TRAFFIC FLOW THEORY MILESTONES IN DEVELOPING THE TEXAS MODEL FOR INTERSECTION TRAFFIC IN THE EARLY 1970S

Thomas W. "Tom" Rioux, Ph.D., P.E.
Rioux Engineering, Austin, Texas, President
2505 Watercrest Drive, Austin, Texas, 78738-5487, USA
512-327-0520
Tom.Rioux@att.net

ABSTRACT

The Traffic EXperimental and Analytical Simulation Model for Intersection Traffic (TEXAS Model) was developed by the Center for Transportation Research at The University of Texas at Austin beginning in the late 1960's under the leadership of Dr. Clyde E. Lee. Dr. Thomas W. Rioux was leader of the team of graduate students that developed the TEXAS Model and has been upgrading the TEXAS Model since its initial development. The TEXAS Model is being enhanced to include Connected Vehicle messages by Harmonia Holdings Group and Dr. Rioux to be a test bed for Connected Vehicle applications. The TEXAS Model source code is available for use by the public under the GNU General Public License as published by the Free Software Foundation. The TEXAS Model source code for the standard version may be downloaded from http://groups.yahoo.com/neo/groups/TEXAS_Model while the version with Connected Vehicle applications may be downloaded from http://www.etexascode.org. This paper chronicles the evolution of the TEXAS Model from the early 1970s through 2008 and the early traffic flow theory concepts of triangular acceleration, triangular deceleration, equations of motion, car following, intersection conflict checking, intersection conflict avoidance, sight distance restriction checking, lane changing, and crashes.

INTRODUCTION

Microscopic traffic simulation involves defining the movement of individual driver-vehicle units through a roadway system in response to driver desires and control, other driver-vehicle units in the system, and the absence or presence of traffic control. A driver-vehicle unit is a vehicle with specified characteristics (such as type of vehicle, length, maximum acceleration, maximum speed, etc.) controlled by a driver with specified characteristics (such as driver type, reaction time, desired speed, etc.) that has an intersection origin leg and lane and a destination leg. Every driver-vehicle unit in the system is processed every small time-step increment (generally 1 second or less) wherein each individual driver makes many decisions (change lanes, slow down, speed up, stop, turn, avoid crash, etc.), vehicle detectors and signal controllers are simulated, and many Measures of Effectiveness (MOEs) are gathered and reported.

Dr. Clyde E. Lee was the faculty member who, in the late 1960s, conceived the idea of applying the University of Texas at Austin's (UT) new Control Data Corporation (CDC) 1604 mainframe digital computer for simulating traffic flow through an intersection. He initiated the first development efforts and supervised several ensuing research projects that culminated in the Traffic EXperimental and Analytical Simulation Model for Intersection Traffic (TEXAS Model) being released in 1977. Dr. Lee continued supervising research projects that enhanced or used

the TEXAS Model until his retirement from UT in 1999. The TEXAS Model was developed by the Center for Highway Research and later the Center for Transportation Research (CTR) at UT using FORTRAN and mainframe computers. Initial funding for the development efforts was provided by the Texas Department of Transportation (TxDOT) in cooperation with the Federal Highway Administration (FHWA) with later funding by the FHWA and the UT College of Engineering.

The original TEXAS Model simulated a single intersection with no control, yield-sign control, less-than-all-way-stop-sign control, all-way-stop-sign control, pretimed-signal control, semi-actuated-signal control, or full-actuated-signal control using time-step increments between 0.5 and 1.5 seconds, inclusive, for a total of 4,500 seconds (1.25 hours). The geometry included up to 6 legs with up to 6 inbound and 6 outbound lanes per leg; up to 1,000 feet straight lanes which could be blocked at the near end, far end, or in the middle; specification of movements allowed to be made from each inbound lane; specification of movements allowed to be accepted for each outbound lane; sight distance restrictions; detailed intersection path geometry using arcs of a circle and tangent sections; and the calculation of potential points of geometric conflicts between intersection paths. The traffic stream was stochastically generated using constant, Erlang, Gamma, lognormal, negative exponential, shifted negative exponential, and uniform distributions for headways with user-specified parameters; the normal distribution for desired speeds; and discrete percentages for turn movements, lane assignments, and other percentage-based parameters. For each inbound leg, the user specified the hourly volume, the headway distribution name and any parameters, the mean and 85th percentile speed, and the percentage of each vehicle class in the traffic stream. For each vehicle class (10 provided with a maximum of 15), the user specified the percentage of each driver class (3 provided with a maximum of 5). The model included intersection conflict checking; sight distance restriction checking; cooperative lane changing using a cosine curve for the lateral position; car following using the Gazis-Herman-Rothery model (Gazis et. al. 1960 OR and May et. al. 1967 HRR 199) with user-specified values for lambda (power for relative position), mu (power for speed), and alpha (constant); jerk-rate-driven equations of motion; triangular acceleration; triangular deceleration; and crashes with the driver-vehicle unit in front. MOEs included (1) total delay (actual travel time minus the time to travel the same distance at the time-averaged desired speed), (2) queue delay (time from initially joining the end of the queue of driver-vehicle units at the stop line until crossing the stop line), (3) stopped delay (time stopped from initially joining the end of the queue of driver-vehicle units at the stop line until crossing the stop line), (4) delay below a user-specified speed such as 10 miles per hour, (5) vehicle-miles of travel, (6) travel time, (7) volume, (8) time and space mean speed, (9) turn percentages, (10) maximum and average queue length in 20-foot vehicles, and (11) number of crashes. The MOEs could be printed per driver-vehicle unit and were summarized per lane or movement, per inbound leg, and for the entire intersection.

Initial model development effort began in 1968. Many students, faculty, and staff at UT have been involved in the development and use of the TEXAS Model.

- Mr. James W. Thomas, a graduate student in Civil Engineering at the time, began defining the concepts and techniques for modeling traffic flow through an intersection.
- Dr. Roger S. Walker, a graduate student in Electrical Engineering at the time, wrote some of the earliest CDC 1604 computer code for the TEXAS Model. His work included the

development of the <u>CO</u>ordinated <u>L</u>ogic <u>E</u>ntity <u>A</u>ttribute <u>S</u>imulation <u>E</u>nvironment (COLEASE) program which provided extremely efficient storage of model data and implemented an efficient means for processing logical binary networks. He was assisted by Mr. Dennis Banks.

- Dr. Thomas W. "Tom" Rioux, a graduate student in Civil Engineering at the time, started work on the project in 1971 and followed up on Dr. Walker's initial work and became the leader of the team that developed the TEXAS Model into a viable tool for practical use in traffic engineering and research using the CDC 6600 computer system until the TEXAS Model was released in 1977 (Rioux 1973 TexITE, Rioux 1973 thesis, Fett 1974 thesis, Rioux 1977 dissertation, Rioux et. al. 1977 TRB TRR 644, Lee et. al. 1977 184-1, Lee et. al. 1977 184-2, Lee et. al. 1977 184-3, and Lee et. al. 1978 184-4F). Dr. Rioux was the primary person who developed the field data analog-to-digital processing software that was used for model validation, DISFIT, GEOPRO, SIMPRO, the CDC 250 Display System version of DISPRO, SIMSTA, REMOVEC, REPLACEC, and gdvsim. He also participated in the development of DVPRO, the Intergraph UNIX X Windows version of DISPRO, the Java version of geoplot, and the Java version of dispro. In 1973, Dr. Rioux developed an animation on the CDC 250 Display System that was used during initial development efforts. Field measurements of queue delay using specifically-designed recording devices were used to calibrate and validate the TEXAS Model at a 4-leg intersection with pretimed-signal control in Austin, Texas.
- Mr. Charlie R. Copeland, Jr., an undergraduate and then a graduate student in Civil Engineering at the time, was part of the original development team and was the primary person who developed DVPRO and EMPRO. He also participated in the development of the field data analog-to-digital processing software, DISFIT, GDVDATA, GDVCONV, SIMDATA, SIMCONV, and SIMPRO.
- Mr. Robert F. "Bobby" Inman, an undergraduate student in Mechanical Engineering at the time, was part of the original development team and was the primary person who developed the field data collection hardware, GDVDATA, GDVCONV, SIMDATA, SIMCONV, DISPRE, and the DOS version of DISPRO. He also led the development effort of the Texas Diamond and NEMA traffic signal controller simulators within SIMPRO. Mr. Harold Dalrymple assisted him in the development of the field data collection hardware.
- Mr. Ivar Fett, a graduate student in Civil Engineering at the time, was the person who collected and analyzed the field data and developed the original lane changing geometry and decision models, developed the initial all-way-stop sign control logic, and developed the initial pre-timed signal control logic for SIMPRO. He participated in the development of the car-following logic for SIMPRO.
- Mr. William P. Bulloch, a graduate student in Civil Engineering at the time, developed the initial acceleration, deceleration, and car-following models for SIMPRO.
- Ms. Elia King Jordan, a graduate student in Civil Engineering at the time, developed the initial version of DVPRO.
- Mr. Glenn E. Grayson, a graduate student in Civil Engineering at the time, assisted in the development of the actuated signal control logic for SIMPRO and supervised the field data collection and analysis which was used to validate the TEXAS Model.
- Dr. Vivek S. Savur, a graduate student in Civil Engineering at the time, assisted in the field data collection and analysis and assisted in the development of GEOPRO.

- Mr. Scott Carter, a graduate student in Civil Engineering at the time, was the primary person that developed the Intergraph UNIX X Windows version of DISPRO.
- Dr. Moboluwaji "Bolu" Sanu, a graduate student in Electrical and Computing Engineering at the time, was the primary person who developed the Java versions of geoplot and dispro. He later participated in the Small Business Innovative Research Projects performed by Rioux Engineering (Rioux 2004 DTRS57-04-C-10007 and Rioux 2008 DTRT57-06-C-10016).
- Ms. Zhonghui Ning participated in the development of gdvsim in the Small Business Innovative Research Projects performed by Rioux Engineering (Rioux 2004 DTRS57-04-C-10007 and Rioux 2008 DTRT57-06-C-10016).

Many research projects have used the TEXAS Model and their results are documented elsewhere. The original software programs proved to be a very robust and logically sound platform upon which numerous evolutionary enhancements, revisions, and new features were subsequently added through additional projects at CTR and Rioux Engineering as the TEXAS Model migrated from batch mode on a mainframe computer to interactive mode on modern microcomputers:

- 1977/12/01 V1.00 - initial release
- 1983/08/01 V2.00 - Emissions Processor added (Lee et. al. 1983 250)
- 1985/11/01 V2.50 - converted to run on the DOS operating system on a microcomputer using 16-Bit FORTRAN compilers, User-Friendly Interface added, and DOS animation added (Lee et. al. 1985 361)
- 1989/01/01 V3.00 - diamond interchange geometry and TxDOT Figure 3, 4, 6, and 7 dual-ring actuated diamond signal controller added (Lee et. al. 1989 443)
- 1992/01/31 V3.10 - replicate runs added, wide or narrow output selection added, left-turn pull-out option added, hesitation factor added, maximum number of loop detectors per lane was increased from 3 to 6, blocked lane processing modified, intersection conflict avoidance added, and driver-vehicle unit delay for unsignalized lanes modified
- 1992/03/25 V3.11 - intersection conflict avoidance error fixed, lane change errors fixed, and look ahead algorithms modified
- 1992/12/15 V3.12 - converted to run on the Unix operating system on a workstation, Headway Distribution Fitting Processor added, Geometry Plotting Processor added, Simulation Statistics Processor added, UNIX X Window animation added, free u-turns at diamond interchange added, Dallas diamond signal controller phase numbering added, NEMA TS 1-1989 signal controller with volume-density operation added, replicate runs for specified number of runs added, replicate runs to specified statistical tolerance added, spreadsheet macros developed, car following modified, and many small enhancements to numerous algorithms (Rioux et. al. 1993 1258)
- 1993/11/23 V3.20 - car following modified and NEMA controller errors fixed
- 1994/05/10 V3.21 - lane change error fixed
- 1994/06/07 V3.22 - NEMA and Texas diamond controller errors fixed
- 1996/02/28 V3.23 - car-following logic modified
- 1998/09/21 V3.24 - utility programs from80d.exe and to80d.exe added and Y2K-compliant modifications made

- 2000/08/03 V3.25 - Java animation added
- 2003/08/29 V4.00 - compiled using 32-bit FORTRAN compilers and initial vehicle messages added
- 2005/08/12 V5.00 - Java user interface added; Geometry Plotting Processor converted to Java; source code released under GNU General Public License as published by the Free Software Foundation; increased number of driver types to 9; increased number of vehicle types to 99; classify detector added; modified logical binary networks to use type LOGICAL variables; added Vehicle Message System (VMS) messages for special driver-vehicle units: (1) forced go time and duration, (2) forced stop location and duration, (3) forced run red signal time and duration; changed minimum time-step increment to 0.01 seconds; converted all REAL variables to DOUBLE PRECISION; added VMS message types: (1) Driver DMS, (2) Driver IVDMS, and (3) Vehicle IVDMS; added VMS messages: (1) accelerate or decelerate to speed xx using normal acceleration or deceleration, (2) accelerate or decelerate to speed xx using maximum vehicle acceleration or deceleration, (3) stop at the intersection stop line, (4) stop at location xx, (5) stop immediately using maximum vehicle deceleration, (6) stop immediately using crash deceleration, (7) change lanes to the left, (8) change lanes to the right, (9) forced go, and (10) forced run the red signal; add VMS message (1) start time, (2) active time, (3) location (lane or intersection path and beginning and ending positions), (4) driver-vehicle unit number (0=all), and (5) reaction time distributions and parameters; Surrogate Safety Assessment Methodology (SSAM) file support added; Linux version developed (Rioux 2004 DTRS57-04-C-10007 and Rioux 2005 DTFH61-03-C-00138)
- 2008/07/31 V6.00 - all user interface software made Section 508 compliant; built-in help and tool tips added; displaying the sight distance restrictions added; displaying the detector geometry and activity added; Java application developed to automate the running of the TEXAS Model; total simulation time extended to 9999.99 seconds (2.777775 hours); lane length extended to 4000 feet; Java application to display statistics from 1 run or replicate runs developed; stop on crash using crash deceleration and remain stopped option added; crashes between driver-vehicle units on different intersection paths added; automated the running of SSAM; attach and display orthorectified image file added; updated the NEMA traffic signal controller simulator to NEMA TS 2-2003; pedestrians added as they affect the operation and timing of the NEMA and hardware-in-the-loop traffic signal controllers; pedestrian signal operation added to animation; caused other driver-vehicle units to react to a crash; dilemma zone statistics added; time-varying traffic for 2 or more periods added; hardware-in-the-loop traffic signal controller added; additional vehicle attributes added to articulate vehicles; distracted driver VMS message added; an optional lane change before or after the intersection to move from behind a slower driver-vehicle unit added; and simulation of bicycles, emergency driver-vehicle units, and rail driver-vehicle units added (Rioux et. al. 2008 DTRT57-06-C-10016-F)
- 2010 - Small Business Innovative Research (SBIR) project Topic 10.1-FH3 "Simulating Signal Phase and Timing with an Intersection Collision Avoidance Traffic Model" adding Society of Automotive Engineers (SAE) J2735 Basic Safety Message (BSM), Signal Phase and Timing Message (SPAT), and Map Data Message (MAP) awarded to Harmonia Holdings Group, LLC., Blacksburg, Virginia; Phase I completed; Phase II in progress
- 2011 - Small Business Innovative Research (SBIR) project Topic 11.1-FH2 "Augmenting Inductive Loop Vehicle Sensor Data with SPAT and GrID (MAP) via Data Fusion" adding

National Transportation Communications for ITS Protocol (NTCIP) 1202 vehicle detector, traffic signal controller parameter, and traffic signal display messages awarded to Harmonia Holdings Group, LLC., Blacksburg, Virginia; Phase I completed; Phase II in progress

TEXAS MODEL TRAFFIC FLOW THEORY

The TEXAS Model defines the Perception, Identification, Judgment, and Reaction Time (PIJR) as a user-specified parameter for each driver class in seconds. Typical values are 0.5 for aggressive drivers, 1.0 for average drivers, and 1.5 for slow drivers. Throughout the remainder of this document, several functions and constants are used as follows:

ABS(A)	=	the absolute value A
ACOS(A)	=	the arccosine of A
COS(A)	=	the cosine of A
DT	=	the time step increment in seconds
Max(A,B)	=	the maximum value of A and B
PI	=	the value for PI

TRIANGULAR ACCELERATION

An investigation of existing acceleration models was undertaken in the early 1970s by Drs. Lee and Rioux and it was found that the uniform acceleration model did not match observed behavior accurately when considered on a microscopic scale. Using a Chi-Squared goodness-of-fit test, a best-fit uniform acceleration model was calculated and the results plotted (see Figure 1 below) along with observed data points (Beakey 1938 HRB). This figure illustrates that the uniform acceleration model computes velocities which are too low during initial acceleration and which result in the driver-vehicle unit's reaching desired velocity much sooner than it should. A linear acceleration model which hypothesizes use of maximum acceleration when vehicular velocity is zero, zero acceleration at desired velocity, and a linear variation of acceleration over time was investigated. Comparisons of this model with observed data (see Figure 1 below) indicate excellent agreement. This model also compared favorably with the non-uniform acceleration theory (Drew 1968 TFT&C) used in describing the maximum available acceleration for the driver-vehicle unit.
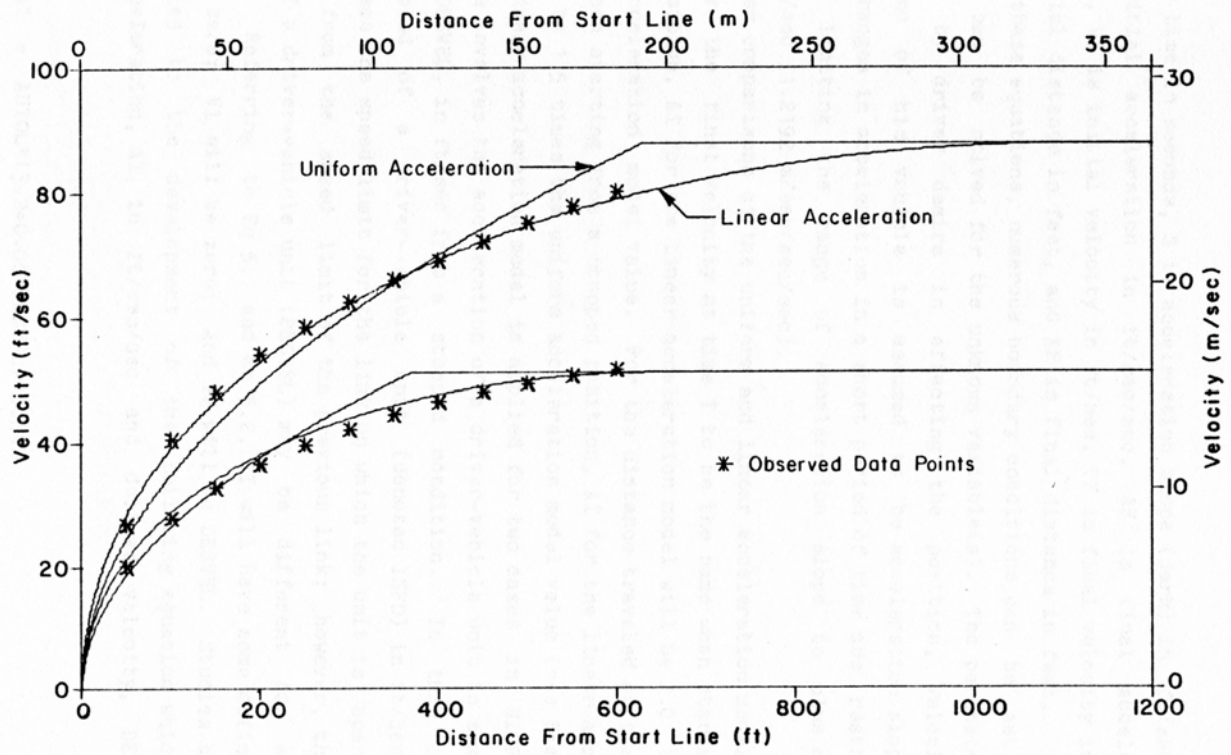
Figure 1 - Uniform versus Linear Acceleration and Observed Data

This work lead to the development of the triangular acceleration model used in the TEXAS Model (see Figure 2 below). The author will use the term "jerk rate" to describe the rate of change of acceleration or deceleration over time and is usually in units of feet per second per second per second. Starting from a stopped condition, a driver-vehicle unit will use a maximum positive jerk rate until it reaches the maximum acceleration then the driver-vehicle unit will use a negative jerk rate until the acceleration is zero at the driver-vehicle unit's desired speed. The maximum acceleration is defined by the driver-vehicle unit's desired speed and the maximum acceleration for the driver-vehicle unit.
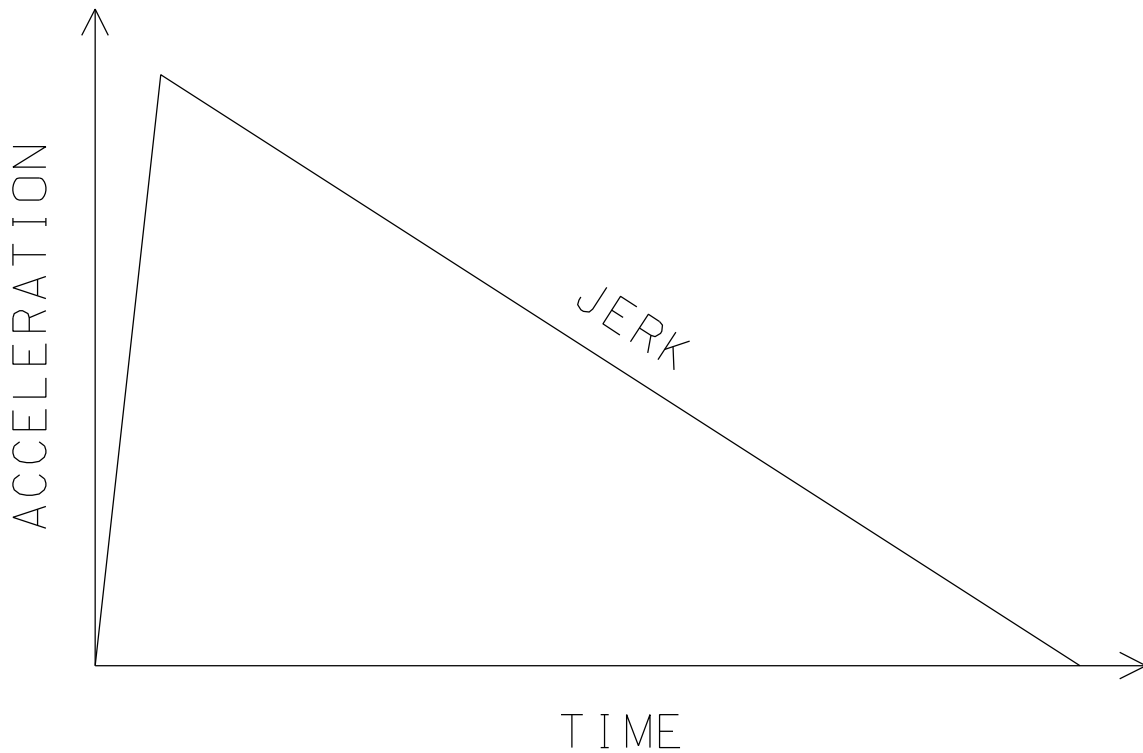
Figure 2 - Triangular Acceleration Model

TRIANGULAR DECELERATION

An investigation of existing deceleration models was also undertaken in the early 1970s by Drs. Lee and Rioux and it was found that the uniform deceleration model did not match observed behavior accurately when considered on a microscopic scale. Using a Chi-Squared goodness-of-fit test, a best-fit uniform deceleration model was calculated and the results plotted (see Figure 3 below) along with observed data points (Beakey 1938 HRB). This figure illustrates that the uniform deceleration model yields a higher velocity during the first part of the deceleration maneuver and, as the velocity approaches zero, produces values that are lower than observed values. A linear deceleration model which hypothesizes use of a zero initial deceleration, maximum deceleration at the instant the driver-vehicle unit stops, and a linear variation of deceleration over time was investigated. Comparisons of this model with observed data (see Figure 3 below) indicate excellent agreement.
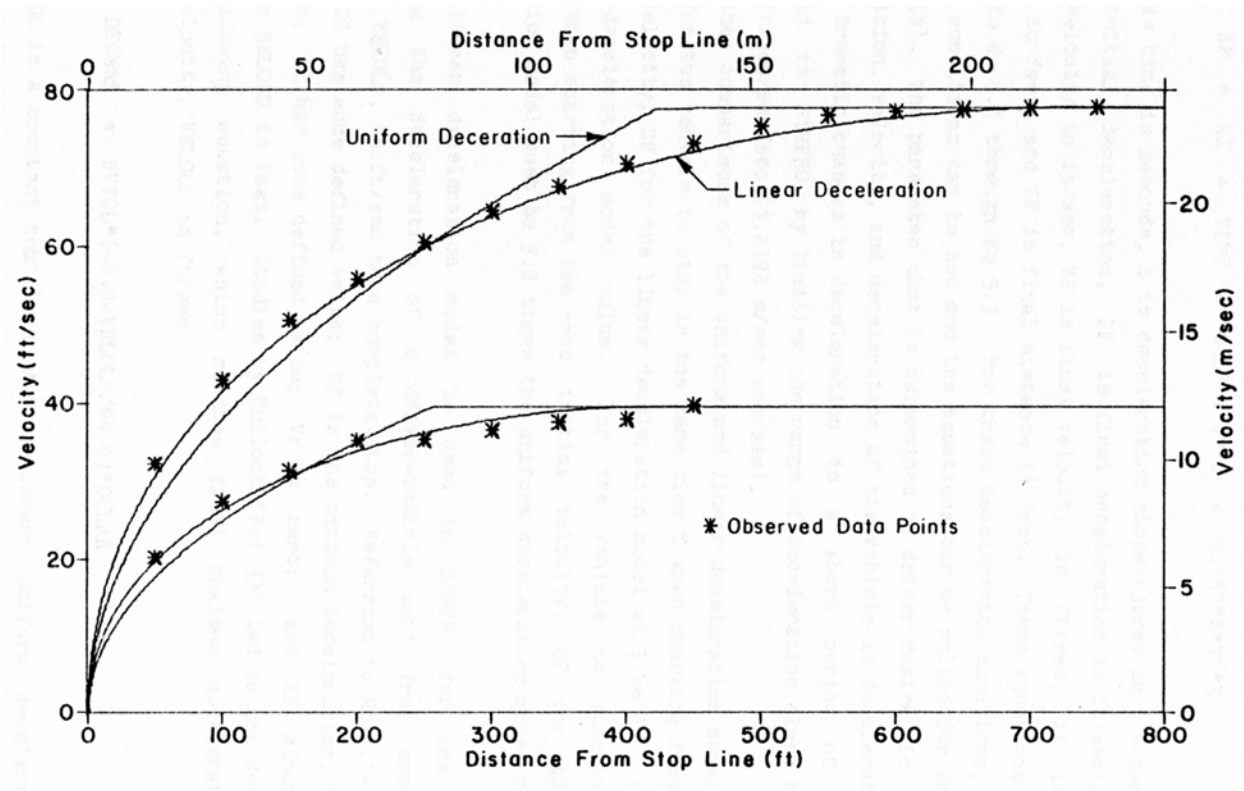
Figure 3 - Uniform versus Linear Deceleration and Observed Data

This work lead to the development of the triangular deceleration model used in the TEXAS Model (see Figure 4 below). Starting from a moving condition, a driver-vehicle unit will use a maximum negative jerk rate until it reaches the maximum deceleration when the driver-vehicle unit stops. The maximum deceleration is defined by the driver-vehicle unit's current speed and the maximum deceleration for the driver-vehicle unit. If a driver-vehicle unit is to decelerate to a stop, the time to stop and then the distance to stop is calculated each time step increment using current speed, current acceleration/deceleration, and current maximum deceleration. A deceleration to a stop is initiated when the driver-vehicle unit's distance to the location for a stop becomes less than or equal to the distance to stop.
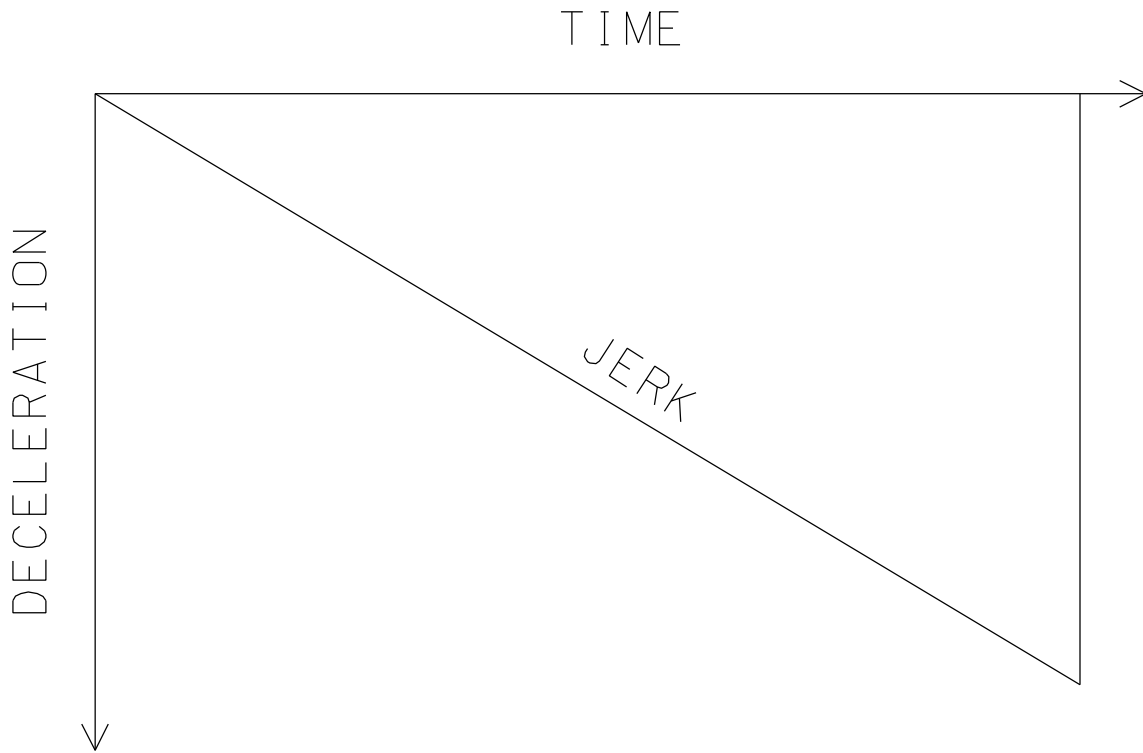
Figure 4 - Triangular Deceleration Model

EQUATIONS OF MOTION

With the development of the triangular acceleration and triangular deceleration models, it was clear that the equations of motion had to include jerk rate as follows:

$$AN \ = \ AO + J * DT$$

$$VN \ = \ VO + AO * DT + 1/2 * J * DT^2$$

$$PN \ = \ PO + VO * DT + 1/2 * AO * DT^2 + 1/6 * J * DT^3$$

where:

AN = acceleration/deceleration new in ft/sec/sec
AO = acceleration/deceleration old in ft/sec/sec
J   = jerk rate in ft/sec/sec/sec
PN = front bumper position new in feet
PO = front bumper position old in feet
VN = velocity new in ft/sec
VO = velocity old in ft/sec

In the TEXAS Model, only the jerk rate is possibly changed each time step increment and limits are placed on the maximum positive and negative values for jerk rate. Only in collisions are extremely large values of jerk rate used to stop a driver-vehicle unit in about 3-6 feet.

CAR FOLLOWING

An investigation of existing car-following models was undertaken in the early 1970s by Drs. Lee and Rioux and the non-integer, microscopic, generalized Gazis-Herman-Rothery (GHR) car-following model (Gazis et. al. 1960 OR and May et. al. 1967 HRR 199) was selected because of its superiority and flexibility. If there is no previous driver-vehicle unit (no driver-vehicle unit ahead of the current driver-vehicle unit) then it can not car follow and thus other logic is used. If the previous driver-vehicle unit is stopped then it can not car follow and thus other logic is used. The GHR Model equation is as follows:

$$RelPos = PVPos - PO$$
$$RelVel = PVVel - VO$$
$$AN = CarEqA * VO^{CarEqM} / RelPos^{CarEqL} * RelVel$$

where:

AN	=	current driver-vehicle unit acceleration/deceleration new in ft/sec/sec
AO	=	acceleration/deceleration old in ft/sec/sec
CarEqA	=	user-specified GHR Model Alpha parameter (min=1, def=4000, max=10000)
CarEqL	=	user-specified GHR Model Lambda parameter (min=2.3, def=2.8, max=4.0)
CarEqM	=	user-specified GHR Model Mu parameter (min=0.6, def=0.8, max=1.0)
PO	=	current driver-vehicle unit front bumper current position old in feet
PVPos	=	previous driver-vehicle unit rear bumper position in feet
PVVel	=	previous driver-vehicle unit velocity in ft/sec
RelPos	=	relative position in feet
RelVel	=	relative velocity in ft/sec
VO	=	current driver-vehicle unit velocity old in ft/sec

The acceleration/deceleration new AN is not allowed to exceed the maximum acceleration or deceleration for the vehicle. The jerk rate to go from the current driver-vehicle unit acceleration/deceleration old AO to the current driver-vehicle unit acceleration/deceleration new AN is not allowed to exceed the maximum jerk rate. A conservative car-following distance is defined as follows:

$$RelVel = PVVel - VO$$
$$CarDis = (1.7 * PVVel + 4 * RelVel^2) / DrivChar$$

where:

CarDis	=	car-following distance in feet
DrivChar	=	user-specified driver characteristic (<1=slow, 1=average, >1=aggressive, min=0.5, & max=1.5)
PVVel	=	previous driver-vehicle unit velocity in ft/sec
RelVel	=	relative velocity in ft/sec

      VO   =   current driver-vehicle unit velocity old in ft/sec

If the relative velocity RelVel is greater than or equal to zero (the previous driver-vehicle unit is going faster than the current driver-vehicle unit) and the relative position RelPos is greater than some minimum value then the driver-vehicle unit is allowed to accelerate to its desired speed.

If the relative position of the vehicle RelPos is less than or equal to zero then emergency braking is applied. If the relative position of the vehicle RelPos is greater than the 1.2 times the car-following distance CarDis then the driver-vehicle unit is allowed to accelerate to its desired speed.

If the previous driver-vehicle unit is decelerating then calculate where it will stop and calculate the deceleration to stop behind the driver-vehicle unit ahead when it stops and if this deceleration is less than the car following deceleration then use it.

If the traffic signal changed from green to yellow and the current driver-vehicle unit decides to stop on yellow then calculate a deceleration to a stop at the stop line. If the traffic signal is yellow and the driver-vehicle unit previously decided to stop on yellow then continue a deceleration to a stop at the stop line.

INTERSECTION CONFLICT CHECKING AND INTERSECTION CONFLICT AVOIDANCE
Intersection Conflict Checking (ICC) and Intersection Conflict Avoidance (ICA) are essential algorithms for microscopic traffic simulation. ICC is the algorithm that determines whether a driver-vehicle unit, seeking the right to enter the intersection, has a predicted time-space trajectory through the intersection that does not conflict with the predicted time-space trajectory through the intersection of all other driver-vehicle units that have the right to enter the intersection. ICA is the algorithm used to simulate the behavior of driver-vehicle units that have the right to enter the intersection and try to maintain a non-conflict time-space trajectory through the intersection with the predicted time-space trajectory through the intersection of other driver-vehicle units that have the right to enter the intersection.

Certain driver-vehicle units automatically gain the right to enter the intersection when there are no major collisions within the system: driver-vehicle units on an uncontrolled lane at a sign-controlled or signal-controlled intersection, driver-vehicle units going straight or right on intersection paths that do not change lanes within the intersection when the signal displays circular green, and all driver-vehicle units on signalized lanes when the signal displays protected green for their movement. Typical applications of ICC and ICA include a left-turning driver-vehicle unit crossing opposing leg straight through driver-vehicle units. The TEXAS Model included the ICC algorithm in Version 1.00 released 12/01/1977, added the ICA algorithm in Version 3.10 released 01/31/1992, and enhanced both algorithms in subsequent versions. The functionality and effectiveness of these algorithms has been verified extensively over the years by evaluation of the animation and analysis of the corresponding summary statistics from many, varied simulations.

The TEXAS Model Geometry Processor (GEOPRO) calculates intersection paths starting at the coordinate for the middle of the stop line for an inbound lane, ending at the coordinate for the middle of the entry line for a diamond interchange internal inbound or outbound lane, tangent to the inbound lane, tangent to the outbound lane, and using the largest radius circular arc when needed. The user defines the turn movements that can be made from an inbound lane and the turn movements that can be accepted by an outbound lane. An intersection path consists of 4 segments in sequence. Each segment may or may not be used in the intersection path and is tangent at each end. The 1st segment is a tangent section, the 2nd segment is an arc of a circle, the 3rd segment is an arc of a circle, and the 4th segment is a tangent section. After calculating the geometry for all intersection paths, GEOPRO calculates the geometric conflicts between intersection paths including dual left turn side swipes (the intersection paths come within a user-specified distance but do not cross) and merges into the outbound lane. Finally, GEOPRO creates a list of geometric conflicts ordered by the distance from the beginning of the intersection path down the intersection path centerline to the point of geometric conflict. Data for each geometric conflict include the intersection path information and the conflict angle.

For each intersection path involved in a geometric conflict, the TEXAS Model Simulation Processor (SIMPRO) maintains a linked list of driver-vehicle units whose rear bumper plus a time safety zone has not crossed the point of geometric conflict. When a driver-vehicle unit gains the right to enter the intersection, SIMPRO adds the driver-vehicle unit to the end of the linked list for each geometric conflict for the driver-vehicle unit's intersection path. When a driver-vehicle unit is denied the right to enter the intersection, such as when a driver-vehicle unit decides to stop on a yellow signal indication, SIMPRO removes the driver-vehicle unit from the linked list for each geometric conflict for the driver-vehicle unit's intersection path. As the rear bumper plus a time safety zone crosses the point of geometric conflict, SIMPRO removes the driver-vehicle unit from the linked list for the geometric conflict for the driver-vehicle unit's intersection path.

To process the intersection conflicts for ICC for a driver-vehicle unit on an inbound lane or diamond interchange internal inbound lane that has not gained the right to enter the intersection, SIMPRO first checks whether there are any geometric conflicts for the driver-vehicle unit's intersection path and if there are none, then intersection conflicts are clear. Next, SIMPRO processes each geometric conflict for the driver-vehicle unit's intersection path in distance order. If a geometric conflict does not have a driver-vehicle unit whose rear bumper plus a time safety zone has not crossed the point of geometric conflict, then the geometric conflict is clear and the next geometric conflict is tested, else this geometric conflict is processed. In this discussion, "I", "me", or "my" refers to the driver-vehicle unit being processed while "he", "him", or "his" refers to the next driver-vehicle unit whose rear bumper plus a time safety zone has not crossed the point of geometric conflict. The time for my front bumper to arrive at the geometric conflict (TCM), velocity at the geometric conflict for me (VCM), acceleration at the geometric conflict for me (ACM), and jerk rate at the geometric conflict for me (SCM) are predicted using my current distance to the geometric conflict, velocity, acceleration, jerk rate, driver characteristics, vehicle characteristics, speed limit for my intersection path, and information about any lead driver-vehicle unit that must be car-followed. The time for his front bumper to arrive at the geometric conflict (TCH), velocity at the geometric conflict for him (VCH), acceleration at the geometric conflict for him (ACH), and jerk rate at the geometric conflict for him (SCH) are

predicted using his current distance to the geometric conflict, velocity, acceleration, jerk rate, driver characteristics, vehicle characteristics, speed limit for his intersection path, and information about any lead driver-vehicle unit that must be car-followed. A mini-simulation is used by SIMPRO to determine the time it takes the driver-vehicle unit to traverse the specified distance assuming that the driver-vehicle unit can accelerate to its desired speed or speed limit of its intersection path or car follow any lead driver-vehicle unit. The lead driver-vehicle unit, if any, is assumed to continue its current jerk rate. The velocity, acceleration, and jerk rate of the driver-vehicle unit when it has traversed the specified distance is also calculated. For ICC and ICA purposes, the lead gap is the space between my rear bumper and his front bumper when I go ahead of him through the geometric conflict whereas the lag gap is the space between his rear bumper and my front bumper when I go behind him through the geometric conflict.

SIMPRO then calculates the time for the front safety zone for him (TFZ) and the time for the rear safety zone for him (TRZ) will arrive at the geometric conflict (see the top diagram in Figure 5) using the following equations:

$$
\begin{aligned}
\text{ERRJUD} &= \text{if TCH > 5 then Max(0.0,PIJR*(TCH-5.0)/7.0) else 0} \\
\text{TPASSM} &= \text{LVAPM / VCM} \\
\text{TPASCM} &= \text{DISCLM / VCM} \\
\text{TPASSH} &= \text{LVAPH / VCH} \\
\text{TPASCH} &= \text{DISCLH / VCH} \\
\text{TFZ} &= \text{TCH - TPASSM - TPASCM - (TLEAD-APIJR) - PIJR - ERRJUD/2} \\
\text{TRZ} &= \text{TCH +TPASSH + TPASCH + (TLAG-APIJR) + PIJR + ERRJUD/2 +} \\
&\quad \text{TPASCM}
\end{aligned}
$$

where:

APIJR	=	average PIJR time for all driver-vehicle units in the entire traffic stream in seconds (calculated by the TEXAS Model Driver-Vehicle Processor (DVPRO))
DISCLH	=	safety distance for him for merge into the same outbound lane in feet
DISCLM	=	safety distance for me for merge into the same outbound lane in feet
ERRJUD	=	error in judgment in seconds for TCH values greater than 5
LVAPH	=	length of vehicle along the intersection path for him at his current position in feet
LVAPM	=	length of vehicle along the intersection path for me at my current position in feet
PIJR	=	Perception, Identification, Judgment, and Reaction Time for the current driver-vehicle unit in seconds
TCH	=	time for his front bumper to arrive at the geometric conflict in seconds
TFZ	=	the time for the front safety zone for him in seconds
TLAG	=	user-defined lag time gap for ICC in seconds (min=0.5, def=0.8, & max=3.0)
TLEAD	=	user-defined lead time gap for ICC in seconds (min=0.5, def=0.8, & max=3.0)
TPASCH	=	time for his driver-vehicle unit to pass through the geometric conflict because of a merge into the same outbound lane in seconds (zero if no merge)
TPASCM	=	time for my driver-vehicle unit to pass through the geometric conflict because of a merge into the same outbound lane in seconds (zero if no merge)

TPASSH = time for his driver-vehicle unit to pass through the geometric conflict in seconds

TPASSM = time for my driver-vehicle unit to pass through the geometric conflict in seconds

TRZ   = time for the rear safety zone for him in seconds

VCH   = velocity at the geometric conflict for him in ft/sec

VCM   = velocity at the geometric conflict for me in ft/sec

The time period from TFZ until TRZ is blocked for me by his driver-vehicle unit. See the bottom diagram in Figure 5 to look at the time sequences from a gap perspective. If I can go safely in front of him (TCM is less than TFZ) or I can go safely behind him (TCM is greater than TRZ), then there is no conflict with his driver-vehicle unit at this geometric conflict. If I am blocked by his driver-vehicle unit at this geometric conflict (TCM is greater than or equal to TFZ and TCM is less than or equal to TRZ), then there is a conflict with his driver-vehicle unit at this geometric conflict. If there is a conflict, then the ICC process is completed with a conflict found. If there is no conflict, I go behind him (TCM is greater than TFZ), and there is another driver-vehicle unit whose rear bumper plus a time safety zone has not crossed the point of geometric conflict, then I check the next driver-vehicle unit whose rear bumper plus a time safety zone has not crossed the point of geometric conflict. If there is no conflict and I go before him (TCM is less than or equal to TFZ), then I check the next geometric conflict for his intersection path because if I can go before him, then I can go before all other driver-vehicle units behind him. If all geometric conflicts for his intersection path have been checked and there are no conflicts, then the ICC process is completed with no conflict found. There are many special cases accommodated within the actual code when the geometric conflict is a merge, when there is a major collision somewhere within the system, when the other driver-vehicle unit is stopped and blocked by a major collision, when there is an emergency driver-vehicle unit in the system, and/or when a driver-vehicle unit is currently processing a forced go or forced run the red signal Vehicle Message System message.
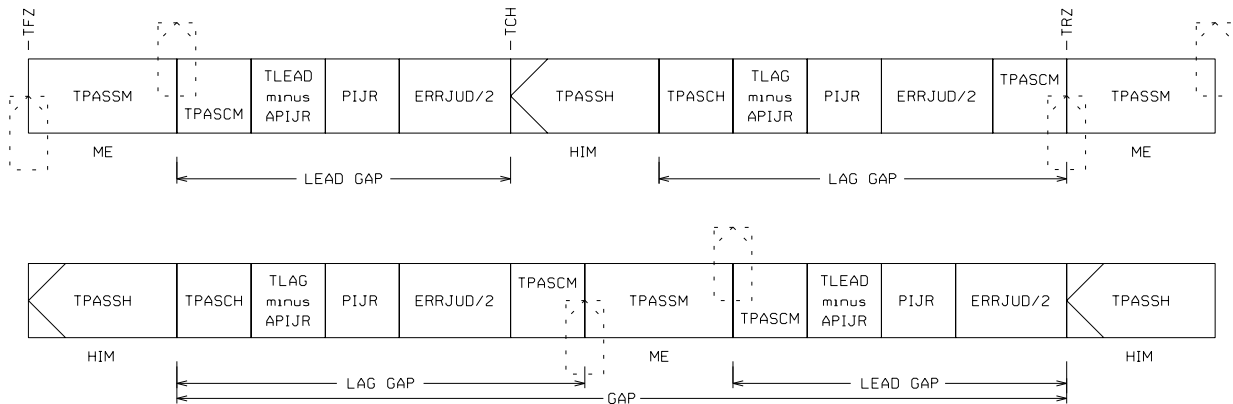

Figure 5 - TEXAS Model Intersection Conflict Checking Gap Calculations

ICA is the algorithm used to simulate the behavior of driver-vehicle units that have the right to enter the intersection and try to maintain a non-conflict time-space trajectory through the intersection with the predicted time-space trajectory through the intersection of other driver-

vehicle units that have the right to enter the intersection. The linked list of driver-vehicle units whose rear bumper plus a time safety zone has not crossed the point of geometric conflict as described for ICC is also used for ICA. The jerk rate used for ICA (SLPCON) is initialized to 0.0.

To process the intersection conflicts for ICA for a driver-vehicle unit on an inbound lane or diamond interchange internal inbound lane that has gained the right to enter the intersection or a driver-vehicle unit that is within the intersection, SIMPRO uses a similar process as described for ICC. TCM, TCH, TFZ, TRZ, and the other variables are calculated in the same manner and the same tests are performed to determine whether there is a conflict. The difference between the ICC and ICA process is the action that is taken when a conflict is found. A variable TIM is calculated based upon TCH, the turn movement for my intersection path, the turn movement for his intersection path, and whether there is a new green signal setting for me. TIM gives priority to a straight driver-vehicle unit over a turning driver-vehicle unit when they are both predicted to arrive at the geometric conflict at approximately the same time. If my turning movement is straight and his turning movement is straight, then TIM is set to TCH. If my turning movement is straight and his turning movement is left or right, then if I have a new green signal setting, then set TIM to TCH - 1.0, else set TIM to TCH + 1.5. If my turning movement is left or right and his turning movement is straight, then set TIM to TCH - 1.5. If my turning movement is left or right and his turning movement is left or right, then set TIM to TCH. Finally, if I am not an emergency driver-vehicle unit and he is an emergency driver-vehicle unit, then set TIM to TCH - 5.0. The jerk rate SLPTCM required for me to travel from my current position to the geometric conflict in time TCM starting with my current velocity and acceleration is calculated. This jerk rate represents the average value from the prediction process. If I have already passed the geometric conflict (TCM is less than or equal to 0.0), then nothing is done for this geometric conflict and the next driver-vehicle unit or the next geometric conflict is processed.

The following logic is used when I am trying to go in front of him (TCM is less than or equal to TIM) therefore I try to accelerate to avoid the conflict. If the front safety zone for him has already arrived at the geometric conflict (TFZ is less than or equal to 0.0), then I should accelerate as fast as possible (set SLPTFZ to 6 times the critical jerk rate CRISLP). If the front safety zone for him has not already arrived at the geometric conflict (TFZ is greater than 0.0), then I should accelerate to go in front of him (set SLPTFZ to the jerk rate required for me to travel from my current position to the geometric conflict in time TFZ starting with my current velocity and acceleration). A temporary jerk rate SLPTMP is set to the maximum of (SLPTFZ-SLPTCM) and 0.0. If I need to accelerate more than normal (SLPTMP is greater than 0.0), and there is no driver-vehicle unit ahead that I must car follow, and the temporary jerk rate is greater than the jerk rate used for ICA (SLPTMP is greater than SLPCON), then set SLPCON to SLPTMP. If I need to accelerate more than normal (SLPTMP is greater than 0.0), and there is a driver-vehicle unit ahead that I must car follow, and my speed is less than my desired speed, and the distance between me and the driver-vehicle unit ahead that I must car follow is greater than the car following distance, and the temporary jerk rate is greater than the jerk rate used for ICA (SLPTMP is greater than SLPCON), then set SLPCON to SLPTMP. The next driver-vehicle unit or the next geometric conflict is processed. This procedure will find the maximum positive jerk rate needed to accelerate to go in front of any driver-vehicle unit where a conflict has been found.

The following logic is used when I am trying to go behind him (TCM is greater than TIM) therefore I try to decelerate to avoid the conflict. If his rear safety zone has not reached the geometric conflict (TRZ is greater than 0.0), then I should decelerate to go behind him (set SLPTRZ to the jerk rate required for me to travel from my current position to the geometric conflict in time TRZ starting with my current velocity and acceleration). A temporary jerk rate SLPTMP is set to the minimum of 4.5*(SLPTFZ-SLPTCM) and 0.0. If I need to decelerate more than normal (SLPTMP is less than 0.0), then set SLPCON to SLPTMP and the ICA checking process is completed. This procedure will find the negative jerk rate needed to decelerate to go behind the first driver-vehicle unit where a conflict has been found. If SLPCON is not set to SLPTMP, then the next driver-vehicle unit or the next geometric conflict is processed.

If the jerk rate used for ICA has been set (SLPCON is not equal to 0.0), then SLPCON is added to the jerk rate calculated for this driver-vehicle unit (SLPNEW) if it is the critical value. There are many special cases accommodated within the actual code when the geometric conflict is a merge, when there is a major collision somewhere within the system, when the other driver-vehicle unit is stopped and blocked by a major collision, when there is an emergency driver-vehicle unit in the system, and/or when a driver-vehicle unit is currently processing a forced go or forced run the red signal Vehicle Message System message.

SIGHT DISTANCE RESTRICTION CHECKING
The user defines the coordinates of all critical points needed to locate sight obstructions in the intersection area and the TEXAS Model Geometry Processor (GEOPRO) calculates the distance that is visible between pairs of inbound approaches for every 25-foot increment along each inbound approach. The TEXAS Model Simulation Processor (SIMPRO) checks sight distance restrictions. Each driver-vehicle unit on an inbound approach assumes that it must stop at the stop line until it gains the right to enter the intersection. If the inbound lane is stop sign controlled or signal controlled, the assumption is made that sight distance restrictions are not critical and therefore do not need to be checked. If adequate sight distance is not available to a unit stopped at the stop line, this will not be detected in SIMPRO.

For driver-vehicle units on inbound lanes to an uncontrolled intersection, if there are units stopped at a stop line waiting to enter the intersection and the inbound driver-vehicle unit being examined is not stopped at the stop line, the approaching driver-vehicle unit will continue to decelerate to a stop at the stop line without checking sight distance restrictions again until it is stopped at the stop line or until there are no driver-vehicle units stopped at the stop line. This procedure eliminates unnecessary computations and gives the right of way to other driver-vehicle units already stopped at the stop line when the intersection is uncontrolled. If there are no sight distance restrictions for driver-vehicle units on an inbound approach then intersection conflicts are checked (see the ICC discussion above). If (1) a driver-vehicle unit is on an uncontrolled lane approaching a yield-sign-controlled, (2) the driver-vehicle unit is stopped at the stop line, or (3) the intersection path of the driver-vehicle unit has no geometric intersection conflicts then it is assumes that there are no sight distance restrictions.

The maximum time from the end of the inbound lane that the driver-vehicle unit is permitted to begin checking sight distance restrictions, so that it may decide to proceed to ICC if sight distance restrictions are clear, is initially set to 3 seconds for all intersections. This prohibition prevents the driver-vehicle unit from gaining the right to enter the intersection when it is relatively far away from the intersection and thereby unnecessarily affecting the behavior of driver-vehicle units on other inbound approaches. If the inbound lane is an uncontrolled lane approaching a yield-sign-controlled intersection, the time is increased by 2 seconds plus the time for the lead safety zone for ICC. This longer time allows driver-vehicle units on the uncontrolled lanes to gain the right to enter the intersection ahead of other driver-vehicle units on the yield-sign-controlled lanes. If the intersection is uncontrolled then the time is reduced to 2 seconds.

In SIMPRO, the time required for the driver-vehicle unit being checked to travel to the end of the lane is predicted. If this predicted time is greater than the maximum time from the end of the lane that the driver-vehicle unit may decide to proceed to ICC then the driver-vehicle unit can not clear its sight distance restrictions and it must check again in the next time step increment.

The order in which sight distance restrictions are checked by SIMPRO is determined by the sequence in which intersection conflicts might occur. The sight distance restriction associated with the longest travel time to an intersection conflict is checked first then other sight distance restrictions are checked in descending order of travel time to the intersection conflict. This order of checking facilitates early detection of an opportunity to pass in front of a driver-vehicle unit approaching on a sight-restricted lane. Checking continues until all inbound approaches which have possible sight distance restrictions with the subject inbound approach are cleared.

To check sight distance restrictions in SIMPRO, the time required for a fictitious driver-vehicle unit, traveling at the speed limit of the approach, to travel from a position that is just visible on the inbound approach to the point of intersection conflict is predicted. Next, the time required for the driver-vehicle unit being examined to travel to the point of intersection conflict is predicted. This prediction assumes that the driver-vehicle unit under examination has gained the right to enter the intersection and that it may accelerate to its desired speed. If the unit being checked may not safely pass through the point of intersection conflict ahead of the fictitious driver-vehicle unit then it may not clear its sight distance restrictions and it must check again in the next time step increment, otherwise, it clears the sight distance restriction and continues checking other sight distance restrictions.

This procedure ensures that a driver-vehicle unit may safely enter the intersection even if a driver-vehicle unit were to appear from behind the sight distance restriction just after the decision to enter the intersection was made.

LANE CHANGING
An investigation of lane changing models was undertaken in the early 1970s by Dr. Lee and Mr. Ivar Fett (Fett 1974 thesis). Mr. Fett collected and analyzed the field data, developed the original lead and lag gap acceptance decision models, and used a cosine curve for the lateral position for a lane change.

Dr. Rioux developed the concept of distinguishing between two types of lane changes: (1) the forced lane change wherein the currently occupied lane does not provide an intersection path to the driver-vehicle unit's desired outbound approach and (2) the optional lane change wherein less delay can be expected by changing to an adjacent lane which also connects to the driver-vehicle unit's desired outbound approach. Later, Dr. Rioux added cooperative lane changing and a lane change to get from behind a slower vehicle.

When a lane change is forced, a check is made to determine whether an alternate lane is geometrically available adjacent to the current position of the driver-vehicle unit being examined and is continuous to the intersection ahead. In the case of the alternate lane not being accessible from the current position, but available ahead, one of the two following conditions exists: (1) there is a lead driver-vehicle unit in the alternate lane ahead in which case the driver-vehicle unit sets the lane change jerk rate to car follow the lead driver-vehicle unit in the alternate lane or (2) there is not a lead driver-vehicle unit in the alternate lane ahead in which case the lane change jerk rate is set to stop the driver-vehicle unit at the end of the alternate lane. If the end of the alternate lane has already been passed by the driver-vehicle unit when the check for an available alternate lane is made then the driver-vehicle unit is forced to choose one of the available intersection paths leading from the currently occupied lane and abandon the original destination. Otherwise, the driver-vehicle unit checks for an acceptable gap for lane changing.

When a lane change is optional, SIMPRO delays further lane-change checking until the driver-vehicle unit is dedicated to an intersection path. If there are no lane alternates adjacent to the current lane then the lane change status flag is set to no longer consider a lane change. If the driver-vehicle unit is the first unit in the current lane and its intersection path does not change lanes within the intersection then the lane change status flag is set to no longer consider a lane change. The expected delay is then computed for the driver-vehicle unit's current lane as well as for its alternate lane(s). If less delay can be expected if the driver-vehicle unit changes into one of the alternate lanes then that lane is checked for the presence of an acceptable lead gap and an acceptable lag gap otherwise the process is repeated the next time step increment. If there is an acceptable lead gap and an acceptable lag gap then the driver-vehicle unit is logged out of the current lane, logged into the new lane, and the lane change is initiated.

When the lead gap and/or the lag gap is not acceptable, the driver-vehicle unit tries to maneuver itself to make the gaps acceptable the next time step increment by accelerating, decelerating, and/or asking the lag driver-vehicle unit to car follow the current driver-vehicle unit to increase the lag gap (this is cooperative lane changing).

SIMPRO keeps track of the lateral position for the lane change old LatPosOld in feet which starts at the value for the total lateral distance for a lane change in feet TLDIST and decreases to zero when the lane change maneuver is completed. The lateral position of the lane change is computed using a cosine curve. Each time step increment, the current position on the cosine curve XOLD and the new position on the cosine curve XNEW are calculated as follows:

$$\text{XTOT} = 3.5 * \text{VO} / (\text{DrivChar} * \text{VehChar})$$
$$\text{TLDIST} = 1/2 * \text{LanWidOrg} + 1/2 * \text{LanWidNew}$$
$$\text{XOLD} = \text{XTOT} * \text{ACOS}(2 * \text{ABS}(\text{LatPosOld}) / \text{TLDIST} – 1) / \text{PI}$$

$$XNEW = XOLD + VO * DT + 1/2 * AO * DT^2 + 1/6 * JN * DT^3$$

where:

AO	=	current driver-vehicle unit acceleration/deceleration old in ft/sec/sec
DrivChar	=	user-specified driver characteristic
		(<1=slow, 1=average, >1=aggressive, min=0.5, & max=1.5)
JN	=	current driver-vehicle unit jerk rate new in ft/sec/sec/sec
LanWidNew	=	new lane width in feet
LanWidOrg	=	original lane width in feet
LatPosOld	=	lateral position for the lane change old in feet
TLDIST	=	total lateral distance for a lane change in feet
VehChar	=	user-specified vehicle characteristic
		(<1.0=sluggish, 1=average, >1=responsive, min=0.5, & max=1.5)
VO	=	current driver-vehicle unit velocity old in ft/sec
XNEW	=	new position on the cosine curve in feet
XOLD	=	current position on the cosine curve in feet
XTOT	=	total length of the lane change in feet

If the new position on the cosine curve XNEW is greater than 95% of the total length of the lane change XTOT then the lane change is completed. The lateral position for the lane change new LatPosNew is calculated and stored as follows:

$$LatPosNew = 1/2 * TLDIST * (1 + COS(PI * XNEW / XTOT))$$

where:

LatPosNew	=	lateral position for the lane change new in feet
TLDIST	=	total lateral distance for a lane change in feet calculated above
XNEW	=	new position on the cosine curve in feet calculated above
XTOT	=	total length of the lane change in feet calculated above

If lateral position for the lane change new LatPosNew is less than 0.3 feet then the lane change is completed. Note that if the driver-vehicle unit speeds up then the total length of the lane change XTOT increases which causes the lane change to lengthen.

In 2008, Dr. Thomas W. Rioux extended the maximum lane length from 1,000 feet to 4,000 feet (Rioux et. al. 2008 DTRT57-06-C-10016-F). This enhancement caused an additional optional lane change to be added before or after the intersection to move a driver-vehicle unit from behind a slower driver-vehicle unit. If the adjacent lane did not have an intersection path to the driver-vehicle unit's desired outbound approach, a lane change that would temporarily use the adjacent lane, pass the slower moving driver-vehicle unit, and lane change back into the original lane was performed if possible.

CRASHES
If the front bumper position of the driver-vehicle unit (lag driver-vehicle unit) is greater than the rear bumper position of the driver-vehicle unit ahead (lead driver-vehicle unit) then there is a

crash. These were called "clear zone intrusions". A message giving the details of the lead driver-vehicle unit and the lag driver-vehicle unit involved in the "clear zone intrusion" was output and the "clear zone intrusions" were counted. The lag driver-vehicle unit defied physics by placing itself 3 feet behind the lead driver-vehicle unit traveling at the speed of the lead driver-vehicle unit and with zero acceleration/deceleration and jerk rate and the traffic simulation continued normally. Only crashes between a lead driver-vehicle unit and a lag driver-vehicle unit were detected.

In 2008, Dr. Thomas W Rioux added the option to stop a driver-vehicle unit involved in a "major" crash using crash deceleration and remain stopped for the remainder of the simulation (Rioux et. al. 2008 DTRT57-06-C-10016-F). This involved defining a "major" crash. Additionally, a crash between driver-vehicle units on different intersection paths was detected. Finally, code was added to cause other driver-vehicle units to react to driver-vehicle units involved in a "major" crash by slowing down as they passed near a crash if the driver-vehicle unit was not blocked by the "major" crash. After the driver-vehicle unit stopped because it was blocked by the "major" crash and a stochastically generated response time had elapsed, the driver-vehicle unit could possibly reverse a lane change maneuver if the driver-vehicle unit was still in the original lane and/or choosing a different intersection path to a possibly different desired outbound approach.

CONCLUSION
This paper chronicles the evolution of the Traffic EXperimental and Analytical Simulation Model for Intersection Traffic (TEXAS Model) which was developed by the Center for Transportation Research at The University of Texas at Austin beginning in the late 1960's. Topics include the early traffic flow theory concepts of triangular acceleration, triangular deceleration, equations of motion, car following, intersection conflict checking, intersection conflict avoidance, sight distance restriction checking, lane changing, and crashes. The TEXAS Model is being enhanced to include Connected Vehicle messages by Harmonia Holdings Group and Dr. Rioux to be a test bed for Connected Vehicle applications.

The TEXAS Model source code is available for use by the public under the GNU General Public License as published by the Free Software Foundation. The source code for the TEXAS Model may be downloaded from:
standard version   http://groups.yahoo.com/neo/groups/TEXAS_Model
version with messaging   http://www.etexascode.org

The TEXAS Model Animations may be watched from YouTube (or search YouTube for "TEXAS Model for Intersection Traffic Animation"):
1970's http://www.youtube.com/watch?v=1z4WIeIOfbw
1980's http://www.youtube.com/watch?v=S0utMJ9fZls
1990's http://www.youtube.com/watch?v=PcU6WcaOAcE
2000's http://www.youtube.com/watch?v=oah6nCGKwig

Most of the references may be downloaded from Files at:
http://groups.yahoo.com/neo/groups/TEXAS_Model_Documentation1

00000000_READ_ME.TXT
00000001_TEXAS_Model_Development_History.txt
19730126_TexITE.zip
19730500_Rioux_thesis.zip, z01, & z02
19740500_Fett_thesis.zip
19770000_TRB_TRR_644.zip
19771200_CTR_Research_Report_184-1.zip, z01, z02, z03, z04, & z05
19771200_CTR_Research_Report_184-2.zip, z01, z02, z03, z04, z05, z06, & z07
19770700_CTR_Research_Report_184-3.zip & z01
http://groups.yahoo.com/neo/groups/TEXAS_Model_Documentation2
19771200_Rioux_dissertation.zip, z01, z02, z03, z04, z05, z06, z07, z08, z09, & z10
19780700_CTR_Research_Report_184-4F.zip
19801100_Torres_Evaluation_of_TEXAS_Model.zip
19830800_CTR_Research_Report_250-1.zip, z01, z02, z03, z04, z05, z06, & z07
http://groups.yahoo.com/neo/groups/TEXAS_Model_Documentation3
19851100_CTR_Research_Report_361-1F.zip & z01
19890100_CTR_Research_Report_443-1F.zip, z01, z02, z03, & z04
19910800_CTR_TEXAS_Model_Version_3_0_Documentation.zip, z01, z02, & z03
19930100_CTR_Research_Report_1258-1F.pdf
19931100_CTR_TEXAS_Model_Version_3_20_Documentation.zip, z01, & z02
20040824_RiouxEngineering_DTRS57-04-C-10007_report.pdf
20050800_CTR_DTFH61-03-C-00138.pdf
20080731_RiouxEngineering_DTRT57-06-C-10016_report.pdf
20100110 TRB Intersection Conflict Checking and Avoidance.pdf (not accepted)
20120122 TRB Simulating Crashes and Creating SSAM Files.pdf
20120122 TRB Simulating Crashes and Creating SSAM Files.ppt
Evolution_of_Animation_of_the_TEXAS_Model.ppt
TEXAS_Model_for_Intersection_Traffic.ppt
TEXAS_Model_for_Intersection_Traffic_Section_508.ppt
TEXAS_Model_Online_Documentation.htm

ACKNOWLEDGEMENTS

REFERENCES
1.   Beakey, John, "Acceleration and Deceleration Characteristics of Private Passenger Vehicles", Proceedings, Highway Research Board, 1938, pp 81-89.

2. Gazis, D. C., Herman, R., and Rothery, R. W., "Nonlinear Follow-the-Leader Models of Traffic Flow", Operations Research, Vol. 9, No. 4, 1960, pp 545-567

3. May, Adolf D., Jr., and Keller, H. E. M., "Non-Integer Car-Following Models", HRR No. 199, Highway Research Board, 1967, pp 19-32

4. Drew, Ronald R., "Traffic Flow Theory and Control", McGraw-Hill, January 1968, p 9.

5. Rioux, Thomas W., "Step-Through Simulation Is Faster Than Driving", Compendium of the Annual Meeting of the Texas Section of the Institute of Traffic Engineers, Bryan, Texas, January 26-27, 1973, pp 54-73

6. Rioux, Thomas W., "Simulation of Traffic Movements in an Intersection", Masters Thesis, The University of Texas at Austin, Austin, Texas, May 1973, 151 pp

7. Fett, Ivar Henning Christopher, "Simulation of Lane Change Maneuvers on Intersection Approaches", Masters Thesis, The University of Texas at Austin, Austin, Texas, May 1974, 63 pp

8. Rioux, Thomas W., and Lee, Clyde E., "Microscopic Traffic Simulation Package for Isolated Intersections", Transportation Research Record Number 644, Transportation Research Board of the National Academy of Sciences, Washington, D.C., 1977, pp 45-51.

9. Lee, Clyde E., Grayson, G. E., Copeland, C. R., Miller, J. W., Rioux, Thomas W., and Savur, V. S., "The TEXAS Model for Intersection Traffic - User's Guide", Research Report No. 184-3, Project 3-18-72-184, Center for Highway Research, The University of Texas at Austin, July 1977, 89 pp

10. Rioux, Thomas W., "The Development of the Texas Traffic and Intersection Simulation Package", Doctoral Dissertation, The University of Texas at Austin, Austin, Texas, December 1977, 698 pp

11. Lee, Clyde E., Rioux, Thomas W., and Copeland, C. R., "The Texas Model for Intersection Traffic-Development", Research Report No. 184-1, Project 3-18-72-184, Center for Highway Research, The University of Texas at Austin, December 1977, 408 pp

12. Lee, Clyde E., Rioux, Thomas W., Savur, V. S., and Copeland, C. R., "The Texas Model for Intersection Traffic - Programmer's Guide", Research Report No. 184-2, Project 3-18-72-184, Center for Highway Research, The University of Texas at Austin, December 1977, 346 pp

13. Lee, Clyde E., Savur, Vivek S., and Grayson, Glenn E., "Application of the TEXAS Model for Analysis of Intersection Capacity and Evaluation of Traffic Control Warrants", Research Report No. 184-4F, Project 3-18-72-184, Center for Highway Research, The University of Texas at Austin, July 1978, 102 pp

14. Lee, Fong-Ping, Lee, Clyde E., Machemehl, Randy B., and Copeland, Charlie, R., Jr., "Simulation of Vehicle Emissions at Intersections", Research Report No. 250-1, Project 2/3-8-79-250, Center for Transportation Research, The University of Texas at Austin, Austin, Texas, August 1983, 333 pages.

15. Lee, Clyde E., Inman, Robert F., and Sanders, Wylie M.., "User-Friendly TEXAS Model - Guide to Data Entry", Research Report No. 361-1F, Project 3-18-84-361, Center for Transportation Research, The University of Texas at Austin, November 1985, 210 pp

16. Lee, Clyde E., Machemehl, Randy B.., and Sanders, Wylie M.., "TEXAS Model Version 3.0 (Diamond Interchanges)", Research Report No. 443-1F, Project 3-18-84-443, Center for Transportation Research, The University of Texas at Austin, January 1989, 224 pp

17. Rioux, Tom, Inman, Robert, Machemehl, Randy B., and Lee, Clyde E., "TEXAS Model for Intersection Traffic -- Additional Features", Research Report No. 1258-1F, Project 3-18-

91/2-1258, Center for Transportation Research, The University of Texas at Austin, Austin, Texas, January 1993, 115 pp

18. Rioux, Thomas W., "Enhancing the Usability of the TEXAS Model for Intersection Traffic Final Report", Research Report Number SBIR DTRS57-04-C-10007-F, Federal Highway Administration Small Business Innovation Research Program Solicitation Number DTRS57-03-R-SBIR Contract Number DTRS57-04-C-10007, Rioux Engineering, Austin, Texas, August 2004, 31 pp

19. Rioux, Thomas W., "Enhancement of the TEXAS Model for Simulating Intersection Collisions, Driver Interaction with Messaging, and ITS Sensors - Final Report", Research Report Number DTFH61-03-C-00138, Center for Transportation Research, The University of Texas at Austin, Austin, Texas, August 2005, 81 pp

20. Rioux, Thomas W., Inman, Robert F., Copeland, Jr., Charlie R., Sanu, Moboluwaji "Bolu", and Ning, Zhonghui, "Enhancing the Usability of the TEXAS Model for Intersection Traffic Final Report", Research Report Number SBIR DTRT57-06-C-10016-F, Federal Highway Administration Small Business Innovation Research Program Solicitation Number DTRS57-03-R-SBIR Contract Number DTRT57-06-C-10016, Rioux Engineering, Austin, Texas, July 2008, 318 pp