis.

7. SIMULATIONS RESULT

Simulation outputs could be used to evaluate the impact of the system, by comparing the number of head-on collisions in "**without** the system" (base case) and "**with** the system" (improvement case) simulations.

7.1 Risk Comparison Tools

Following the stimulus and the perception-reaction period, there are three actions that could be taken by the violator once he/she perceives the oncoming vehicle C or the warning message. Since we cannot tell which one of those actions will be finally adopted in each violation maneuver, we ended up with analyzing all three actions for all the 890 annual violations simulated in both directions. The outcome of every violation tested for every action type is either 0 or 1 indicating that no crash or a crash occurred for that violation associated with the action specified.

That kind of analysis would allow us to view risks associated with violations from two angles:

1- Assess the crash risks of each action and then tell which action is the riskiest move after we test all the violations.
2- Assess the risk level of every violation in term of possible crashes that could occur pending on the actions taken. So, a violation could result in a "crash" or "no crash" when it is tested for the three possible actions. The outcomes of every violation when tested for the three actions serve as risk indicators for that violation. For example, when a violation ends up with a crash as it is tested with all the three actions, we may conclude that we have a case with an "unavoidable crash" fate, whatever the action taken by vehicle A driver. This case represents the highest risk indicator (denoted 3). Whereas the zero possible crash result means that there is no collision regardless of the action adopted by vehicle A driver, indicating the lowest (or risk free) risk indicator.

Actually, those two assessments would help as an effective tool when comparing the "with" and " without" cases. Table 1summarizes the runs output in terms of crash outcomes of every action, and crash risk indicators, all for both "with" and "without" the system cases.

7.2 Crashes Output of The "Without System" Simulation

An average was taken for all runs output to represent the number of crashes as well as the risk levels on yearly basis under the actual prevailing conditions.

Table 1 exhibits the average crash outcome of every action when tested for all the violations. The table indicates that decelerating and merging back behind vehicle B (action 2) is the safest move to make in order to avoid a crash. Action 2 percent crashes are the lowest among the three possible actions in both east, and westbound directions (23.1% and 24.9 % respectively). Action 3 seems to be the riskiest action to make in the eastbound whereas action 1 is the riskiest in westbound directions, most probably due to the differences of the geometric conditions of the two sides of the hill (in grade and length).

Table 1 exhibits also the risk levels that the violations are exposed to, presented in terms having 0, 1, 2 and 3 (unavoidable crash) risk indicators. So, in terms of **unavoidable** crashes, Table 1 shows that a mean of 1.41 unavoidable crashes (with a standard deviation of 1.5) would result from the controlled simulated violations per year, a figure, which is very close to the actual fact of 0.71 head-on crash per year (5 reported crashes in the last 7 years with 0.95 standard deviation). A two-tail t-test showed that the variation of the actual and simulated mean parameters is not significant ($\alpha/2 = 25.3\%$).

Another information that the table provides is that the eastbound direction is much less riskier than the westbound. This conclusion is expressed, in addition to the unavoidable crashes percent (0.1% vs. 0.4%), by the high percent of westbound riskier violations, i.e. violations with possible two head-on crashes outcomes (69.3% and) when compared to the eastbound percentages (27.0%). Moreover, one out of every three of eastbound violations is at no risk (or 0 possible crashes) versus one out of five in the westbound direction.

7.3 Crashes Output of The "With System" Simulation

Surprisingly, all simulations output showed a consistent and robust outcome of low risk levels when a detection and warning system is deployed. In fact, Table 1 shows that it is virtually impossible to have a head-on crash if the violator responded to the warning message when displayed and perceived either by making full stop (action1) or by setting back and resuming the right lane behind vehicle B (action 2). This outcome could be explained by the very early warning that the system sends to the violator; early enough to allow him take the appropriate corrective action in obeying the law and discontinuing the illegal maneuver.

It remains that action 3 is the only action that could put the situation in jeopardy and lead to a possible head-on crash. This means that the violator is so persistent so that he/she takes his chances in attempting to complete the risky maneuver.

Here comes the enforcement system, which can play the role of the "awaken eye" over those hindering the lives of the others. The low camera system installed and activated by the control system to capture the violating vehicle license plate, in addition to role as an evidence material, is a tool aiming at putting more pressure on the violator in order to affect his/her decision and force him/her not to continue the risky takeover.

Based on the crash analysis by action type above, and as table 1 also indicates for all the 22 years runs, the entire violations risks were either 0 or 1 possible crash and no single violation showed a higher risk level including the unavoidable crashes. The risk indicator 1 results from action 3 only as we have seen before, and this is true for both east and west directions. More than half of violations are at zero risk levels: 58.1% eastbound, 59.9 % westbound, and 58.5 % combined. The low risk indicator result means that head-on collisions could be virtually eliminated if the human intelligence responded correctly to the early warning of the system and took the appropriate action.

7.4 Accidents Severity

Another important aspect that we can examine from simulation is the comparison of accidents severity between the "with " and " without" system cases. One way of doing that is by comparing the speeds of the vehicles A and C at the moment of collision in both cases and for the three actions.

7.4.1 The Speed of Unavoidable Crashes

A separate crash speed analysis was made for violations with crash risk level 3 (or unavoidable crashes). The analysis showed that the average crash speeds are quite high: 49 mph for vehicle A and 35 mph for vehicle C. Actually this result reflects the fact that having A and C unable to avoid crash, means that both vehicles -when they saw each other- were close and running at high speed in a way they couldn't help it whatever the action that might be taken.

8. CONCLUSION

The paper proposed a new approach to simulating no-passing zone violations on two-lane rural roads without having enough passing distance. Simulations output showed very close results to the actual real-world condition (1.41 Vs. 0.71 average head-on crash per year).

The Simulation tool was also used to evaluate the performance of a newly proposed Advanced Rural Transportation System ARTS Application, which consists of video detection cameras, warning signs and enforcement cameras. The simulation runs of "with the warning system" case showed also that the system could virtually eliminate all head-on collisions, as long as the violators obey the early warning message displayed and discontinue their illegal passing.

Hence, the suggested risk free outcome is conditionally reached when all violators take the appropriate action (under the pressure of the flashing warning message displayed and the enforcement camera). However, that does not eliminate the possibility of having some violators insisting to continue their maneuvers despite all pressures. A real distribution of the obeying and disobeying violators will be determined by the system itself once it is installed and starts surveillance and data collection tasks.

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List of Tables

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TABLE 1 Crash Outcomes and Crash Risk Indicators by Direction (Without and with System)

		Crash Outcomes of Actions by Directions											
	Crashes	Action1 Crashes			Action2 Crashes			Action3 Crashes			All Actions Crashes		
	Direction	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
"Without" Case	Average	210	123	333	154	63	217	302	68	370	665	254	919
	Percent	31.6%	48.3%	36.2%	23.1%	24.9%	23.6%	45.3%	26.8%	40.2%	100.0%	100.0%	100.0%
	St. Dev.	13.2	6.2	14.7	9.8	7.2	13.7	8.7	7.2	10.0	23.9	10.0	27.9
"With" Case	Average	0	0	0	0	0	0	302	68	370	302	68	370
	Percent	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	St. Dev.							8.7	7.2	10.0	8.7	7.2	10.0
		Crash Risk Indicator in Term of Possible Crashes by Direction											
		Violations With Crash Risk Indicator 0			Violations With Crash Risk Indicator 1			Violations With Crash Risk Indicator 2			Unavoidable Crash Violations (Crash Risk Indicator 3)		
	Direction	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
"Without" Case	Average	250	35	286	275	16	291	194	118	312	0.68	0.73	1.41
	Percent	34.8%	20.8%	32.1%	38.2%	9.4%	32.7%	27.0%	69.3%	35.1%	0.1%	0.4%	0.2%
	St. Dev.	13.9	4.7	15.4	9.5	4.6	9.6	11.0	5.6	12.8	0.9	1.0	1.5
"With" Case	Average	419	102	520	302	68	370	0	0	0	0	0	0
	Percent	58.1%	59.9%	58.5%	41.9%	40.1%	41.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	St. Dev.	8.7	7.2	10.0	8.7	7.2	10.0						

N.B *Action 1: Make full stop* *Action 2: Return to right lane behind vehicle B* *Action 3: continue takeover maneuver*

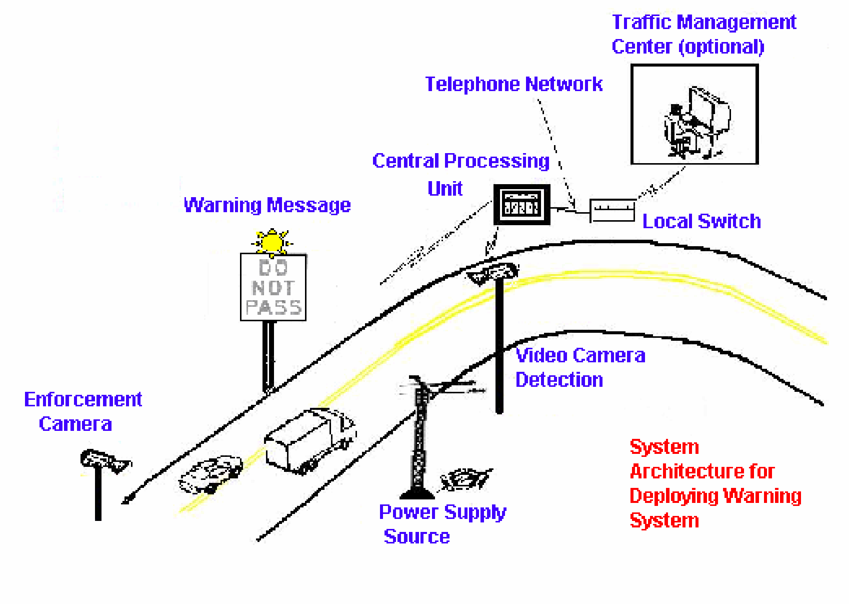


FIGURE 1 Physical architecture of the system

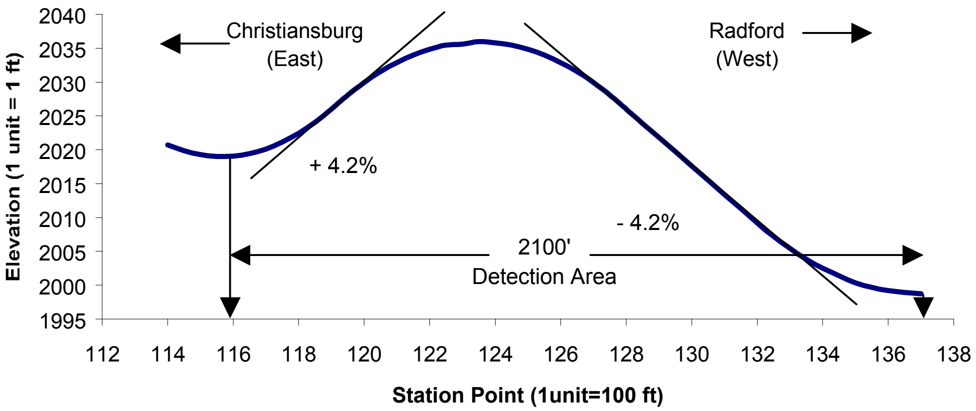


FIGURE 2(a) Road profile

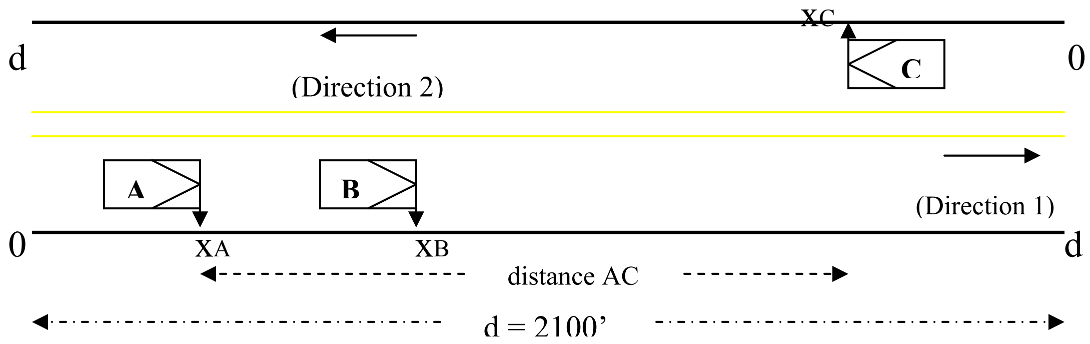


FIGURE 2(b) Road plan

FIGURE 2 Road plan and profile

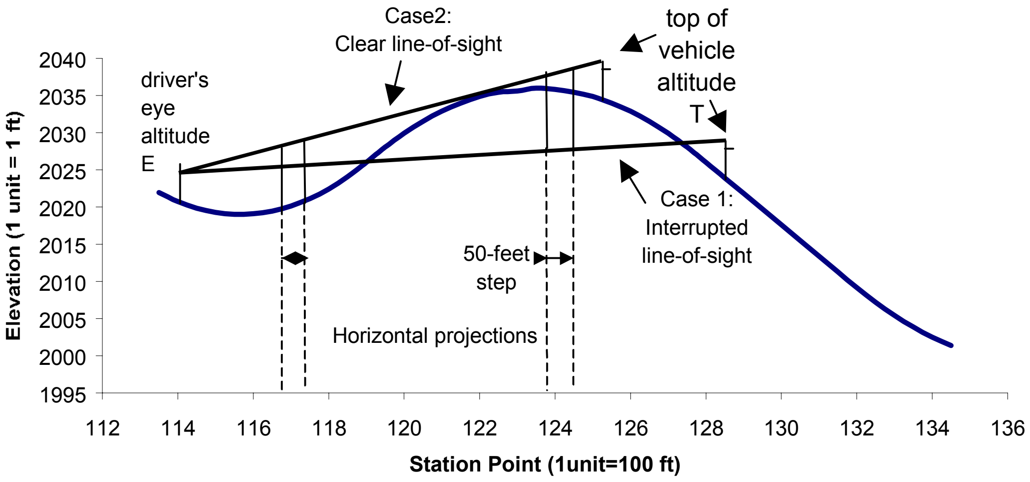


FIGURE 3 Line-of-sight verification

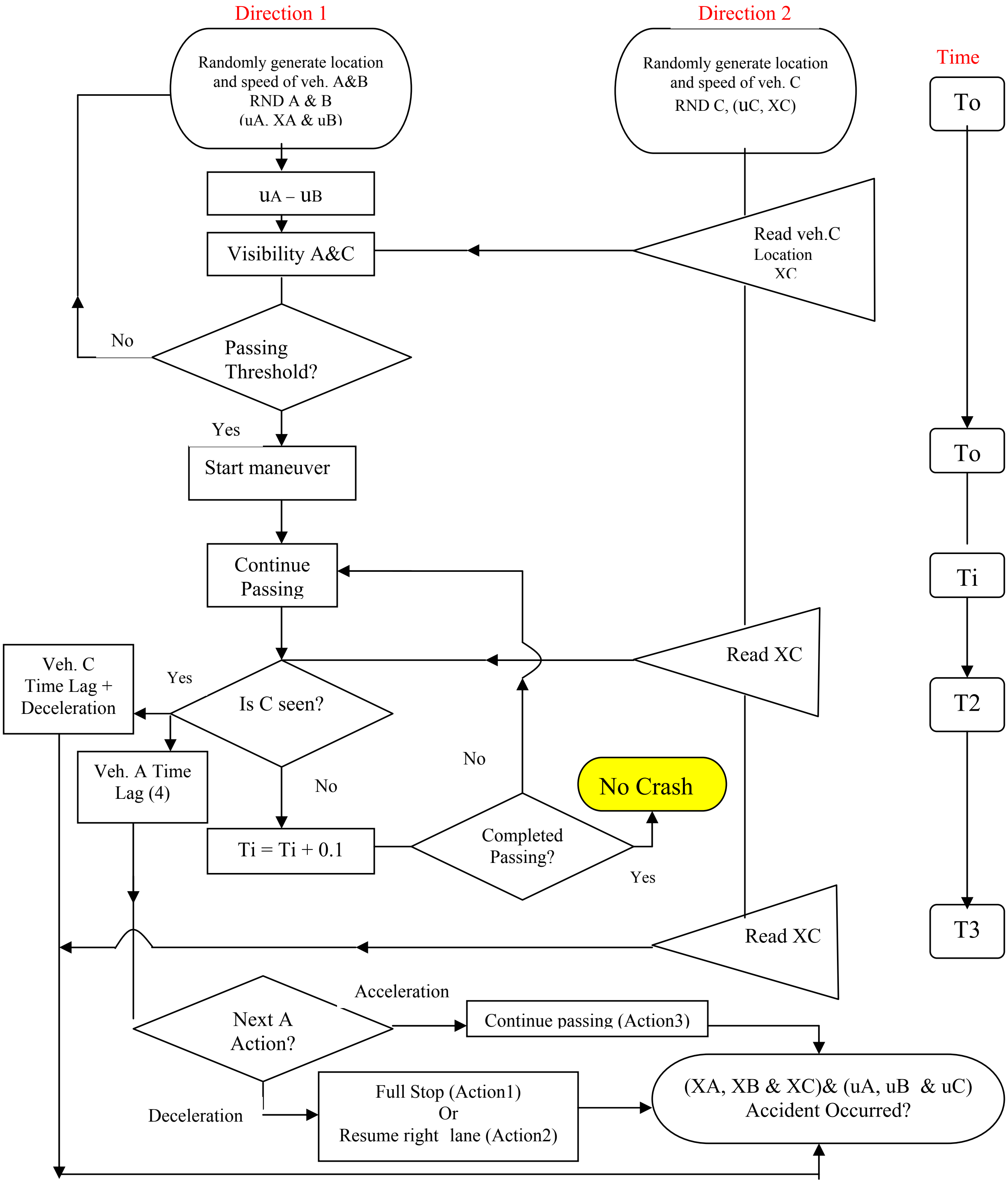


FIGURE 4 Passing violation without the warning system

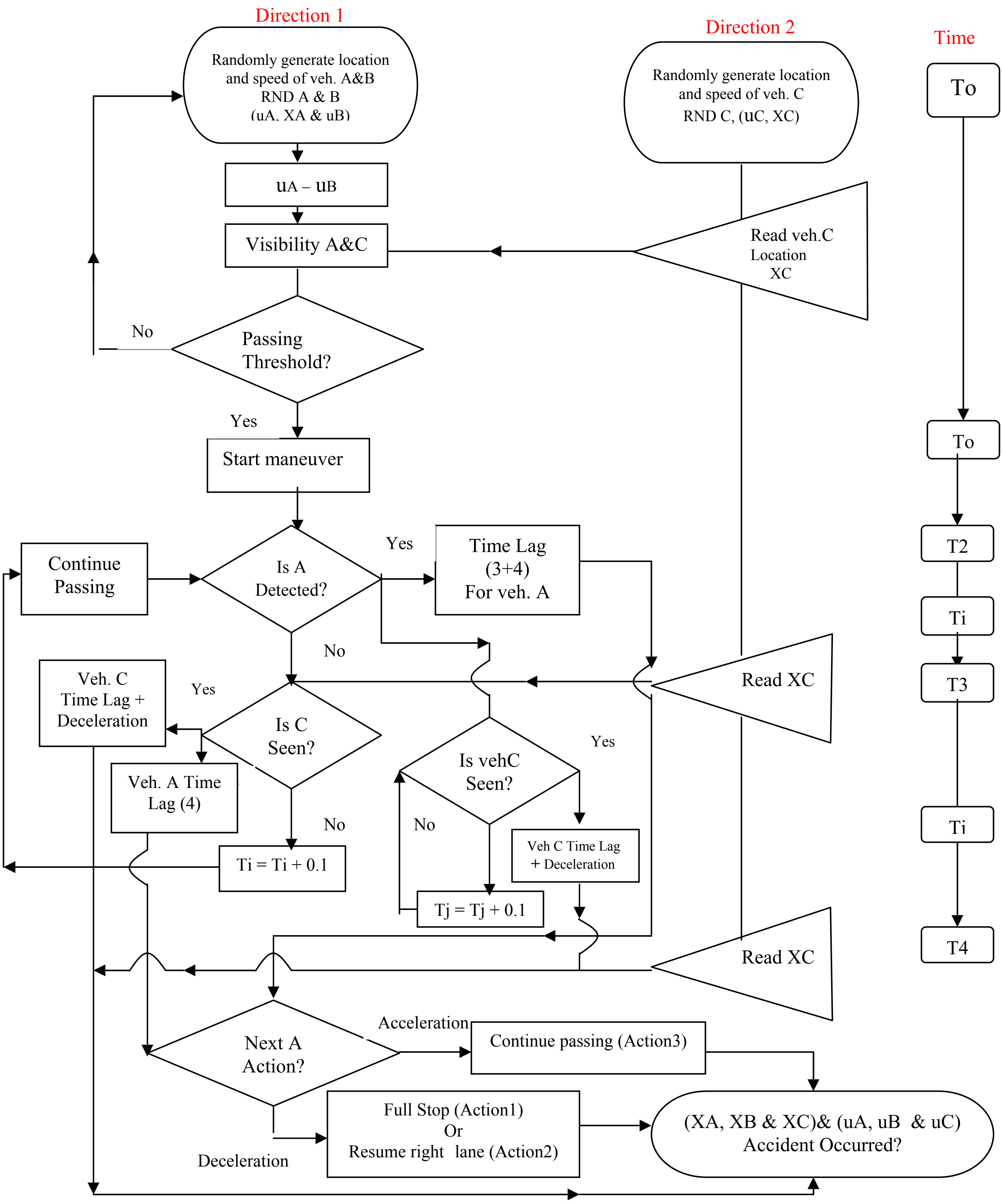
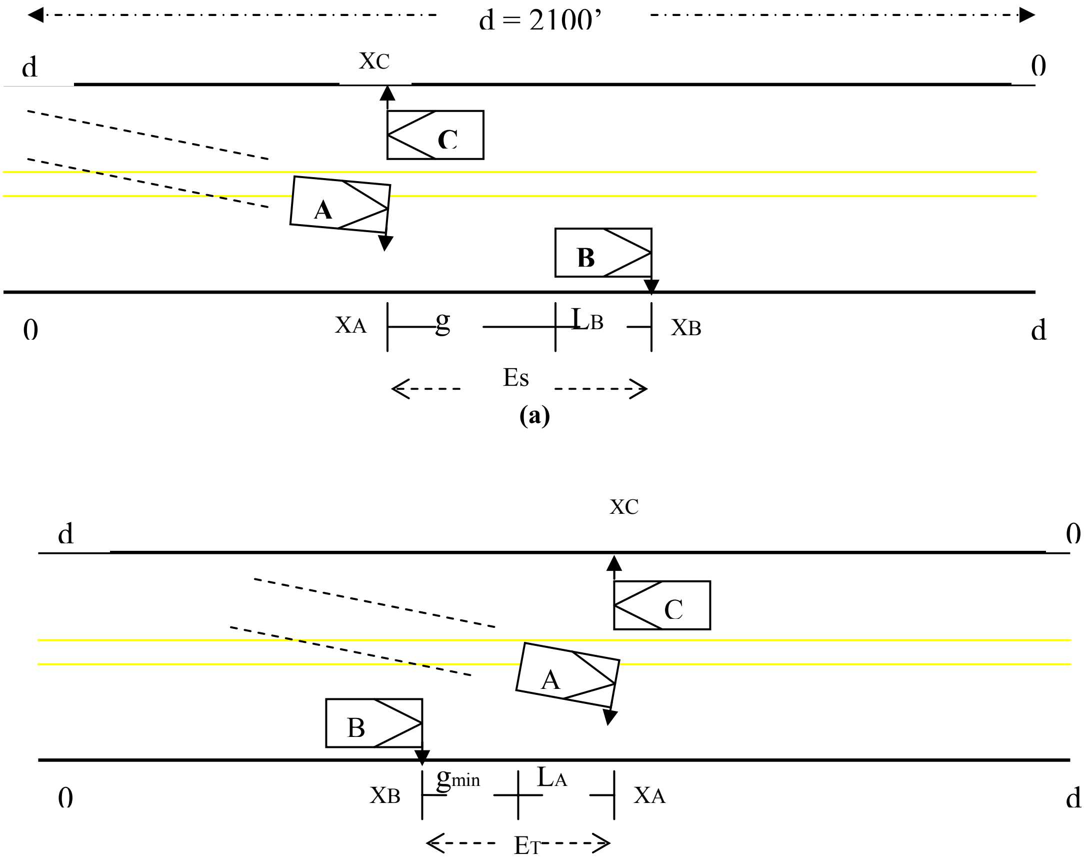


FIGURE 5 Passing violation with warning system



(a)

(b)

FIGURE 6 Vehicle A merging under emergency regime behind and ahead of B