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Final Report for Task Order 4222

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Human Driver Model Development

Task Order 4222

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Abstract

This report presents the continuation of the development of a naturalistic driver model (PADRIC) initiated under MOU 369 Human driver model. The development consists of increasing the scope of simulation capabilities to lane-change maneuvers and gathering data for the calibration of the car-following mode already implemented. The first part of the report presents the development of the model architecture for integrating lane change maneuver. The second part is focused on the data collection that was conducted and proposes a discussion of the method and shortcoming for gathering the data of interest.

Keywords: cognitive driver model, naturalistic driving

Executive Summary

This project is a continuation of MOU369. It continues and extends the effort on human driver modeling development. The goal is to provide other researchers with a tool for analyzing the effects of ITS systems on conventional driving performance in terms of throughput by reproducing the information processing string developed by the driver. The project extends and refines the capabilities of the human driver model by developing more processing mechanisms that assess the effectiveness of other driving assistance systems. It also increases the number of driving parameters that the model should incorporate, and begin to validate the model using data collected during real driving.

This report presents the progress realized in the development of the model from a conceptual point of view, with the description of the addition to the modules constituting the model in a first part, and the protocol and data collected in the frame of a naturalistic data collection. In more detail, the first part is dedicated to the description of the integration of the strategic module and the integration of the itinerary representation. This is essential in order to be able to simulated situations where drivers' choices are motivated not only by traffic but by the infrastructure. In order to be able to integrate this aspect in the model, we also had to develop the perception module capacity of the model. At the end of MOU 369, the perception module was processing mainly the range and range rate with a lead vehicle. Here, we have augmented this capacity to the perception of up to three vehicles in the front (front left lane, front right lane and front same lane), two vehicles on each sides (right side, left side) in the peripheral field of view and three vehicles in the back via the rear view mirrors (rear left lane, rear right lane and rear same lane). We process range and range rate for the vehicle that is being looked at and let the values for the other vehicles to the last value recorded when they were being looked at. The other very important development is the addition of landmark and directions signs in the simulation world, as well as the creation of entrance and exit on the highway.

The second part of the report focuses on the naturalistic data collection, data processing, and use of the data for the model development. It turns out that the naturalistic data collection provided a very rich set of data and brought a few challenges for the data analysis in terms of extraction of relevant data. We developed a set of scripts in order to reduce as much as possible human manipulation of the data. However, some data cannot be reduced automatically; for example, one of the goals of this data collection was to obtain data about car following behavior, in order to support the categorization of car following that we developed in the course of MOU 369. The data supports the computation of the necessary variables, such as time gap, time to collision, but in order to identify the category, the researcher has to watch the video, note for each following situation whether the subject reached the lead vehicle or the lead vehicle cuts in the front of the subject and so on. This constraint made the data processing a much longer process than was initially envisaged. As the full data set has not been totally analyzed yet, the end of the second part illustrates the method used for integrating the data to the model.

Model Architecture development

The original architecture of the model was described and partly implemented during the MOU 369. This architecture is evolving in order to accommodate the development of the model. This development has to do with the architecture of the model, with the addition of a strategic module, and the behavior of each of the module, with an increase of the modules processing capabilities. These additions are illustrated in Figure 1, where the additions to the architecture are written in italics.
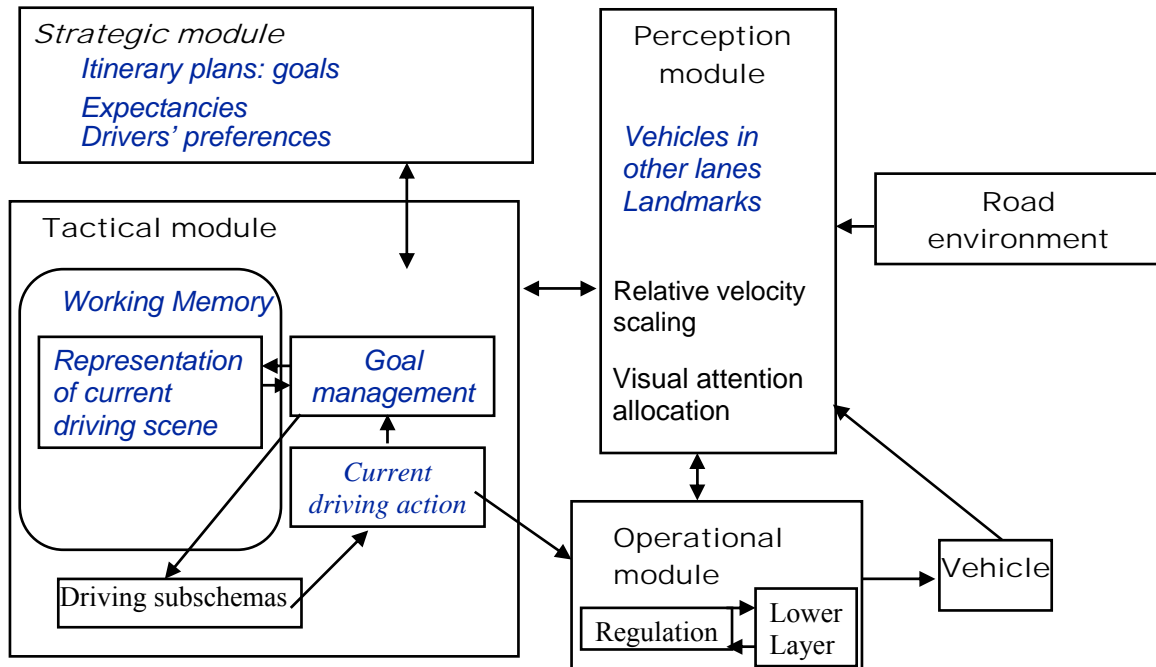

Figure 1: Model Architecture

Strategic Module

This module contains the description of itineraries, rules for the management of an itinerary, driver's expectancies and preferences. The first effort was applied to the description of the itinerary. The main assumption is that a driver's representation of an itinerary can be decomposed in terms of three main components:
- Direction to follow, such as highway x, street A
- Landmark, elements from the environment, these can be a building, a store, a billboard …
- Driving actions, like turn or stop or change lane

Therefore direction and landmark will be considered as nodes, which can be associated with a driving action. For example: "take a right at the church" or "Follow 80 east". Based on this representation of an itinerary, there is a list of implicit actions to be taken. These implicit actions are part of the knowledge base on either the tactical or operational

module. For instance, the node "Follow 80 east" will activate the schema of merge at the tactical level which is associated with the following actions:

- Identify lane corresponding to direction 80 east
- Get to or stay in lane corresponding to direction 80 east

The merge schema will itself be associated with schemas at the operational level for the lateral and longitudinal control of the vehicle.
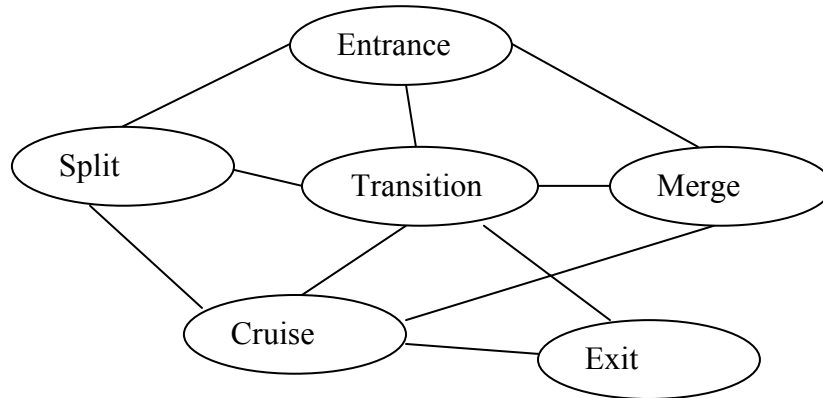

Figure 2: Schemas associated to highway driving at the Strategic level

Strategic subgoal: use highway until exit A

Tactical goal: reach preferred (cruising) lane & then maintain preferred velocity & satisfying gap with lead vehicle
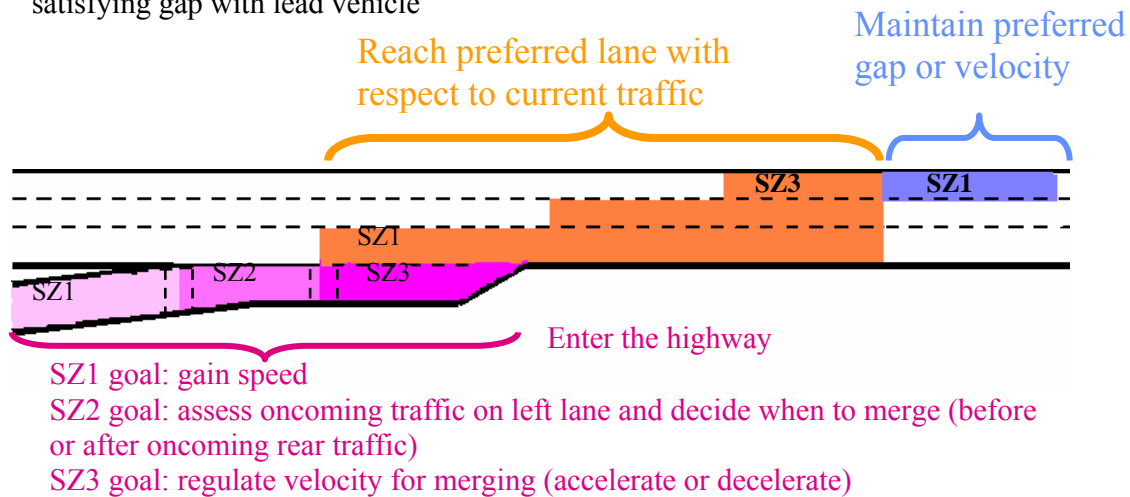

Reach preferred lane with respect to current traffic

Maintain preferred gap or velocity

SZ3   SZ1

SZ1

SZ1   SZ2   SZ3

Enter the highway

SZ1 goal: gain speed
SZ2 goal: assess oncoming traffic on left lane and decide when to merge (before or after oncoming rear traffic)
SZ3 goal: regulate velocity for merging (accelerate or decelerate)

Figure 3: Example of transition between schemas at the strategic level

the main goal: reach destination x
the itinerary to follow for reaching destination x
with "rupture points" breaking the itinerary, e.g. first get to highway Ixxx, then take exit A. These breaking points are used for setting sub goals.

itinerary in-between rupture points, e.g. "to get to highway, take ave …"
switch
from sub goals to sub goals
from sub goals to rupture points
expectancies about traffic congestions
the driver preferences/characteristics

Itinerary file format

first column: Route name
second column: landmark
third column: action
fourth column: lane index

i80 costco cruise 1
i80 gateway cruise 1
i80 microsoft cruise 1
i80 kmart cruise 1
i80 kragen cruise 1
i90 walmart cruise 1

Perceptive Module

The first step in the development of the perceptive module addressed the perception of range and range rate with a leading vehicle. The goal in this project was to increase the capacity of the perceptive module in order to perceive other vehicles than the leading vehicle and also elements of the environment, such as landmarks and traffic signs. These elements support the development of more elaborated scanning patterns as well as the development of the tactical and strategic levels.

The driver perceives 3 lanes and always knows the surrounding.

We can distingue different view in the perception: Scan_front, scan_right_mirror, scan_speedometer…
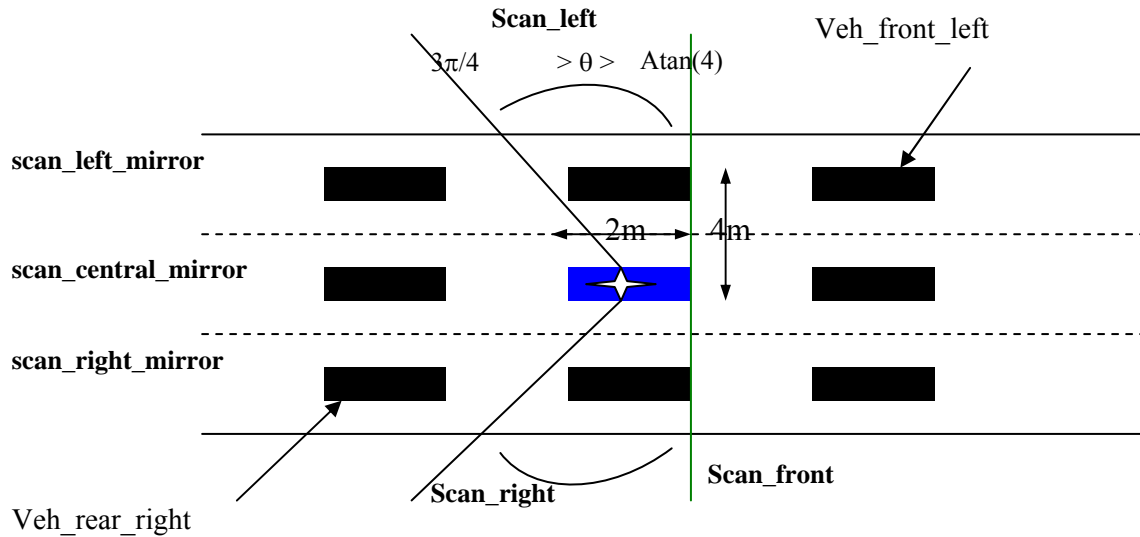
Figure 4: Graphical representation of visual detection of surrounding vehicles

Type detection
While the vehicle is in motion, the driver is able to know the 8 nearest vehicles around him, we use the SEP. We create for each one a type targetdetection SHIFT by example:Veh_rear_right…(see Figure above)(each one is the minimum (range) of a set of targetdetection vehicle).
A type targetdetection is defined as following:
type TargetDetection
{
output
 number range := 0;//range between my car and the detected vehicle
number rangeRate := 0; //range rate between my car and the detected vehicle
number vehID := 0;   //number of the detected car
Vehicle vehicle_detected;
number TTC :=0;   //time to collision
}

Type Filtering
It changes the characteristic of the type targetdetection, which takes into account the perceptive reality (decision map). In transition we need to create a new type targetdetection. We are not able to perceive the range rate after a special threshold. In this part ,we lost one time step(0.01s).
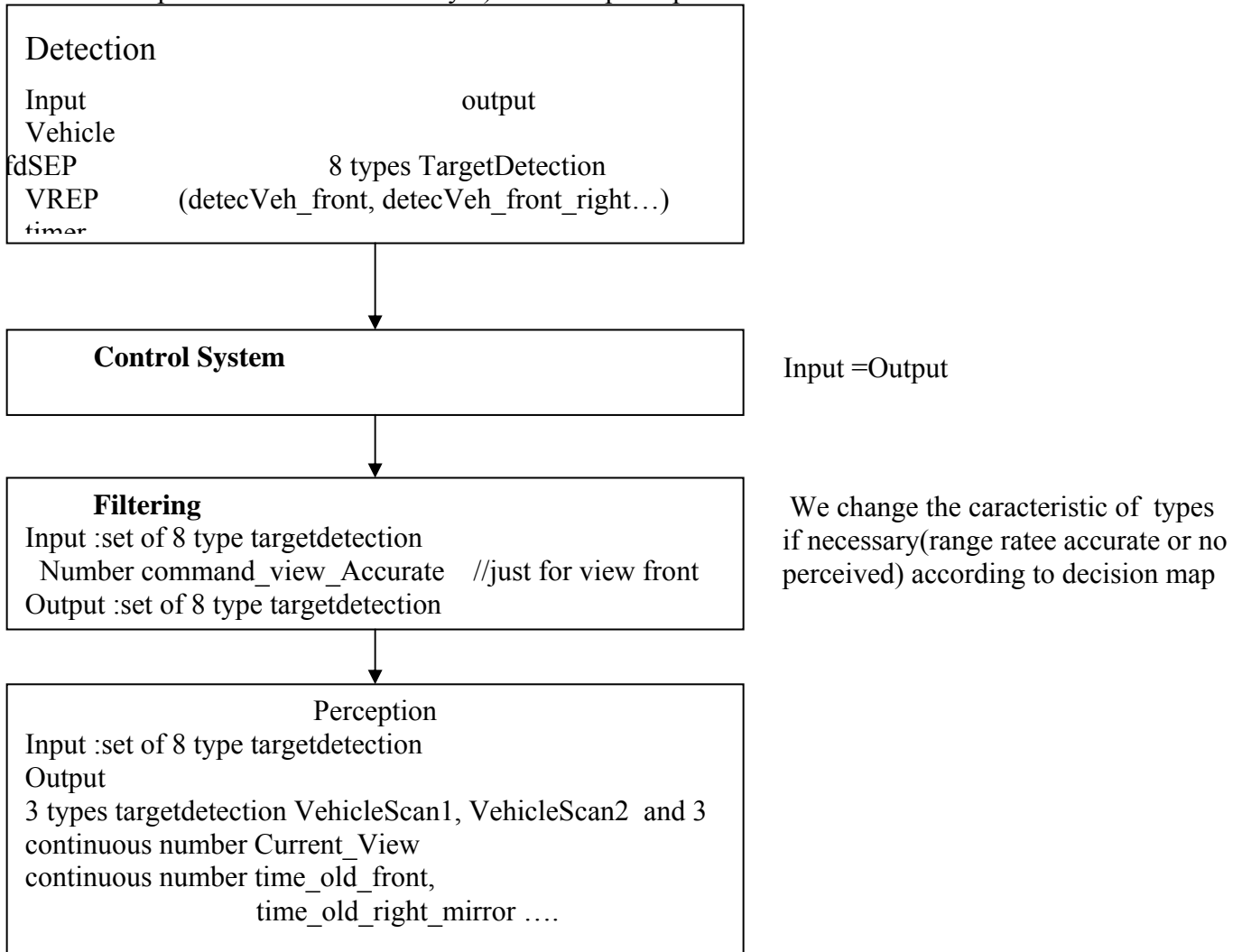
Type perception
we provide every time in output of the perceptive module 3 types Targetdetection: VehicleScan1, 2 and VehicleScan3.

14

When we are in the discrete state Scan_front by example, you have in output :
Vehicle_front, Vehicle_front_left and Vehicle_front_right, but if we are in the discrete
state scan_left_mirror, we provide Vehicle_rear_left.
We provide our current view direction and also the length of time you last viewed other 5
directions. We can also view the speeder, we know in this case our current speed.

We have this structure for the perceptive system implementation (just the surrounding,
we do not implemented infrastructure yet): link: output/input

```
Detection

Input                               output
Vehicle
fdSEP                    8 types TargetDetection
  VREP          (detecVeh_front, detecVeh_front_right…)
  timer
```

```
   Control System
```
Input =Output

```
      Filtering
Input :set of 8 type targetdetection
  Number command_view_Accurate    //just for view front
Output :set of 8 type targetdetection
```
 We change the caracteristic of types
if necessary(range ratee accurate or no
perceived) according to decision map

```
                Perception
Input :set of 8 type targetdetection
Output
3 types targetdetection VehicleScan1, VehicleScan2  and 3
continuous number Current_View
continuous number time_old_front,
                time_old_right_mirror ….
```

Naturalistic Data Collection

Protocol

The protocol of the naturalistic data collection consisted of providing an instrumented vehicle (see Figure5) to commuters for a period of two weeks. Each driver was instructed to use the vehicle as he would use his own personal vehicle in that period of time. The volunteers responded to this flyer that was on the PATH website:

Wanted: research participants for study of driving behavior

Drivers with a valid California driving license and insurance, 30 to 35 years old, without moving violations in the last 3 years or any DUI, normally driving around 50 miles a day and for at least two years in the same area. The study consists in driving and remaining the exclusive driver of an instrumented vehicle instead of your personal vehicle. This instrumented vehicle will be driven like the personnel vehicle would be during this period. All of the costs associated with the use of the vehicle (gas, oil, tires …) will be reimbursed.

Interested individuals can contact:

Delphine Delorme
Phone: (510) 231 9455
e-mail: delorme@nt.path.berkeley.edu

The drivers could use this vehicle for all their trips during that period, without an experimenter in the car; in the same fashion they would use their own personal vehicle for this same period of time. At the end of each trip, the participant documented his degree of familiarity with the trip, the frequency of the trip, the degree of urgency of the trip and any unusual driving events during this trip.

The video for the overall test period was recorded for performing post driving test quantitative measurements of the vehicle's surrounding (i.e. highway driving, entrance ramp, presence of other vehicles, etc). We also used radar information in order to detect the range and range rate of vehicles in front and behind the instrumented vehicle. The participant's control of the vehicle was also measured by the means of sensors. The description of the vehicle instrumentation is provided below.

Once the researcher had conducted an initial processing of the data, the participants were invited to come to the Richmond Field Station for a 2 hour interview. The purpose of this interview was to determine motivations of the driver for certain actions undertaken during their trips (e.g., lane changes). There was also particular interest regarding identification of motivations for itinerary management (e.g., lane change due to closing of

an exit), velocity management (e.g., lane change to overtake a slower vehicle) and the comfort of driving (e.g., perceived comfortable gap limit while following). This interview involved the playback of video collected while the participant was driving.

A total of five drivers participated to the experiment. However, because of technical difficulties with the Data Acquisition System (DAS) (2 failures) and a misunderstanding with the first driver, we could only use the data of three drivers out of the five.

Data Acquisition System

The instrumentation consisted of:

Figure 5: Instrumented vehicle used for data collection

Data processing

The data gathered by the engineering and video computer were synchronized via Time information (Hour:Minute:Seconds.Milliseconds) and alarms generated by the video computer and sent to the engineering computer. These alarms were generated every 1, 5 and 15 minutes. If a trip was less than 15 minutes long, the data could not be synchronized. In this section, we will present the data processing of the data obtained by the engineering computer.

Radar and Engineering files data

The radar data consisted of:

Vehicle ID: Each detected vehicle is assigned with an ID.
Range: The distance of the detected vehicle and the subject vehicle
Range Rate: The variation rate of Range
Azimuth: the relative position of the detected vehicle to the subject vehicle
Velocity: the velocity of the detected vehicle
Acceleration: the acceleration of the detected vehicle

The data mentioned above allows describing the near traffic surrounding the vehicle driven by the subject. To be meaningful, these data has to be considered concurrently with the data recorded for the subject vehicle. This set data includes:

1. Time: (Hour:Minute:Seconds.Milliseconds) synchronized with the time in radar files.
2. Steering Angle: indicates how the drivers control the steering wheel. The unit is in degree. Left turn is positive number and right turn is negative number.
3. X acceleration: This number indicates how the drivers accelerate along the lane as the longitudinal direction of the lane is defined as X axis. The unit is in tenth of a g $(1g = 9.8 m/s^2)$
4. Y acceleration: This number indicates how the drivers accelerate within the lane as the lateral direction of the lane is defined as Y axis. The unit is in tenth of a g.
5. Cruise Control State: indicates the state of cruise control on the vehicle. The state is on/off.
6. Throttle Angle: indicates how the drivers press the throttle paddle. The number is presented 0~100%
7. Brake State: indicates the state of the brake light. The state is on/off.
8. Left Turn Signal State: indicates the state of the left turn signal. The state is on/off.
9. Right Turn Signal State: indicates the state of the right turn signal. The state is on/off.
10. Speed: The speed of the subject vehicle. The unit is m/s.
11. UTC Time: Universal Time.
12. Latitude: A component in GPS format.
13. Longitude: A component in GPS format.
14. Altitude: The unit is m.
15. Speed over Ground: The vehicle speed respect to the ground. The unit is kph.
16. Lateral Offset: Lateral offset of the subject vehicle respect to the center of the lane. Negative number indicates the vehicle is at the left side of the lane. The unit is in cm.
17. Lateral Velocity: Lateral velocity of the subject vehicle. The unit is cm/s.
18. Curvature: indicates the curvature of the lane.
19. Lane width: the width of the lane. The unit is in cm.
20. Boundary type: indicates the boundary type of the lane, including dashed line, solid line, no line, or cannot process.
21. Offset Confidence: The confidence of the offset data. The level of confidence is from 0 to 100.

22. Curvature Confidence: The confidence of the curvature data. The level of confidence is from 0 to 100.
23. Alert Index: The driver's alertness index. 0 = bad, 99 = perfect.
24. Heading: Heading relative to the North. Range is from 0 to 360 degree, where 360= unknown.

The data collected from these additional devices are recorded into a single file. As a result, a total of five files are produced for a single trip. In addition to these recorded data, the trips are recorded by cameras so that we are able to identify the behavior we wish to analyze (see video data coding p 30).

Reliability and quality of the sensor data:

The surrounding traffic data is recorded by sensors. To make sure the result of our analysis is correct and meaningful; we have to ascertain the recorded data is engineering reliable. Unfortunately, the sensors present two major technical problems once the data it recorded.

The first problem is that the data is noisy. It is a common problem in the hardware devices. Between the processes of the radar emits and receives the radio wave, the radio wave is affected by the environmental media and other factors, i.e. vehicle vibrations. Therefore, the radio wave is distorted and its phase changes. The consequence is the output numbers do not represent truly what is happening in reality. To minimize the effect of the noise, the recorded data need to be filtered.

The second problem is multi-object detection for a single vehicle. There are two part of the problem. The first part is that due to the nature of radar design and the size of the vehicles, sometimes, radar will detect a single vehicle as multiple vehicles because the multiple radio waves are reflected by the vehicle. As the result, multiple sets of data are recorded into the log files for a single vehicle. The second part, as we have total of four radars setup on the instrumented vehicle, the two radars on the vehicle front and the two radars at the back would detect the same vehicle if the vehicle is within their ranges; the two radars will output the detected vehicle into the database because they work individually. Therefore, data redundancy is introduced. This is highly not desirable and the extra data sets have to be removed from our database. It introduces a data reduction task in our work.

Data Filtering

Before filtering the raw sensor data, we re-structure the raw radar data per vehicle so that we can visually compare the data with the recorded videos to establish the link between these two pieces of information. However, since there is a lot of noise, such as multi-path reflections and vehicle vibrations added to the radar readings during the radar collection, the state of filtering for the collected data is required.

Based on the needs for our analysis, we only do filtering on steering angle, vehicle's longitudinal acceleration, and lateral acceleration. To build a reliable filter, we need a sample of dataset to tune the parameters. Unfortunately, the collected data is limited and there is no additional reliable (noise free) data available for building up proper estimator and Kalman filter to fuse the steering data because this is the direct input from the drivers.

Moreover, we could not use the steering data as the input state to build the filter for longitudinal acceleration and lateral acceleration because the noise on the steering data would be carried over and have high possibility on amplifying the noise into the filter. On the other hand, as the filtered data does not need to be extremely accurate to represent what happened during the trip. The data is good as long as it satisfies the requirement for our analysis yet carries the characteristics of the raw data. As a result, with the available source and labor, we filter the data and smooth out the curve by spline curve in Matlab.

Collected and fused Steering angle data
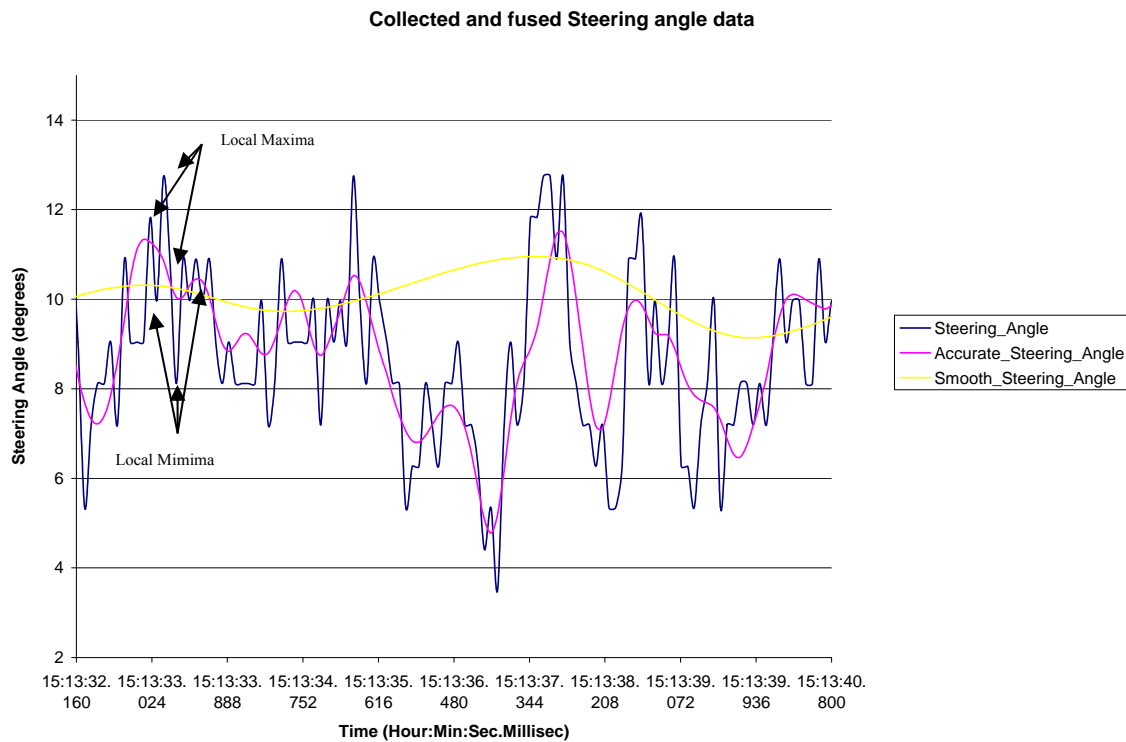
Figure 6: Steering angle, accurate steering angle, and smooth steering angle

The benefit of implementing this spline filter is that the filter is a general and characteristics independent. Meaning the data can be filtered without going through the mathematics for each data type. The implementation of Kalman filter requires input and state variables for the mathematical model for each data type and each data type has its own input and output dataset. For instance, the implementation of a Kalman filter for longitudinal acceleration requires steering angle, throttle angle, vehicle dynamics model, and velocity information if we want accurate output. This is a way too much computation

and theory behind yet the filter is only good for one type of data. If we want to filter another type of dataset, another filter needs to be implemented for the specific characteristics. The spline filter will get rid of the noises based on the available data. In other words, what the spline filter does is to smooth out the curve.

The key role on playing the spline curve is how we choose the control points and the weight factors for the control points from the dataset that we are interested to filter. In other words, we have to carefully select the control points and tune weight factors in order to get rid of the noise.
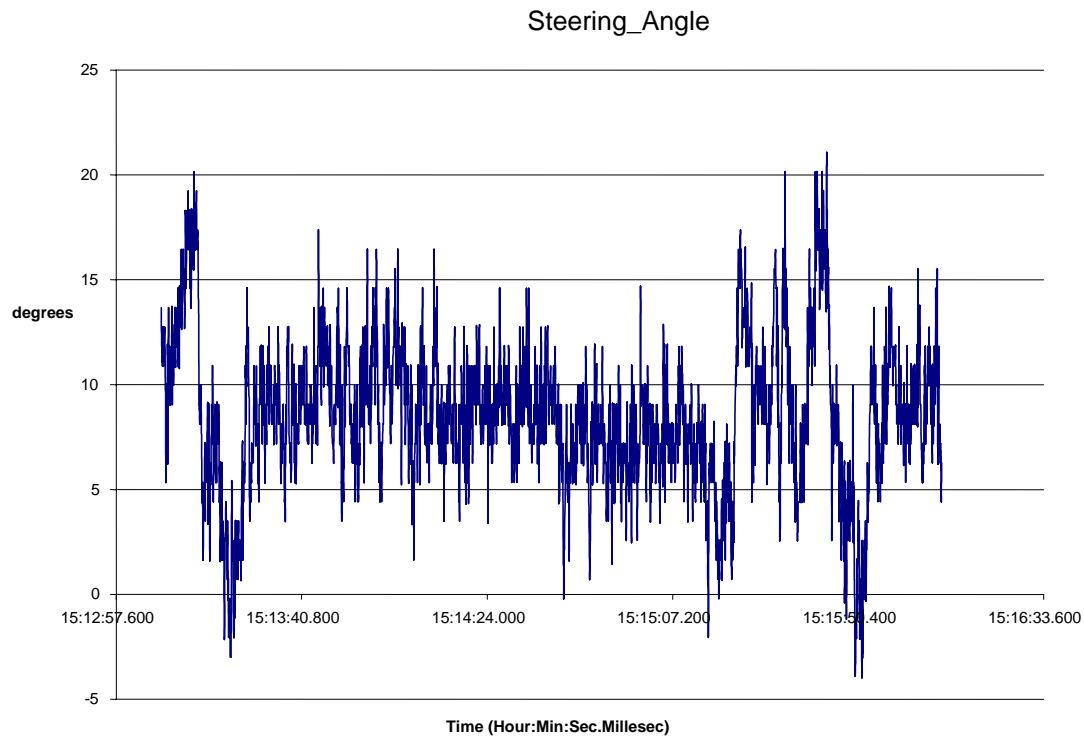
Figure 7: Raw steering angle data

In our implementation, the control points are determined based on local maxima and minima of the curve whenever there is a peak. Figure 6 shows an example on how the local maxima and minima are located. Since the maximas and minimas are alternated to each other and they are happening in the order of 10 milliseconds; as based on our knowledge that the drivers do not jerk the steering wheel so often, the occurrence of the local maximas and minimas are primarily caused by the noise. As a result, the control points for the spline curve are chosen by averaging a pair of local maximas and minimas. After the control points are defined, the Matlab cubic spline function CSAPS is used to calculate the spline curves.

Accurate_Steering_Angle
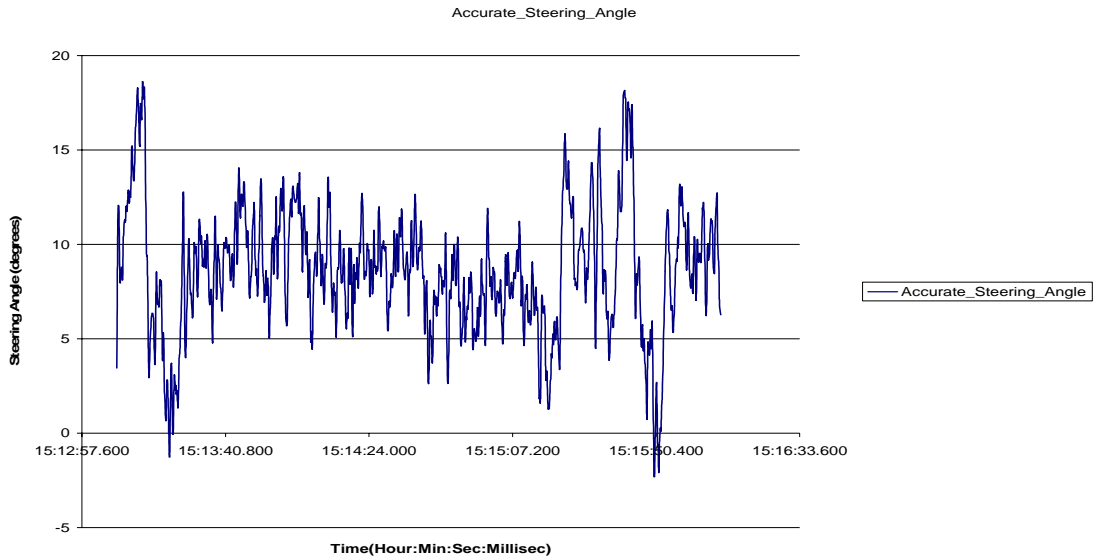
Figure 8: High detailed filtered steering angle data

Smooth_Steering_Angle
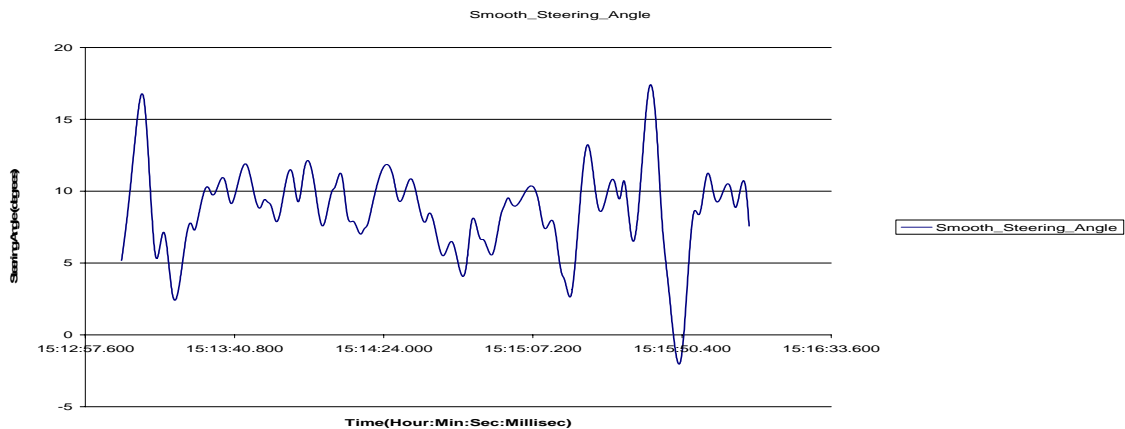
Figure 9: Low detailed filtered steering angle data.

The blue line shown in Figure 6: Steering angle, accurate steering angle, and smooth steering angle is the raw collected data from steering actuator. The purple line is the filtered data. The result is satisfactory from the filtering aspect and it cleans out significant amount of noise from the data. Comparing Figure 7 and Figure 8, it is obvious that the data shown on Figure 8 is shows less noise than the one in Figure 7. The filtered data keeps a high level of details on the steering angles serving engineering studies purpose. However, for the purposes of driver behavior studies, we need to have less noise and smoother data for matching what we observe from recorded videos. To solve this problem, we repeat the same filtering process on filtered data (Figure 8). It turns out that the second run filter data (shown on Figure 9) clears out all the noise and the curve is very smooth, which meets our expectations.

Data reduction

After data filtering, the next step is to solve multiple-detection-on-a-single-vehicle problem. First, we deal with the multiple-detection problem because of the radar detection. To solve this problem, we first need to examine the scenario to finger out the characteristics of the dataset respect to this problem. Theoretically, we use simple trigonometry to eliminate the extra dataset.

In the next two sections, we will discuss how we eliminate the addition dataset due to the multiple detections as we mentioned in previous section.

Multiple detection due to the nature of the radars

First, we look at the fault detection of the vehicles. Figure 7a and 7b show the definition of the parameters and a possible scenario for the multiple detections due to the nature of the radars.

a. Leading vehicle located in the same lane as the subject vehicle
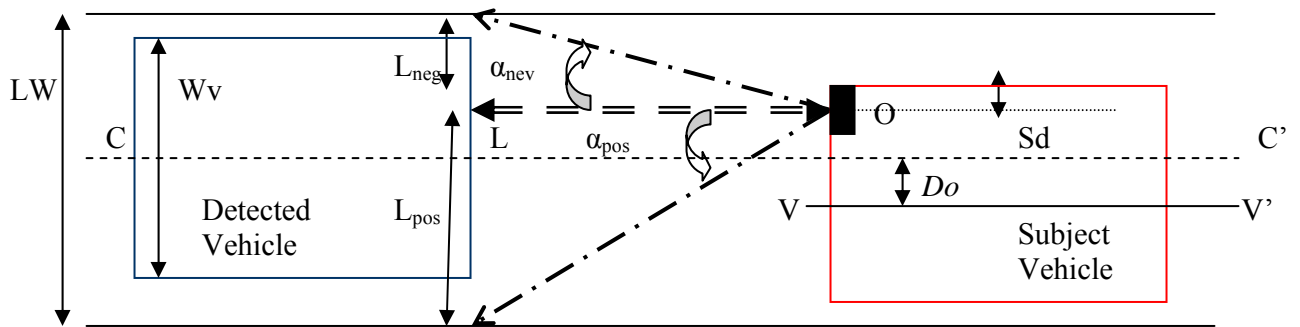
Figure 10: Basic parameter definitions

InFigure 10,

    Line CC' = the center line of the lane
    Line VV' = the center line of the vehicle
   Do = the lateral offset of the vehicle, value is taken from item 16 from the data above.
   Wv = Vehicle width, we assume it is 6 ft for all vehicles (including subject vehicle).
   LW = Lane width, value is taken from item 19 from the data above.
   Sd = The distance from the center of the subject vehicle to where the radar is installed
       = 2.8 ft
   Lneg = 0.5LW-Do-Sd;
   Lpos = 0.5LW+Do+Sd;
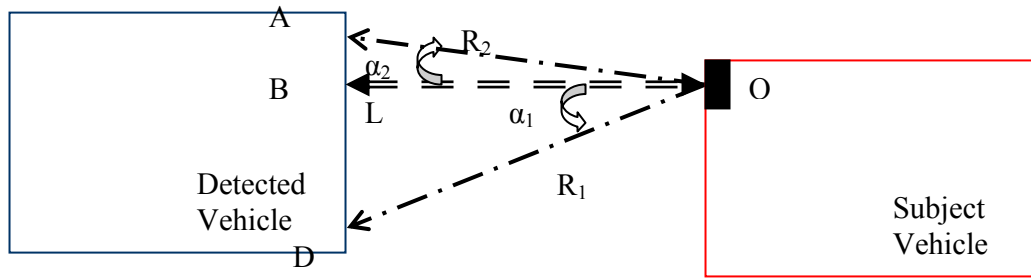
Figure 11: Method use to get rid of the multiple-detection data

In Figure 11,
Let
R = detected vehicle range
α = detected vehicle azimuth
=>
R_1 is the range in dataset 1 and R_2 is the range in dataset 2.
α_1 is the azimuth in dataset 1 and α_2 is the range in dataset 2.

Also,
R_1 is the hypotenuse of triangle OAB and $\alpha1$ is the angle between OA and OB.
$R2$ is the hypotenuse of triangle OBD and $\alpha1$ is the angle between OD and OB.
L is the length of OB, which is the absolute distance between the two vehicles.
$L = L_1 = R_1 * \cos(\alpha_1)$;
$\alpha_{neg} = \tan^{-1}(L_{neg}/L)$;
$\alpha_{pos} = \tan^{-1}(L_{pos}/L)$;

The following rules are used to determine whether dataset 1 and dataset 2 are the same vehicle when α_1 is within α_{neg} and α_{pos}. In other words, the following rules only work for the front leading vehicle.
Let $L_2 = R_2 * \cos(\alpha_2)$
If L_2 is within $L_1 \pm 10\%$ then
  If α_2 is negative and $\alpha_2 < \alpha_{neg}$ then
   The detected vehicles of dataset 1 and dataset 2 are the same vehicle
  Else if α_2 is positive and $\alpha_2 < \alpha_{pos}$ then
   The detected vehicles of dataset 1 and dataset 2 are the same vehicle
  Else
   The detected vehicles of dataset 1 and dataset 2 are different vehicles
  End
 Else
  The detected vehicles of dataset 1 and dataset 2 are different vehicles
End

b. Leading vehicle located in the adjacent lane to subject vehicle

For the detected vehicles on the adjacent lane, we could not detail calculations simply because we do not have sufficient data. Instead, we just compare the range, range rate, and azimuth. If the range, range rate, and azimuth are similar in two sets of data (within 10% of error range), then we determine the two sets of data are for a single vehicle.

c. Elimination of the addition set of dataset
When two sets of data contain the information for a single vehicle, we average out the numbers so that the noise is reduced. The two datasets will be removed and the averaged dataset will be written in our database. In addition to the original data types, we add a new macro to indicate the location of the detected vehicles.
The definition of the macro is
0 = front leading/rear following vehicles
1 = left front leading/ left rear following vehicles
2 = right front leading/right rear following vehicles
This examination is running in all radar files.

Multiple detection due to radars setup

The methods discussed above are used within a radar output file. After running through this data reduction, we solve the first part of the multiple detection problem describe above. Then, we need to deal with the second part of the problem; which is caused by radar settings.
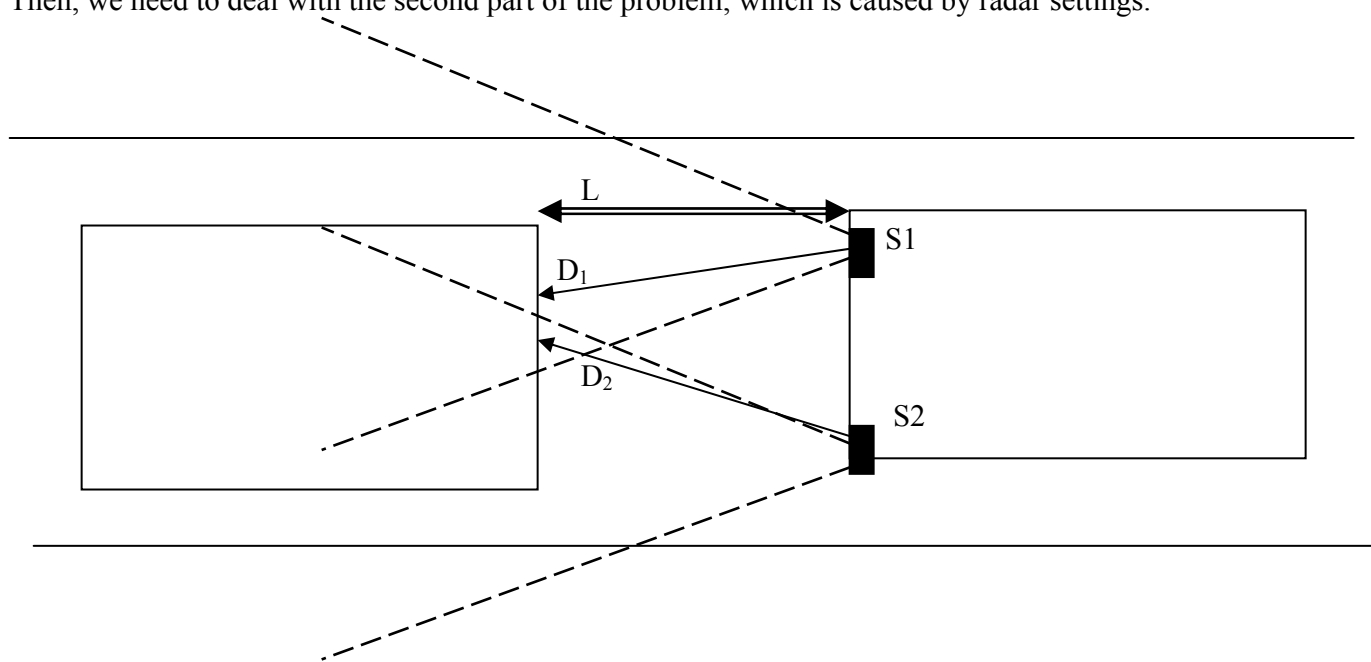
Figure 12: The scenario where the multiple-detection happens due to the setup of the radars

Two radars will detect the same vehicle only if when the vehicle falls into the range of both radars as indicated in Figure 12. As a result, only the front-leading and rear-following vehicles have this problem. The method for finding the same detected vehicles for the two radars is simple.

In Figure 12, S1 and S2 are the two front radars and the dash lines are their ranges.

Let
   D_1, consist of range R_1 and Azimuth α_1, is detection from S1.
   D_2, consist of range R_2 and Azimuth α_2, is detection from S2.
   (Please refer to Fig. 7b to see the definition of R_1 and α_1.)

   L is the true distance between the two vehicles.
   $L_1 = R_1*\cos(\alpha_1)$
   $L_2 = R_2*\cos(\alpha_2)$

  If L_1 is within the range of $L_2 \pm 5\%$ then
      $D_1 = D_2$
End

If the two detections are identical, then the dataset will be averaged out. If not, the dataset will be kept. In both cases, the dataset will be written into a new file. This examination is running with front pair and rear pair radars.

Below are examples of the raw data gathered by the two front radars.
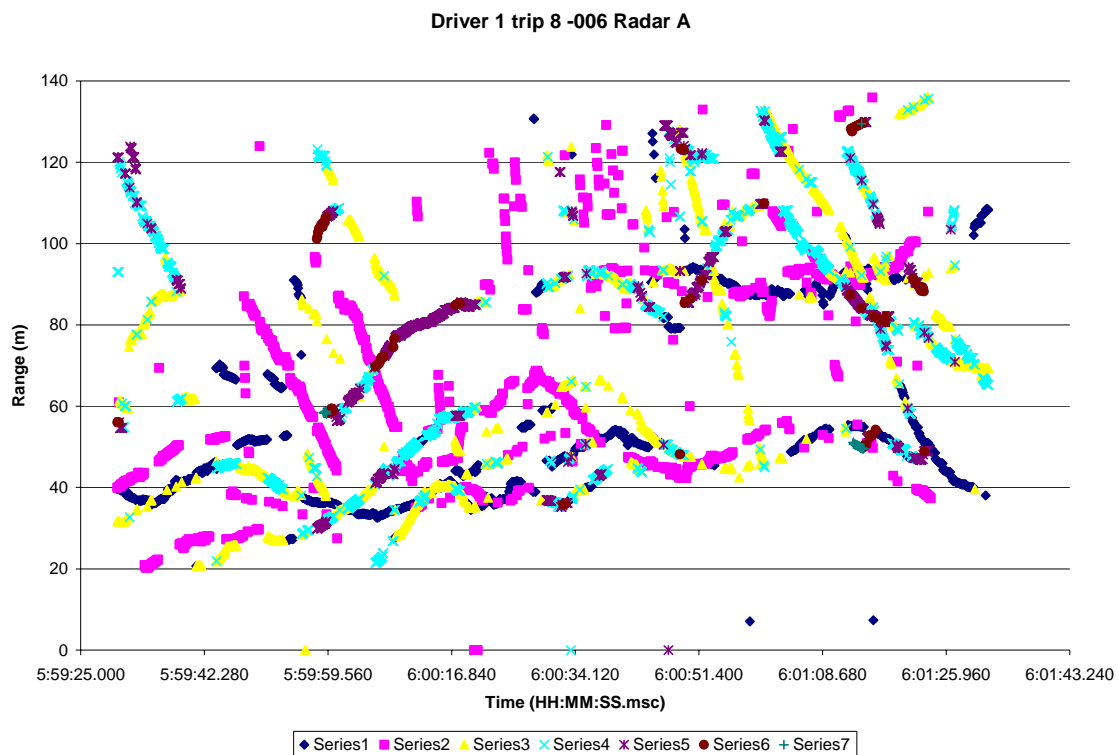
Figure 13: Front left radar raw data

Driver 1 trip 8 - 006 Radar B
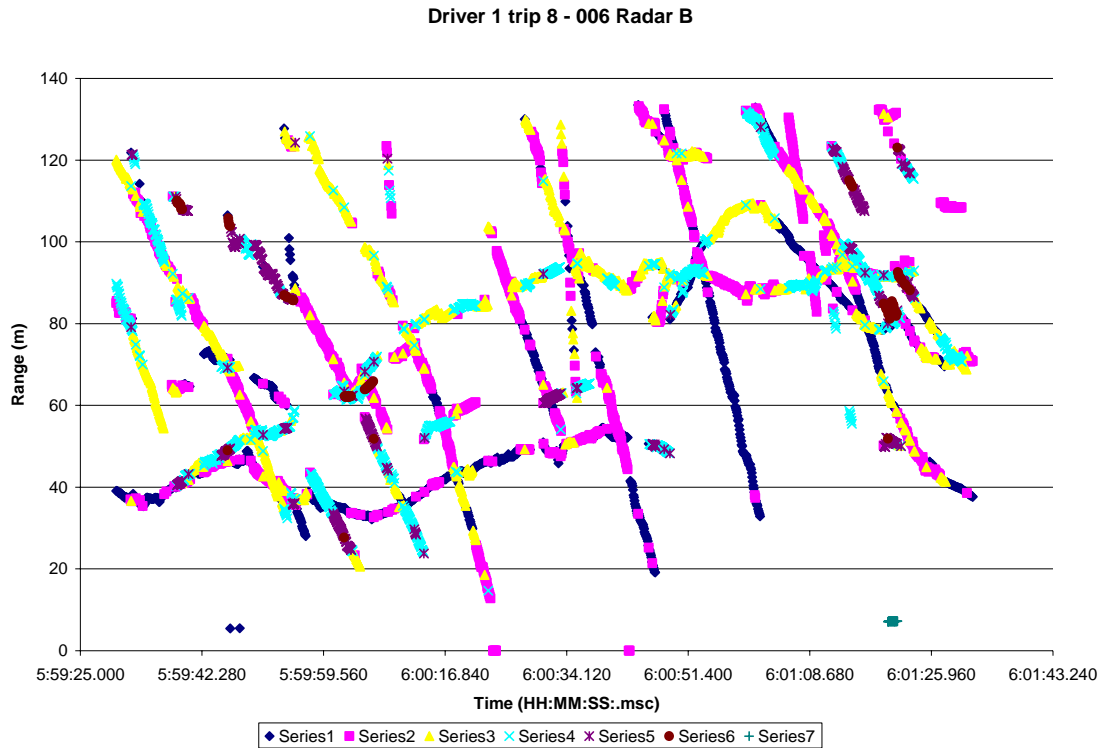
Figure 14: Front right radar raw data

Figure 13 and 14 illustrates the issues met for obtaining usable data. The reader can identify two "waves" that are almost horizontal and are vehicles in front of the Taurus and going at approximately a similar velocity. The other pattern is the long almost vertical lines, which are likely to be slower vehicles in the adjacent lanes or in some cases for radar A some on-coming traffic from the other side of the highway.

The other point of showing this graph is to illustrate one of the radar software functionality which consist of shifting the data for one target to different column when new targets are identified or existing target are lost. This leads to the need of reordering the data file before to be able to reduce the data. A plot of the reordered data combined for the two radars is shown below in Figure 15. This plot illustrates that even once the targets' IDs are reordered, a same vehicle is considered as different targets. The drops can usually be explained by the road geometry, when the Taurus is going through curves, then a target is lost and then reacquired or by vehicles movement that can create obstruction.

Driver 1 trip 08 -006 Radar AB vehicle ID sorted
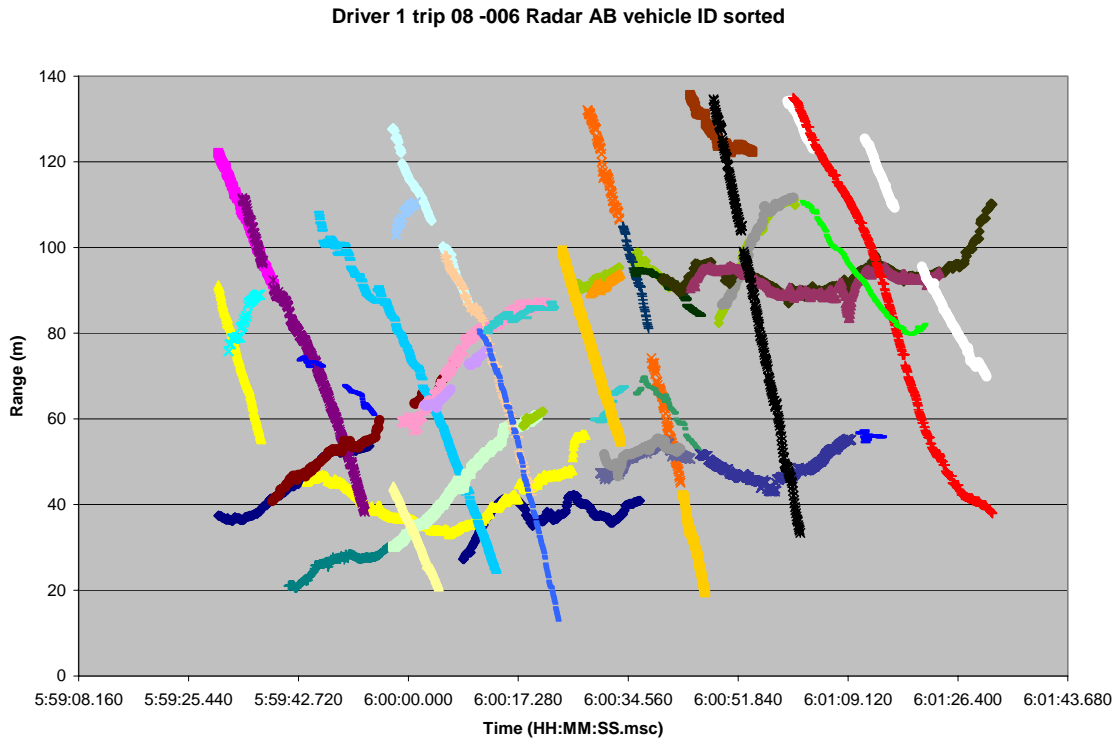
Figure 15: Re-ordered data for radar A and B

Figure 16 below illustrates the selection of vehicles that are in front of the Taurus. The next step is then to identify which vehicle is the one that is directly in front of the Taurus in the same lane. Two methods can be used for this: 1) use the azimuth provided by the radar, 2) watch the video and try to figure out which vehicle is closest and furthest. The limitation of using the azimuth are i) vehicles are moving within their lanes and that we do not know which part of the vehicle is detected, so it can be difficult to determine whether the vehicle is within the same trajectory or a parallel trajectory, ii) curves also bring a limitation to this method, iii) at long range, the difference of azimuth between two vehicle might not be sufficient to determine which one is in which lane. Watching the video is a satisfying method as long as there are not too many lanes and vehicles. For situations were there is more than three lanes and 6 vehicles visible on the video, it becomes difficult to assess which vehicle is where. In Figure 16 below, we illustrate the video method for identifying the lead vehicle and Figure 17 illustrates first trials for automatic selection. That case illustrates the need of constant verification of the data with the video. These issues with using the radar data were not foreseen before the data collection and led to considerable delay in the data processing.

Driver 1 trip 08 -006 Radar AB vehicle ID sorted lead vehicles
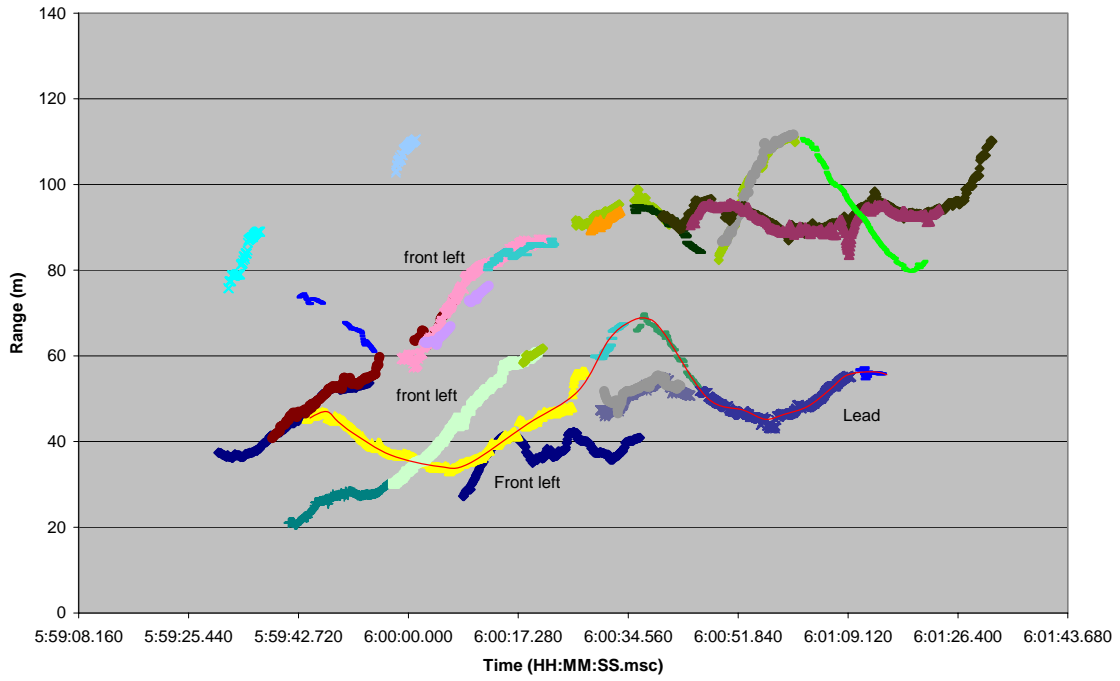
Figure 16: lead vehicles and lane position relative to Taurus

Driver 1 Trip 8 - 006
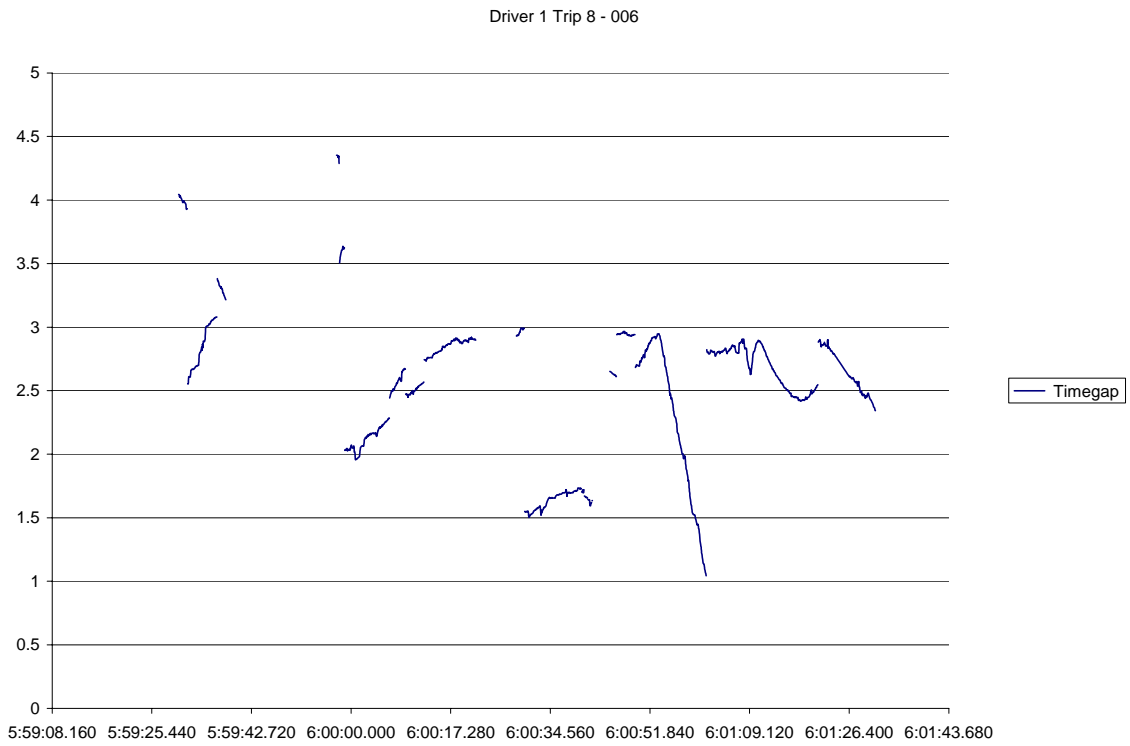
Figure 17: automatic selection of lead vehicle for computing time gap

Video Data coding

The video was watched and relevant events were coded using an in-house developed playback tool[1]. This playback tool allows creating driver behavior and driving situation description files that can be linked to the engineering files through a common time stamp on each file. Figure 18 below shows the interface of the software that was developed.
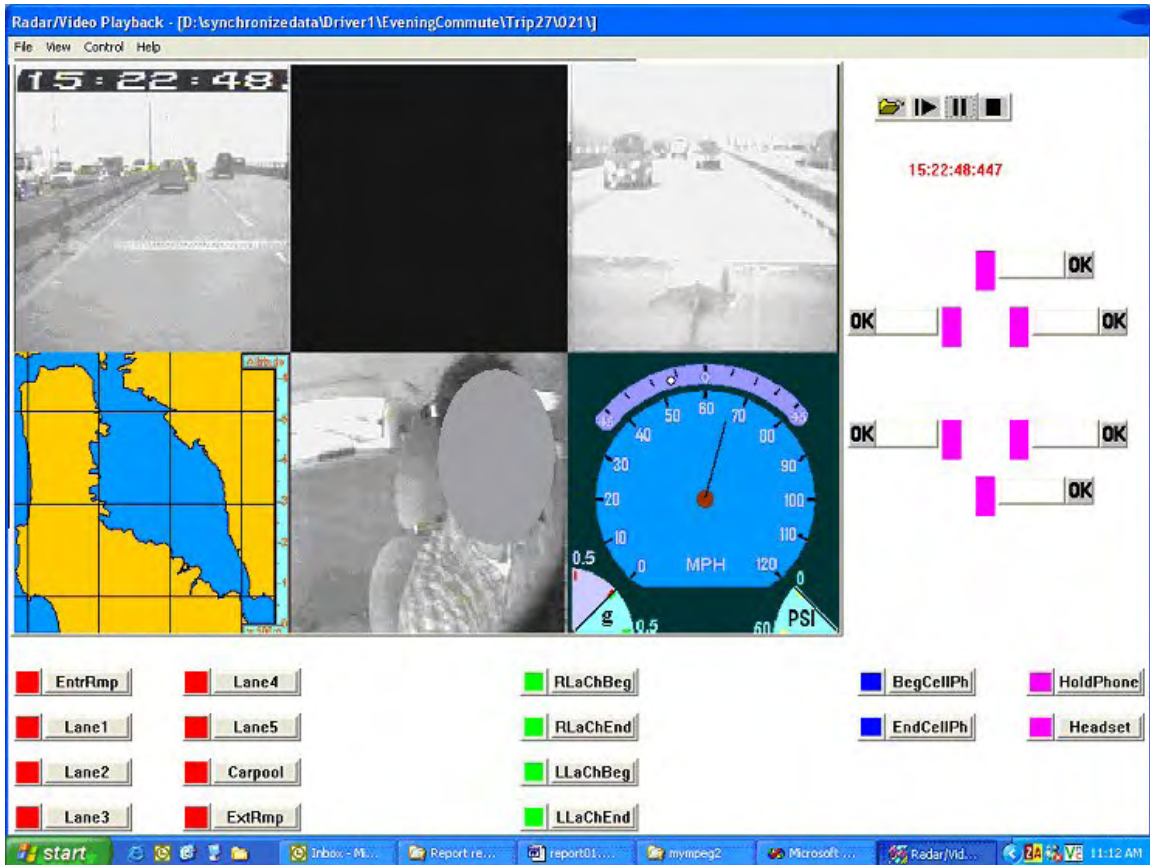
Figure 18: Snapshot of the data playback tool

The video window is composed of six different images. The top left image shows the front view, the middle is voluntarily left black as there is only three video image recorded. The top right image describes the rear view. The bottom left image is a map that would be used for displaying the GPS coordinate but that was not used for this coding. The middle image displays the driver's face. This was decided in order to ensure that the data that were analyzed corresponded to the driver who was given the vehicle and not to an acquaintance. This video does not allow performing eye movement coding because it was recorded at a rhythm of six frames per seconds, or every 166 ms, which is too slow for obtaining interesting data about eye scanning patterns. The bottom right

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[1] This software was developed by Natalia Kourjanskaia in the frame of TO 4223 - Development of a Vehicle Data Acquisition System for Naturalistic Driving Data Collection. The base of the software was provided by Xiqin Wang who developed a viewing tool in the frame of project.

image displays some of the engineering data, the speed in mph, the steering angle in degrees, and the throttle and brake use.

Under the video window is a set of buttons that are used for coding. These elements are grouped by categories. For example, in the snapshot in Figure 18, the coding is about driver behavior. There are four categories: driver's position on the highway, lane change behavior, cell phone used and cell phone type. Each of these categories contains several items, exclusive of each other. For example, in the first category, driver is either on lane 1 or 2 but cannot be on both lanes at once. Because of all of the information we gathered through the video analysis, each trip was watched twice. One watching goal was to code driver behavior during the driving, and the other one was to describe the surrounding driving scene. The list of elements manually coded is presented below for each coding.

Table 1: Driver behavior description

Category and item name	Item description
Driver's position on highway	
Entrance Ramp	driver is on entrance ramp
Lane1	driver is on 1st lane starting from the right side of the road
Lane2	driver is on 2nd lane starting from the right side of the road
Lane3	driver is on 3rd lane starting from the right side of the road
Lane4	driver is on 4th lane starting from the right side of the road
Lane5	driver is on 5th lane starting from the right side of the road
Carpool	driver is on carpool lane
Exit Ramp	driver is on exit ramp
Lane change behavior	
Right Lane Change Begin	driver initiate lane change to the right
Right Lane Change End	lane change to the right is done
Left Lane Change Begin	driver initiate lane change to the left
Left Lane Change End	lane change to the left is done
Cell phone use	
Begin Cell Phone	driver starts a cell phone
End Cell Phone	driver is done with the cell phone
Cell phone type	
Handheld	Driver uses a handheld phone
Headset	Driver uses a headset and therefore does not hold the phone

Table 2: Driving situation description

Category and item name	Description
Level of traffic	
Free Flow	free space around the driver
Heavy	all of the lanes are full but traffic is still moving
Congested	all of the lanes are full and slow speed (below 40 mph)
Type of environment	
Rural	
Highway	
Urban	
Number of lanes	
2lanes	
3lanes	
4lanes	
5lanes	
Specific infrastructure	
Entrance	
Exit	
Merge	
Split	
No Specific Infra	
Carpool status	
Carpool on	
Carpool off	
No Carpool	

Results and integration of data to model

An enormous amount of data has been collected and the biggest challenge is to extract the relevant information that can be used for supporting the model development. The data to extract for supporting the development of the model is:

- strategic module
  - driver representation of the itinerary: identification of the landmark that the driver uses for initiating a new sub-schemas
  - driver's preferences: identification of the driver desired speed, preferred lane when driving on the highway
- tactical module
  - refinement of sub-schemas
  - verification of the perception model develop in MOU 369 with real data for calibration of the car following sub-schema

The data supporting the development of the strategic module are the verbalization that the driver produced while watching their trip and the written description of their commute. These data are used to analyze the driver representation of the trip. In order to identify the driver's preference, we also use the observation of lane position and speed when no lead in front of the vehicle. The data supporting the tactical module are the engineering data about the vehicle motion as well as the radar data. The development of each module with the data is presented below.

Development of strategic module

The analysis of the driver description of its itinerary will be presented and the data extracted in order to create an itinerary file as described in the presentation of the strategic module in the first section of this report.

<u>Analysis of itinerary representation</u>

Drivers were requested to provide a description of their trip the way they would give instruction to a friend visiting them and would have to join them. Below is the written description provided by driver 1 for his morning commute (see appendix for the evening commute and driver 2 morning and evening commute).

> *"Depending on where you are parked, if you are parked downhill, drive to castle street. Make right turn until you hit hillside blvd. If parked uphill make left turn onto price and drive until you hit hillside. Either way, drive down on hillside until you see 7-11. Make right turn (should be eastside). Pass a stop sign you'll see Mission St. Go straight, you'll see Walgreen's on right. Continue straight until you see the 76 gas station. Make left. After turn, stay on the far right lane for on ramp to 280 S On the on ramp, stay on the left side, this will take you to 280 S. (Not Hwy 1).*

Continue on 280 and exit 380 interchange to get on 101 S. Continue on 101 until you see 3rd street in San Mateo. Start moving to the right lanes. You want to take the 92 E towards Hayward. Proceed on 92 to cross over the San Mateo Bridge. After the bridge stay on the left lane.

92 will change to jackson st and end in Hayward. Continue straight on the left lane. Make left on watkins. Go 2 blocks. On the third block, make a right into the 2 story parking structure. Parking is free, so park whenever. I usually park on the second floor.

Cross the street and you should see the City hall (777 "B" St). I'll meet you in the Lobby"

We identified four sections in the commute:
1. Going from home to the highway,
2. Driving on the highway,
3. Getting off the highway
4. Getting from the parking structure to his office.

Note that street's name are given from home to the highway, as well as store's as landmarks, while on the third section there is a notion of block introduced and not as many landmark. For our modeling effort, our interest is focused on the highway section. We split this section further in eight sections[2] and describe the geometry that we could observe from the video.

- Entrance: Two lanes, split into two directions, one lane, another lane merge onto it from the right before to reach the highway, one lane when reach highway
- cruise_1: entrance merges onto 4 lane highway
- ramp_1: 2 lanes
- merge1: ramp_1 merges from the left onto two lanes highway
- ramp_2: two lane ramp
- cruise_2: ramp_2 merges on the right of a four lane highway, its right lane turns into a fifth lane which will be dropped
- ramp_3: 2 lane ramp
- cruise_3: ramp_3 merges with one lane to the right and turns into a 3 lane highway which will turn onto a 2 lanes highway.

We merged the eight sections with the written descriptions of the itinerary and the data collected during the verbalization while watching the video for Trip 5:
- Entrance: *After turn, stay on the far right lane for on ramp to 280 S)[3] On the on ramp, stay on the left side, this will take you to 280 S. (Not Hwy 1)*

---

[2] see Annex for description of sections with pictures marking the beginning and end of each section
[3] This still relates to the surface street direction

- cruise_1: *Continue on 280 <u>the choice of changing lane to prepare for the exit depends of the density of vehicles on the right lane, if there is not much space between the vehicles, than he will go onto right lane earlier and will wait for going onto the right lane if there is a lot of space between the vehicles</u>*
- ramp_1: *exit 380 interchange*
- merge1: *to get on 101 S*
- ramp_2
- cruise_2: *Continue on 101 until you see 3rd street in San Mateo. Start moving to the right lanes You want to take the 92 E towards Hayward*
- ramp_3
- cruise_3: *Proceed on 92 to cross over the San Mateo Bridge. After the bridge stay on the left lane. 92 will change to Jackson St and end in Hayward. UU<u>Stays on left lane behind the truck because cars merge onto the right lane (right at the beginning of this section)</u>*

Table 3: Itinerary file

Route name	Landmark	Action/subschema	Lane index
Surface street	after turn	Cruise	Far right lane
Entrance ramp 280 S	On ramp	Entrance	Left lane
280 S		Cruise	Middle lane
280 S	380 interchange	Exit	Left lane
380 interchange	Sign for 101 S	Exit	One lane
101 S		Cruise	Middle lane
101 S	Sign for 3rd street in San Mateo	Initiate Exit	Right lanes
101 S	Sign for 92 E	Take exit	Left lane
92 E		Cruise	Right lane
Surface street	After bridge		Left lane

The itinerary file that can be created with the description does not contain all of the sub-schemas that are necessary for carrying on the driving activity. For example, there is no indication of how to enter with ramp 2. This indicates the level of controlled attention given to the sub-schema. In other word, ramp 2 is a tactical subschema that is conducted in automatic mode. Hence, it is necessary to take the itinerary file and integrate the non described subschema to obtain a smooth behavior when running simulations.

As a side note, in order to describe the sections, we initially used the GPS data. The GPS we used was not differential and it turned out that the error was too big for using it in order to identify the trip sections in the engineering file. Therefore, we computed the length of each section for each trip based on at the time the driver went through a specific point in the environment identified from the video. This method was slower than using GPS and here the error is within a 100 meters on section that are 6000 meters long (see table below). The interest of creating a data distance is that then the data of different trip can be plotted together.

Table 4: length of highway sections per trip (in meters)

Trip	entrance	cruise_1	ramp_1	merge1	ramp_2	cruise_2	ramp_3	cruise_3
5	909.5707	6249.275	855.2647	1515.739	1573.516	12191.14	1222.927	21051.87
8	163.6294	10189.51	906.0379	1522.394	1557.005	12131.86	1265.166	21037.69
12	852.114	6324.405	752.5105	1624.533	1591.794	12137.27	1147.855	21157.54
23	663.4613	6316.69	848.8812	1526.594	1576.492	12153.92	1132.526	21132.18
26	848.9773	6298.297	765.4934	1659.998	1609.803	12109.03	1258.957	21011.82
30	861.971	6335.465	756.4275	1622.763	1542.639	12188.01	1192.815	21069.79
33	NA	10822.43	856.359	1517.508	1594.142	12153.66	1203.094	21076.7
37	156.3189	10175.08	871.5259	1527.459	1585.062	12183.73	1194.753	21025.82

This method becomes relevant for the refinement of subschema as we can observe one driver in the same environment with different traffic condition, as will be illustrated in the sub-schema refinement section below.

UDrivers preferences

In order to identify drivers' preference, we used the data collected via the video coding. The table below illustrates driver 1 consistent choice on ramp 3 where whatever the traffic in front or behind is, he chooses the left lane.

Table 5: Driver 1 lane position for each trip on ramp 3

Driver	trip	on-ramp3	lead vehicle	rear vehicle
1	5	left lane	yes	no until shortly before the end of the ramp
1	12	left lane	yes	no
1	26	left lane	yes	yes (tailgate)
1	30	left lane	yes	yes
1	23	left lane	yes	yes
1	8	left lane	no	no
1	33	left lane	yes	yes
1	37	left lane	yes	no

The two figures below illustrate the speed and the steering angle for all of these commutes. Trip 8 is the only without a lead and apparently the driver waited longer before to slow down than when he is following a lead. The presence/absence of traffic does not seem to influence the choice of the driver relative the lane choice. The rational underlying is choice is that the right lane merges with another road, therefore, we can extend that when this driver knows that there is a merge involving several lane, he will avoid the lane which are merging.

Speed on ramp 3 for driver 1 Morning commute
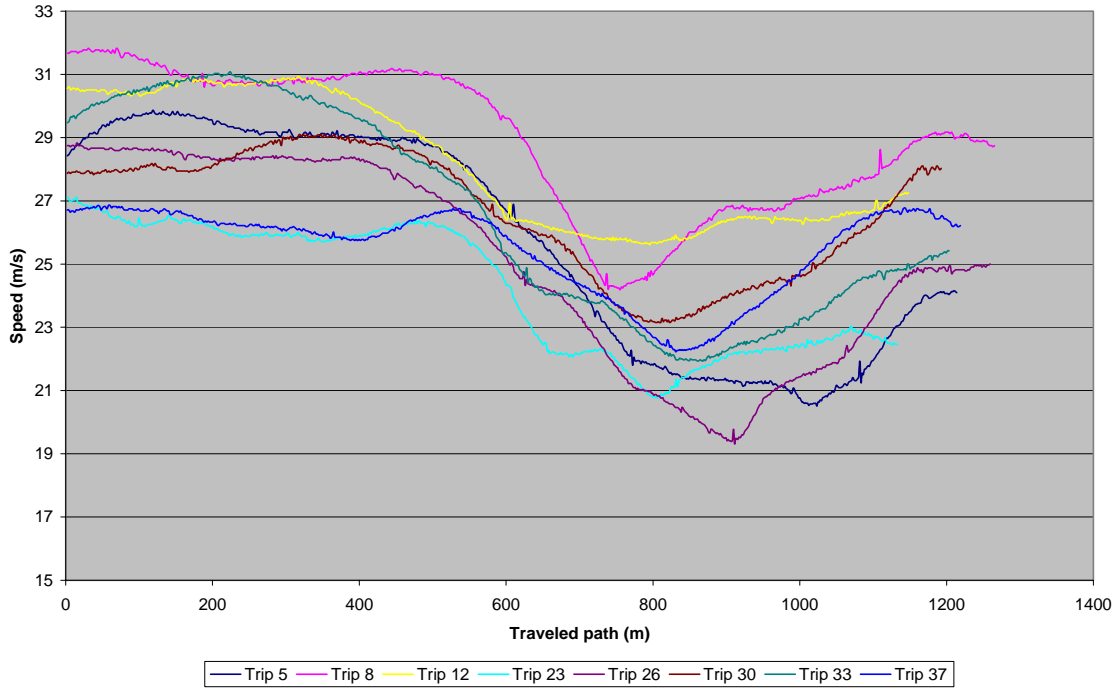
Figure 19: Speed on ramp 3

Steering angle for driver 1 on ramp 3 morning commute
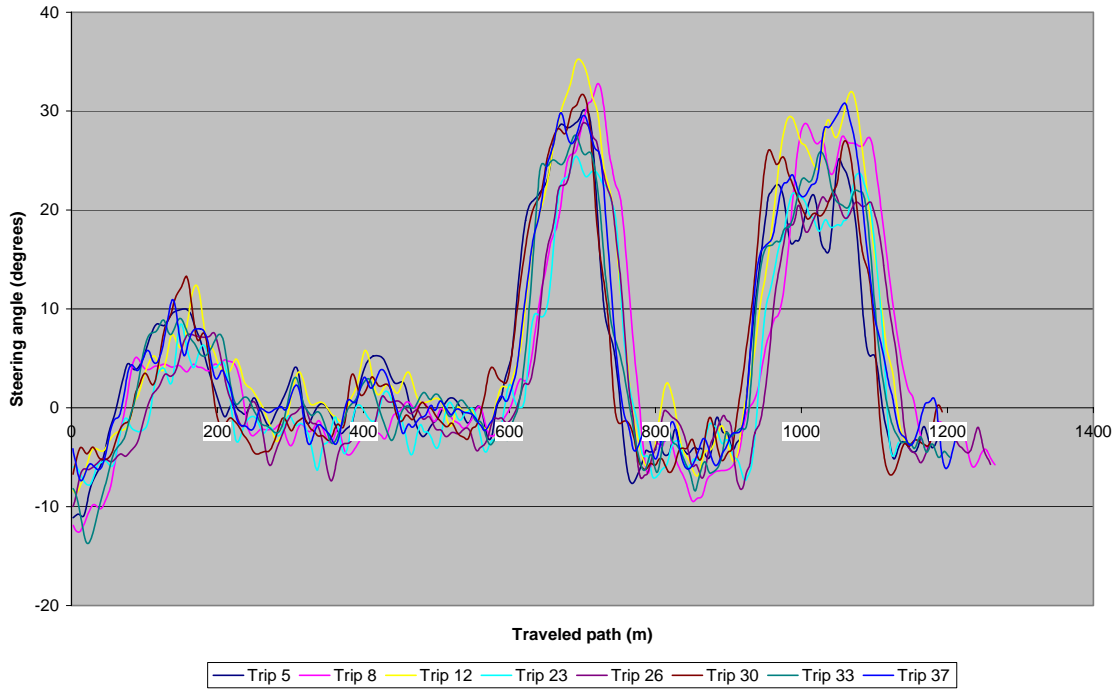
Figure 20: Steering angle on ramp 3

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Tactical module

In order to illustrate how the data support the development of the tactical module, we will expose the method used for proceeding to the sub-schema refinement in terms of local goals and detail the car-following subschema validation.

Sub-schema refinement

The method is very similar that the one used for extracting driver preferences. Here also we bring together the engineering data and the data obtained from watching the video. This data is presented in the table and figures below.

Table 6: Driver 1 entrance morning commute, front and rear traffic

Trip	Lead vehicle	Rear vehicle
5	2 and 3	?
12	1	1
26	2	None at the beginning and one from the second access to the entrance
30	1	1 at the beginning but goes on the right lane

Velocity - Entrance - Morning Commute - Driver 1
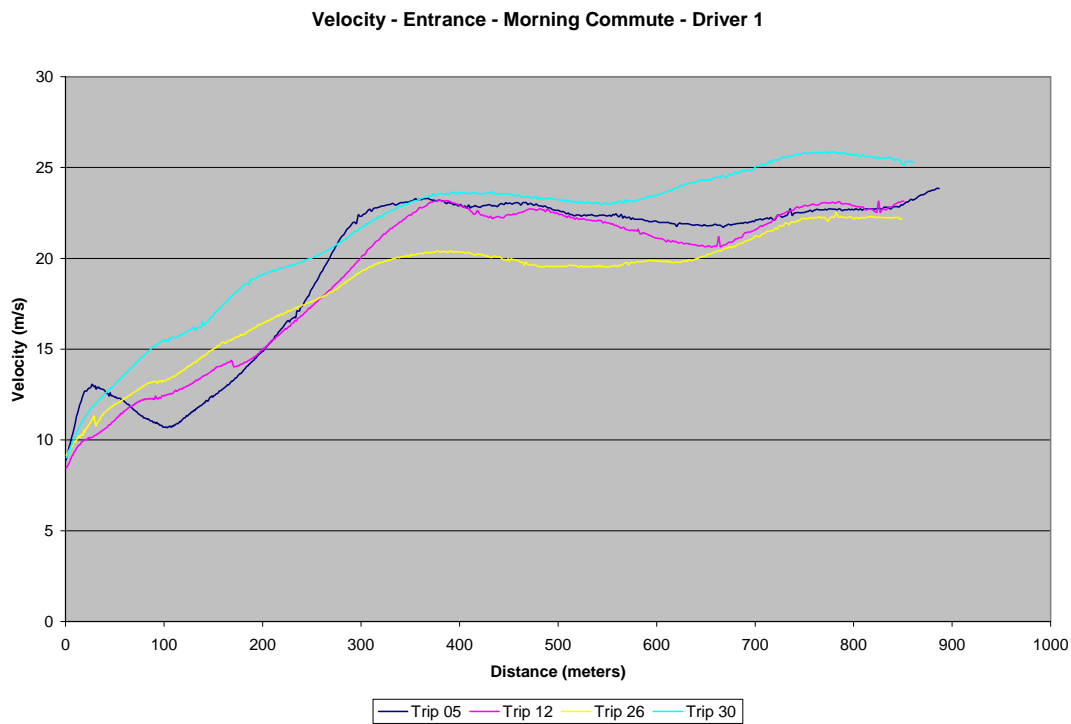
Figure 21: Driver 1 Velocity Entrance morning commute

Following the logic described in chapter 1, we can determine that the entrance can be split in two zones:
1. from the entrance up to 300/370 meters, acceleration to reach "entrance speed", (between 20 and 25 m/s)

2. from 300/370, maintain entrance speed

Entrance - Morning commute driver 1
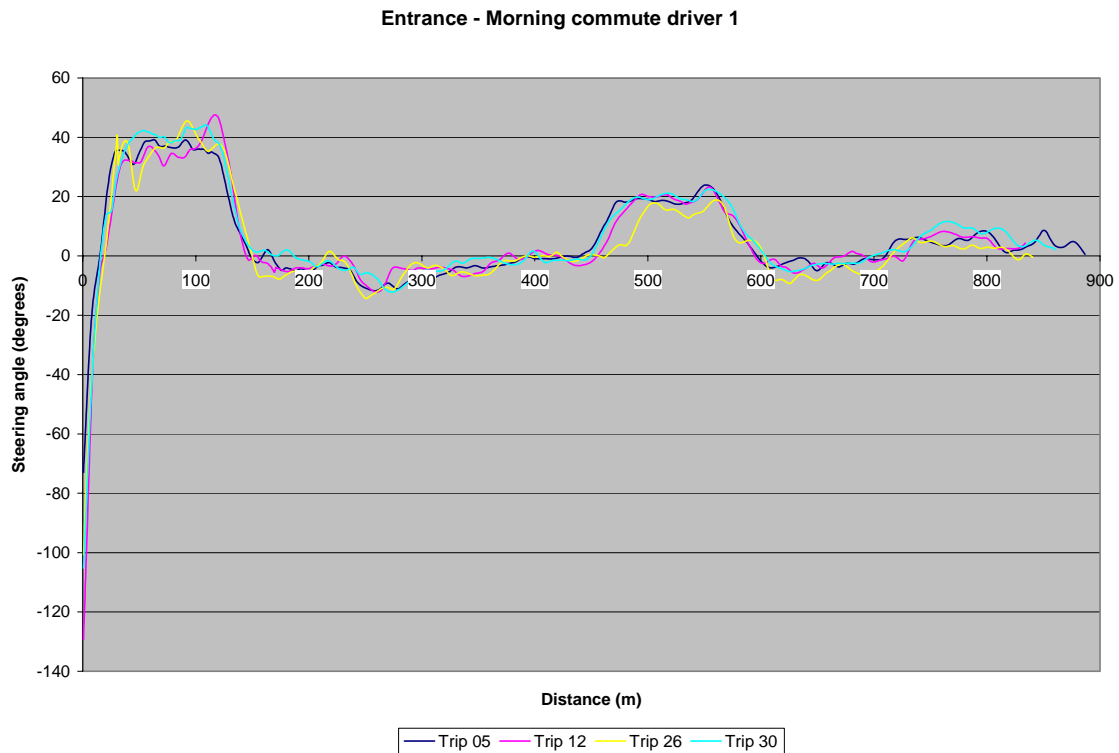
Figure 22: Driver 1 Steering angle Entrance morning commute

Cruising and following.

For each of these sections, we identified car following sequences in the following categories:
- Beginning of following
  - o SV catches up with target
  - o Lead moves in SV lane
- End of following
  - o SV moves out of the lane
  - o Lead moves out of the lane

We also identified specific situations, such as
- Transition: Front vehicle changes lane and transitions in front of POV and changes lane again.

Below are plots illustrating these cases and the explanation about how we use this data for the model.

SV catches up with a slower vehicle and regulate time gap

Range Rate VS Time Gap
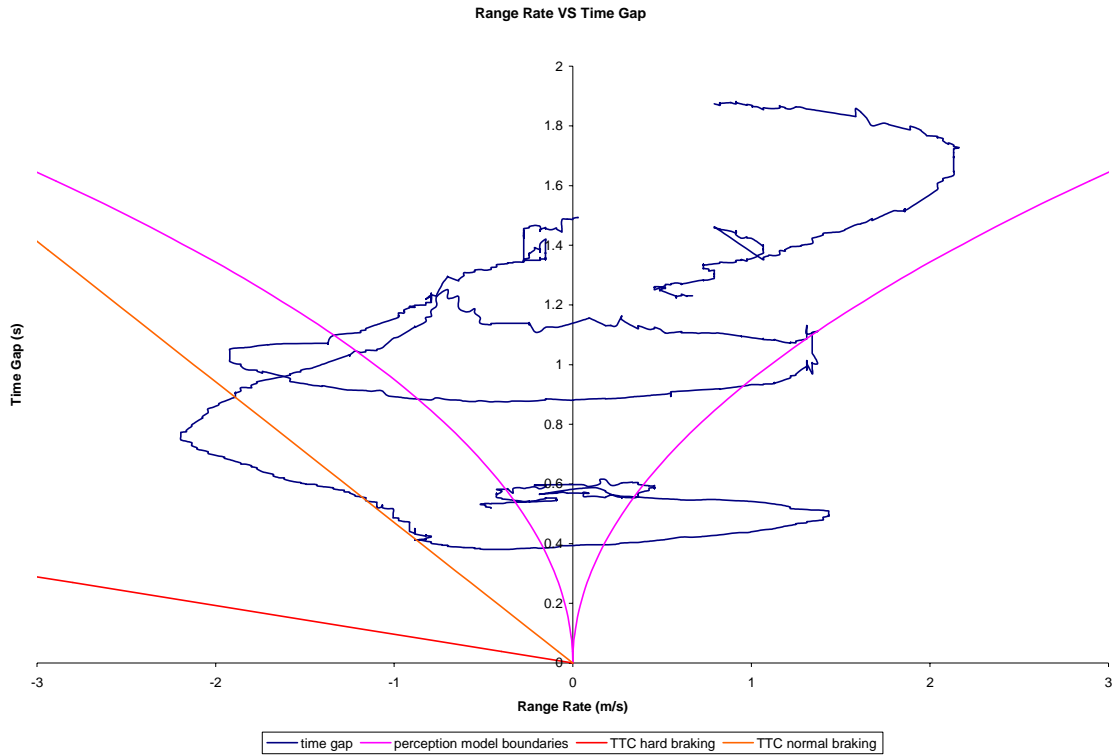
Figure 23: Time gap regulation with front target

Range and Speed VS Time
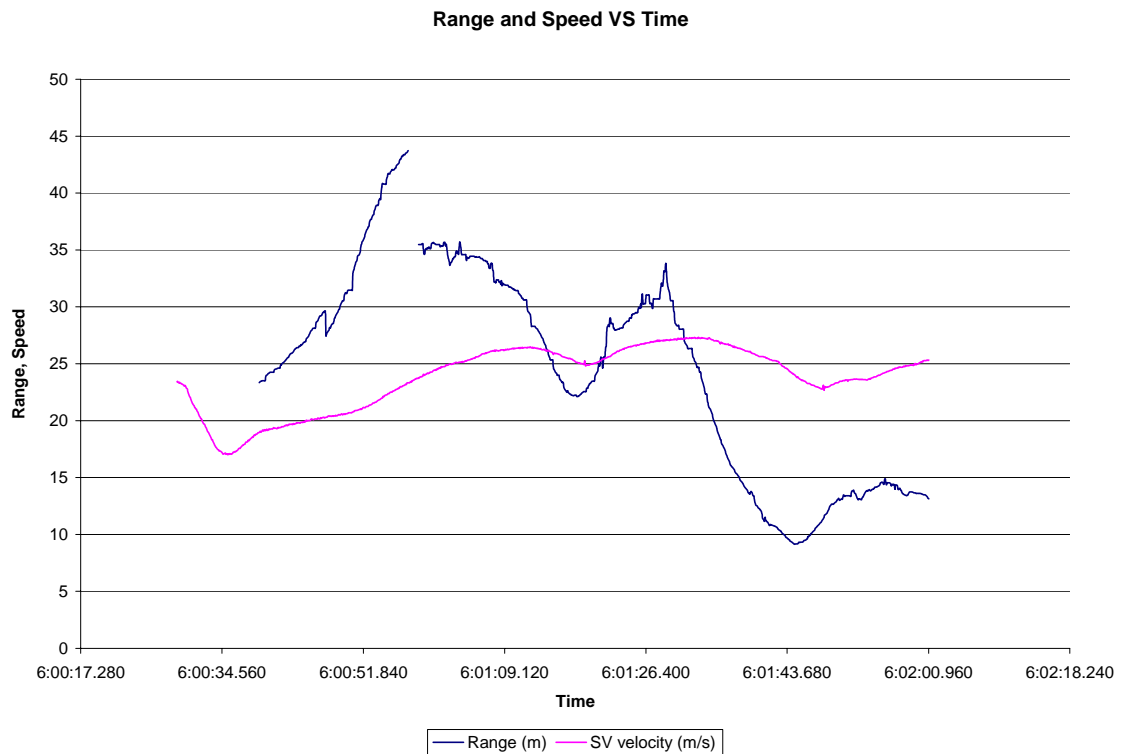
Figure 24: range with lead vehicle and subject speed

In Figure 23, we can see that the regulation follows the boundaries of the perception model. We also see two regulation of time gap, the first one happens at about 0.9, and we will associate this as a following regulation, the second one happens at 0.4 seconds, and we associate this regulation to a waiting for a lane change as this following episode ended with the driver changing lane to the right. Figure 24 allows seeing that the driver intended to keep his speed as much as possible prior to the lane change. Once all of the data is processed, we will compute distribution of the point where the time gap is regulated as a function of these categories.
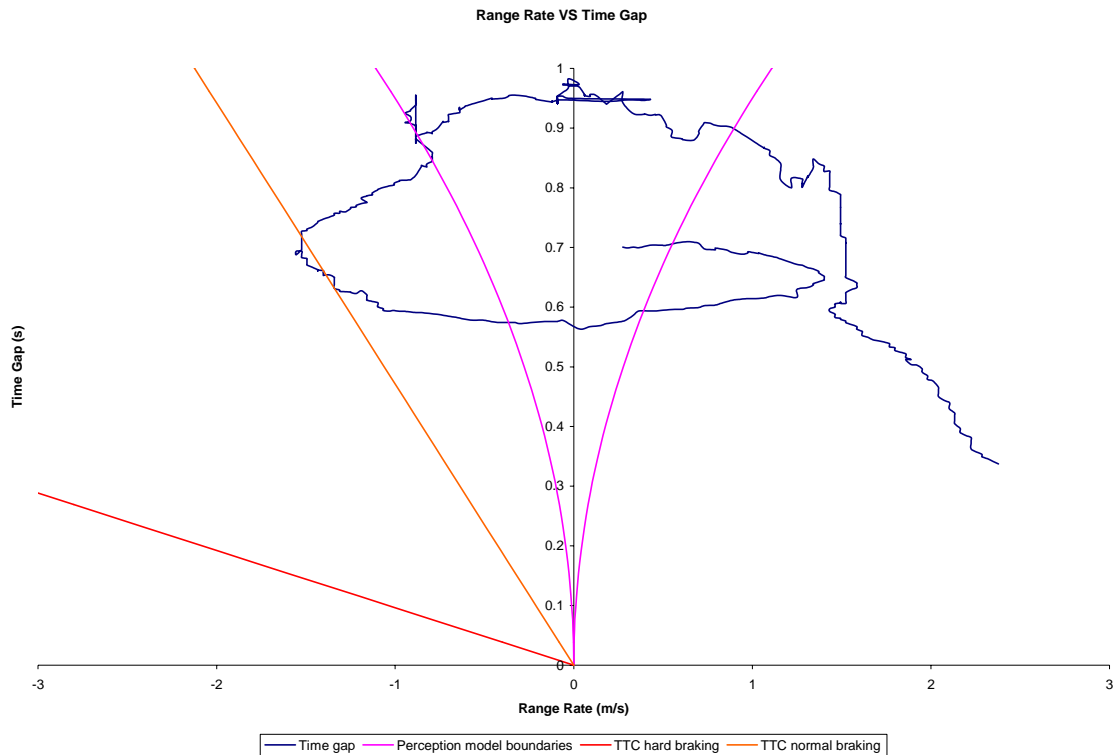
Figure 25: Time gap regulation for cut-in by faster lead

In Figure 25, we can see the time gap regulation with a faster lead that cuts in front of the subject vehicle. The following episode starts on the right of the graph. As the lead goes faster initially, the driver does not have to regulate speed for the time gap to go back in a comfortable region, but then the lead slows down and the subject has to regulate speed in order to maintain a minimum gap (see figure 26). The event finished with the lead changing lane, which is what we call a transition. The next step for this processing is to measure how the driver regulate the speed (strength of the deceleration, use of brake pedal or coast) for these different situations and integrate it to the sub-schemas.

Range and Speed VS Time
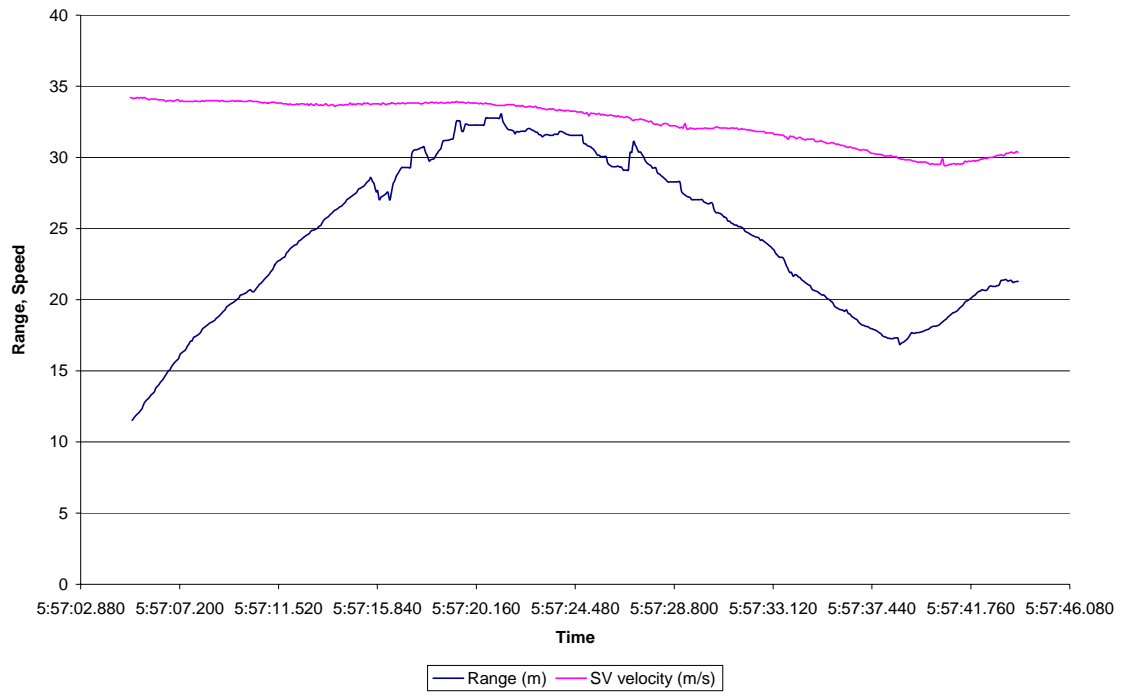
Conclusion

In this report we demonstrated the efficiency of the method that we use for developing the driver model. This method consist of assembling information available in the literature in order to describe the cognitive and perceptive processes underlying driving, and when necessary, collecting data in order to fill in the blank when literature does not cover aspects necessary for the development of the model.

The next steps of this model development include:
- The continuation of the data analysis and integration within the model for car following
- The integration of the lane change maneuver, including further data collection on lane change nearby exit and entrances
- The integration of the driver impairment and emergency management
- The development of simulation world for use by a wider public.

Appendix

Log book

Trip number: Date: Beginning Time:
                                                          End time:

How familiar is this trip to you?

How familiar is this trip to you?

Not familiar   1   2   3   4   5   very
familiar

How frequently do you perform this trip?

   Several   Daily   Weekly   Monthly   A few time a   First time
times a day   year

Did you have to be at your destination at a specific time?   yes   no

        If yes, did you make it on time? yes   no
             If no, how late were you?
Passenger present: yes   no

Stops:

Incidents, events during this trip:

Informed Consent for Naturalistic Driving Collection

My name is Delphine Delorme. I am a researcher at the California PATH program, part of the University of California at Berkeley, under the direction of Prof. Karl Hedrick. I would appreciate your participation in my research study on driving behavior. The aim of this research is to collect data about the way a person drives in a familiar or non-familiar environment and see how this influences his/her control of the vehicle in real traffic.

You will be asked to come to my office at UC Berkeley's Richmond Field Station on a weekday between 9:00 a.m. and 5:00 p.m. There we will show you the instrumented vehicle that you will use and the "debriefing form" that you will have to complete at the end of each trip while using this vehicle. This form concerns mainly your familiarity with the trip you will have just taken and will not contain any personal motivation or the name of a specific location. You will drive in your normal manner, as our intent is to better understand actual driver behavior. The other people who would normally be in your car can be in this car as well, the only condition being that you remain the only driver. If you accept to participate to the experiment, we will make an appointment and deliver the instrumented vehicle to your home. The introduction to the vehicle can be repeated if you wish at this time. Caltrans will take all of the cost associated to the use of the vehicle in charge, i.e., insurance, gasoline, emergency repairs, road side service and so on.

About a week after completing the driving session, and after a first processing of the collected data, I will ask you to come back to my office in order to proceed to an interview. The goal of this interview will be to gather information about the strategies you developed when driving on your commute (do you have a favorite lane, at which part of the commute, why and so on). This interview should last between two and four hours. I will record our interview in order to facilitate my analysis.

If you agree to take part in the research, I will ask permission to inspect your driving record. I will look only for information about moving violations less than six years old and Driving Under the Influence (DUI).

There is no direct benefit to you from the research. I hope that the research will benefit society by improving our knowledge about driver behavior and using this knowledge to improve the development of advanced transportation concepts and prototypes.

All of the information that I obtain about you during the research will be kept confidential. I will not use your name or identifying information in any reports of my research. I will protect your identity and the information I collect from you to the full extent of the law (this does not include subpoena). Should you be involved in an accident while driving the study car, the videotapes taken may be subpoenaed as evidence.

After this project is completed, I may make the data collected during your participation available to other researchers or use the data in other research projects of my own. If so, I will

continue to take the same precautions to preserve your identity from disclosure. Your identity will not be released to other researchers.

I will pay you a total of $145 for your participation in installments of $10 per day of participation and $5 for the half day of the interview.

If you are injured as a result of taking part in this study, care will be available to you. The costs of this care may be covered by the University of California depending on a number of factors. If you have any questions regarding this assurance, you may consult the Committee for Protection of Human Subjects, 101 Wheeler Hall, University of California, Berkeley, CA 94720-1340, 510-642-7461.

Your participation in this research is voluntary. You are free to refuse to take part, and you may stop taking part at any time.

If you have any questions about the research, you may call me, Delphine Delorme, at (510) 231-9455.

I have read this consent form. I agree to take part in the research.

Signature   Date

Evening commute Driver 1

"Exit the parking structure on to Watkins side (west side exit). Make a left turn. Go 2 blocks and make a right onto Jackson. Go straight on Jackson; it will turn into 92 west. At the toll gate I usually stay on the second lane from the left, but if you don't have Fastrack, don't worry, any lane will do.

Cross the bridge and stay on your right lane. You will want to take the 101N exit towards San Francisco. Traffic here gets heavy here around 5 pm so leave before 4 if you can help it. Stay on 101 and take the 380 interchange. This will take you to 280 N. The 380 interchange can be tricky, stay left on the skyway, get to one lane left after interchange. This will take you to 280N w/o being forced to exit.

Continue on 280 until you see the mission st exit. Take that exit, it's a long off ramp. Get to the left lane once you get the chance. At the intersection, take the middle lane. Make a left turn and stay on the far right lane. Make a right onto San Pablo (Albertson on right side). Go straight until you see Mission st. Take the middle lane at the intersection for a left turn onto Mission. Drive on Mission for one block, make right on Castle (kragen). Go straight for a few blocks (2 stop signs). Make a left turn onto Abbot Ave. Park closer to the top of the block.

If you decide to go to the gym, you would continue on 101 N Towards S.F.; don't take the 380 interchange. Continue on 101 until you see the Vermont exit. This exit has a sharp right. Immediately make a left turn. Go down the hill and make a left turn. Go straight on that street until you see Bryant st. Make a left turn onto Bryant. Make a left turn onto Bryant. Make a right turn onto 19th st. Go until you see Harrison. There's usually parking on Harrisson. The gym is at the corner of 19th and Harrison.

To get to my house from the gym, make on right turn (head East) on 18th st head up the hill until you see Portola. Make a right turn onto Portola and drive in the middle lane to get on 101 S.

On 101 S. merge to one left lane to get on 280 S. Continue on 280 until you see the John Daly exit in Daly city. This will be a long off ramp. Take the middle lane to go straight. You'll pass the new movie theater on your left. The street will go over 280. Make a left turn on school street. Drive straight until you see Mission. Make a right onto Mission. Get to your far left lane and make a left turn

onto Castle (Kragen) Drive a few blocks and make a left turn onto Abbot. "

Driver 2 Morning commute

> *"Take the first exit right, then*
> *Take the first left*
> *At the light, make a left*
> *At the circle make a left*
> *At the first big intersection get*
> > *In the #2 lane from center*
> > *And follow it to a slight left,*
> > *Then follow the lane to a slight right*
> *Go over 880 and take the 880 S. exit*
> *Merge onto 880 S.*
> *Go about 20 miles*
> *Go past the 237 exit and take the McCarthy exit*
> *At the light make a right*
> *Stay right, then make a left at the next light*
> *Go over 237*
> *Go through one light*
> *Make a right at the next light on Technology Drive*

Driver 2 Evening commute

> *Start on Technology DR East*
> *Make a left at the first light onto McCarthy Dr*
> *Make a right at the next light onto 237*
> *Merge onto 237 and immediately exit onto 880 N*
> *Exit Jackson/92 Stay in the right lane*
> *When arriving at a major intersection, follow the lane to a slight left*
> *Make a right at the next light onto D-street (at the Shell)*
> *Follow the road to a circle*
> *At the circle turn left (270°)*
> *At the first light make a right*
> *Make the first right and then take a left*
> *The house is on the left*

Sections for Driver 1 and 2

Driver 1

Morning Commute

Trips 5, 12, and 30 have identical sections. Trip 23 has the same entrance point on the highway than those trips but has a different beginning entrance point. Trips 8, 33 and 37 have different entrances.

Trip 5

Picture 1: entrance 1 beginning

Picture 2: entrance 1 end

Picture 3: Split 1

Picture 4: merge 1

Picture 5: Split 2

Picture 6: Merge 2

Picture 7: split 3

Picture 8: Merge 3

Picture 9: Highway turns into a surface street

Trip 12

Picture 10: entrance 1 beginning

Picture 14: Split 2

Picture 11: entrance 1 end

Picture 15: on-ramp junction of Split 2 end

Picture 12: Split 1

Picture 16: Split 3

Picture 13: Merge 1

Picture 17: end split3

Picture 18: end of highway

Trip 23

Picture 19: entrance 1 different origin

Picture 22: Merge 1

Picture 20: Entrance 1 end

Picture 23: Split 2

Picture 21: Split 1

Picture 24: end of on-ramp split 2

Picture 25: split 3

Picture 26: end on-ramp junction 3

Picture 27: end highway

Trip 26

Picture 28: entrance 1 beginning

Picture 31: end on ramp junction

Picture 29: entrance 1 end

Picture 32: split 2

Picture 30: Split 1

Picture 33: end on ramp junction 2

Picture 34: split 3

Picture 35: End on ramp junction 3

Picture 36: end highway

Trip 30

Picture 37: entrance 1

Picture 38: end entrance 1

Picture 39: Split 1

Picture 40: Merge 1

Picture 41: split 2

Picture 42: end off ramp junction split 2

Picture 43: Split 3

Picture 44: end highway

Trip 08

Picture 45: entrance 1 beg

Picture 46: end entrance 1

Picture 47: split 1

Picture 48: end on ramp junction 1

Picture 49: split 2

Picture 50: end off ramp split 2

Picture 51: Split 3

Picture 52: end on ramp junction 3

Picture 53: End highway

Trip 33

Picture 54: entrance 1

Picture 55: split 1

Picture 56: merge 1

Picture 57: split 2

Picture 58: end on ramp split 2

Picture 59: split 3

Picture 60: end on ramp 3

Picture 61: end highway

Trip 37

Picture 62: entrance 1

Picture 63: end entrance 1

Picture 64: split 1

Picture 65: end on-ramp split 1

Picture 66: split 2

Picture 67: end off ramp split 2

Picture 68: split 3

Picture 69: en on ramp junction 3

Picture 70: end highway

Driver 1 Afternoon commute

Trip	entrance	Toll	Split 1
02	Folder 002	003	006
06	015	017	020
09	015	017	020
13	016	018	023
24	016	018	021
27	017	019	022

31	15:18:32 016	15:22:12 017	15:30:35 020
34	15:23:09 017	15:26:52 018	15:36:04 021 (different split – earlier)
38	15:13:58 016	15:17:47 018	15:27:46 021

Trip	End ramp 1	Split 2	End ramp2
02	15:24:41 006	15:39:53 011	
06	15:24:57 020	15:33:05 023 (different split – earlier)	15:33:56 023 end ramp2
09	15:39:12 020	15:48:15 023	15:49:19 024 end ramp 2
13	15:46:09 024	15:56:47 027	15:57:50 027
24	15:24:35 021	15:38:31 026 (take different highway)	No Ramp

27	022	026 (same as trip 24)	No Ramp
31	020	024	024
34	021	023 (??)	No Ramp
38	021	024	025

	Split 3	exit Beg	Exit end
02		014	014
06	023 – split 3	025 beg exit	025 end exit
09	024 split 3	024 beg exit	024 – end exit
13	028 split3	028 beg exit	031-end exit
24	No split 3	026 beg exit	026 end exit
27	No split 3	Video Jump from 15:47:49 (029) to 15:53:50 (030)	

31	024	025 beg exit	025 end exit
34	No Split	028 beg exit	028 end exit
38	025	027 beg exit	028 end exit

Driver 2 Morning Commute

Trip	Ramp1 entrance	Ramp1 end	Split 1
01	007	008	
05	005	006	
08	003 (different entrance)		003 (split 1)
12	002	002	002 (split 1)
16	007 (different entrance)	008	

22	006:31:06. 007	006:34:59. 008	
26	06:39:26. 006	06:39:36. 007	
30	06:48:10. 007	06:50:11. 007	
35	06:33:30. 006	06:35:47. 007	
47	07:00:52. 007	07:02:19. 008	

Trip	Merge 1	Merge 2	Exit 1 beg
08	 004 (Merge 1)	 04 (Merge 2)	 017 (exit 1 beg)
12			 008 (split 2)

Trip	Exit 1 end	Exit 2 beg	Exit 2 end
01		023	023
05		018	018
08	017 (exit 1 end)	019 (exit 2 beg)	019 (exit 2 end)
12		008 exit beg	008 exit end
16		017 (exit beg)	017 (exit end)

22		07:12:47. 022	07:13:12. 022
26		07:15:00. 019	07:15:27. 019
30		07:23:44. 20	07:24:14. 020
35		07:02:20. 016	07:02:44. 016
47		07:45:08. 023	07:45:38. 023

Driver 2 Evening Commute

Trip	Ramp1 entrance	Ramp1 end	Ramp 2 entrance
04	029	029	030
06	021	021	021
11	033 (Different ramp)	033	
13 (different route)	011	012	013 (split 1)
21	033	034	034
25	035	035	035

29	16:48:03 028	16:48:18 028	16:48:42 029
34	17:02:58 032	17:03:13 033	17:03:46 033
36	16:58:22 022 (different entrance)	16:59:26 022	
46	16:44:42 029	16:44:59 029	16:45:34 029
52	16:52:23 038	16:52:37 038	16:53:11 039

Trip	Ramp2 end	Exit 1 beg (exit to local to take another highway)	Exit 1 end
04	 030		
06	 021		
11		 035 (take an exit from highway)	 035 (time jumps from 16:46:17 (035) to 16:52:15 (036) at 036, driver is on another highway
13	 013(merge 1)		
21	 034		
25			

	035		
29	 028	 038	 038 (taking local to take another highway) time jumps from 17:15:29 (038) to 17:35:14 (039)
34	 034	 042	 042 (exit to local)
46	 030		
52	 039	 047	 047 (take local to another highway)

Trip	Ramp3 entrance (reenter highway from local)	Ramp3 end	Exit 2 beg (last highway exit)
4			041
6			031
11			041
13			019
21			040
25			

			046
29			041 exit beg
34	044(take another highway entrance)	045 end entrance	046 exit beg
36			030
46			039
52			

	048 (2nd entrance)	049 (ramp end)	

Trip	Exit 2 End
4	042 Time jumps from 17:35:30 (041) to 17:45:33 (042)
6	032
11	041
13	020

21	040
25	046
29	042 exit end
34	046
36	030

46	
	039
52	