

# How to Directly Measure Level of Service in the Field

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**Abstract:** Level of Service (LOS) studies are commonly done to evaluate the quality of traffic control at signalized intersections and arterials. The basis for LOS for intersections is the *control delay* experienced by the vehicles going through the intersection. However, control delay is considered difficult to measure, so the most common technique to evaluate LOS uses an approximation procedure that requires a dozen or more input parameters, many of which are difficult to measure in their own right. The result is that most engineers use default values and “educated guesses” to determine the values for the input parameters rather than measure them. The results can be difficult to defend.

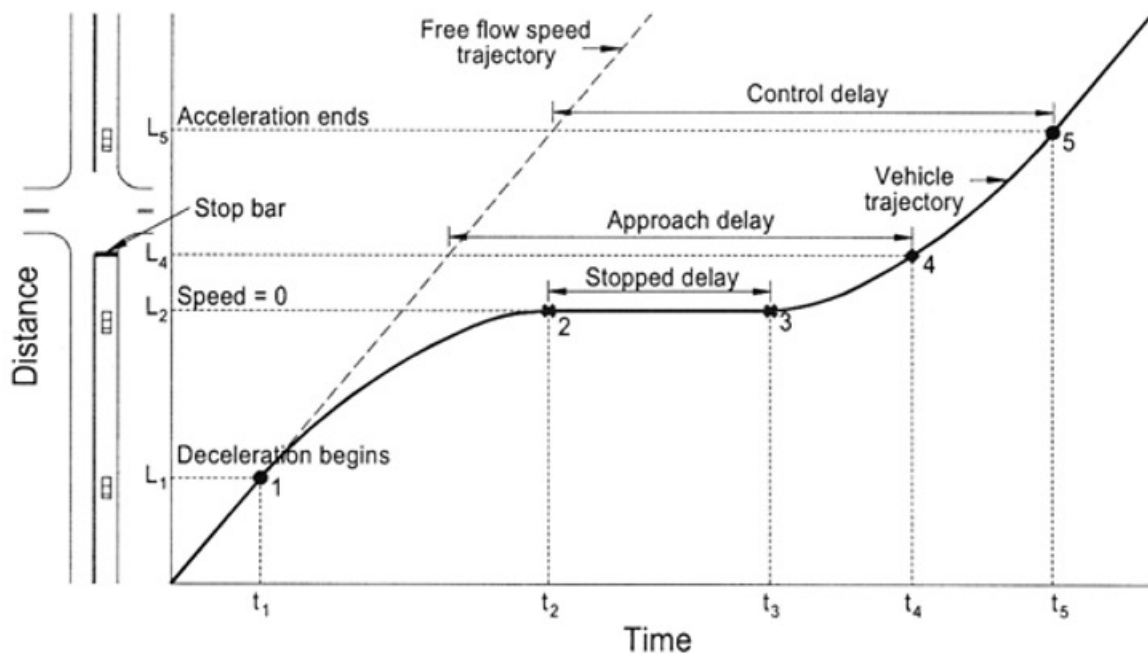
This paper describes a system that allows you to measure control delay directly in the field. It uses equipment typically used for travel time and delay studies. Instrumented vehicles drive through the target intersection during the peak hour as many times as possible collecting distance, time, and speed data. This data is then processed in the office to find the control delay, and hence the LOS. This paper specifically discusses LOS for signalized intersections, but the techniques are applicable to arterial LOS as well.

Three different methods to collect the data in the field are described: 1) Transmission sensor with a Jamar TDC-8 data collector; 2) GPS receiver with a laptop or PDA, and finally 3) OBD-II Scantool interface with a laptop or PDA. The field data is processed in the office using PC-LOS, a software program developed for this application. Operation of PC-LOS is described, with data from an intersection in Pinellas County, FL used as an example.

## **Introduction:**

It is often necessary for traffic engineers to communicate to a non-technical audience. One system that has evolved to explain a somewhat subjective feeling about the *quality* of traffic at signalized intersections is the concept of a Level of Service (LOS). Since the general public is generally interested in minimizing the delay they experience while they drive around doing their errands, it isn't surprising that LOS is based on the concept of delay.

For a long time LOS was defined by the amount of *stop delay*, or the amount of time the driver was essentially not moving forward (*and presumably becoming more and more annoyed*). One reason for this definition was because stop delay was relatively easy to measure using a variety of techniques. A few years ago the definition of LOS was changed to recognize the fact that a driver could be severely delayed at an intersection without actually stopping and the concept of *control delay* was used to define the LOS categories. Basically, control delay is *all* of the delay experienced by a driver due to congestion at an intersection and includes the deceleration phase approaching the intersection, the stopped phase typically in a queue at the intersection, and the acceleration phase after the queue is released through the intersection. It is the difference between the ideal situation and what really happens.



Above is a diagram that shows visually the components that make up control delay. This is a graph of time versus distance traveled as it approaches, goes through, and leaves an intersection. You can see the diagram of the road to the left of the graph.

From time  $t_0$  to  $t_1$  the vehicle is traveling at the free flow speed. At point 1 the vehicle meets some congestion and starts to slow down. It is at distance  $L_1$  at this point. From 2 to 3 (time  $t_2$  to  $t_3$ ) the vehicle is stopped (at  $L_2$ ), this is the stopped delay time. At 3 the vehicle starts moving again. At 4 it reaches the stop bar for the intersection. It then accelerates and gets back up to the free flow speed at 5. At this point the vehicle is at position  $L_5$

If the vehicle had not experienced any delay then it would have followed the Free Flow Speed Trajectory shown on the plot. The Control Delay is the time between when the acceleration actually ended (at 5) and when the vehicle would have reached the same distance traveling at the free flow speed.

If you could do measurements in the field and plot the time vs distance of a vehicle as it goes through an intersection, and mark where the control delay starts and ends, then you could calculate the control delay for that run. You could repeat the procedure and measure the control delay as many times as possible to get the best possible average value, and from that the LOS. This is the strategy you would use to actually measure control delay, but it is a technique that is rarely used.

## **How Is LOS Determined Now?**

Here is a quick summary of the current techniques used to find Level of Service. The first presented is a method used to directly measure control delay. The other two methods estimate the control delay rather than measure it.

### **Floating Car Method: Paper, Pencil & Stopwatch in a Car**

Up until recently, the only practical way to measure control delay in the field was to drive through the intersection and use a stop watch and paper and pencil to collect and store the data. The method normally requires two people in the vehicle, one to drive and call out speeds, distances and times, and another to keep track of time and record the data. Typically the driver calls out when he feels he has started the deceleration phase and the speed and odometer reading (to the nearest 0.1 mile since that is usually the only option to measure distance). The data collector starts a timer using a stopwatch and records the speed and starting distance. The vehicle drives through the intersection and the driver calls out when the acceleration phase has ended along with the speed and the odometer reading again, and the data collector stops the timer and records the accumulated time, the speed, and the distance. This process is repeated for an hour or more. The data is brought back to the office and the data analyzed to find the delay. The time reading is the actual delay experienced by the vehicle. The ideal time is found by using the two odometer readings and the speed reading to calculate the time it would have taken to drive between those two points. The control delay is the difference in these numbers.

The analysis time can easily take as long as the data collection time, and there are a couple of problems with these procedures. It can be hard to tell exactly when control delay begins and ends while you are driving, and the ideal time calculation is not very accurate because the odometer is usually limited to tenths of miles. The result is you get a somewhat imprecise control delay calculation for a relatively large amount of manpower. This isn't a good combination. It is not surprising that this procedure is not used very often.

The problem with this procedure is not the concept, which is good since it actually finds the control delay. The main problem is the implementation of the idea. If this type of data could be easy to collect and analyze then it would be a more attractive option to traffic engineers. As we will show in the next part of this paper, this is what we try to accomplish with the PC-LOS system.

Others have developed many different ways to measure the speed, time, and distance data needed to measure control delay. These systems have generally been expensive to purchase and not designed for the typical traffic engineer to use on a day to day basis so they never have been as popular as they might have been.

### **Manual Intersection Stop Delay Studies:**

There are other techniques to measure delay at an intersection that don't involve a *floating car* methodology. The Highway Capacity Manual and the ITE Manual of Transportation Studies both describe a technique that has been commonly used to find stop delay at intersections. It involves counting the number of cars stopped at 15 second intervals and also counting the number of vehicles that pass through the intersection and classifying them as either stopped or not stopped. A simple calculation gives an estimate of the average stop delay per vehicle. You usually need two technicians per lane group surveyed. It works for most undersaturated signalized intersections; for saturated conditions the queue buildup usually makes this method impractical.

Presumably this procedure is suggested instead of a floating car methodology because it gives better data for the effort expended. However, if you compare the labor required using this procedure to a floating car methodology then you quickly realize there is no obvious advantage to this manual study. You still need to send one, and probably two techs to the site. They need to collect data for an hour or more to get meaningful statistics. They only can do one lane group at a time. But the biggest problem with this method is that you only get an estimate of the stop delay and not the control delay you really need for LOS.

This procedure was useable when LOS was based on stop delay, but it is hard to justify now that LOS is based on control delay. The manuals recommend converting the measured, estimated stop delay into control delay (and hence to LOS) by multiplying by 1.3. This is not very satisfactory to many engineers because it effectively ignores the possibility of variability in the deceleration and acceleration components of the delay. It may be true that over a large number of runs over a large number of intersections the control delay will be 1.3 times the stop delay (it has to be something), but this doesn't mean that for a given intersection this will always be true. If you have a standard that is based on control delay then it seems reasonable that you should have to *use* control delay in some manner. Measuring stop delay and then estimating control delay with a universal factor is bad engineering.

Of course the reason stop delay is considered acceptable is precisely because it *is* difficult to manually measure control delay, which can extend a considerable distance before and after an intersection. You could imagine a platoon of technicians all connected with some wireless radio system to allow them to collect data before and after an intersection, but this is hardly practical.

The definition of LOS was changed for a reason. Control delay *is* a better indicator of the quality of an intersection. If you are going to send techs to the site to collect delay data, then you should have them collect real control delay and not estimated stop delay. It costs about the same in manpower and you get good data.

## **HCM Methodology:**

By far the most common way to find LOS is to use a variation of the Highway Capacity Manual procedure. Whether you use the Highway Capacity Software, which is essentially free, or one of the many commercial programs available that include HCM procedures as part of a modeling or simulation program, you are implementing the same basic methodology. *Note: some microscopic modeling programs find LOS by tracking individual vehicles through the intersections and don't technically use the HCM methodology. However, these systems need most of the same input parameters to initially calibrate the model and therefore are included here for convenience.*

Anybody who starts an analysis using the HCM procedures immediately realizes that there is a tremendous amount of data collection that is required if you were to *precisely* follow the procedures outlined in the HCM. The reality is that many of the parameters are estimated, or the default values are used. This isn't necessarily bad or wrong, but it certainly can bring the accuracy of the results into question. You may say "There is no way you can measure all of the input parameters needed by the HCS software. It would take weeks and require a large crew of techs." And you would be right, which is exactly the point.

It is certainly true that you can do a full HCM study and never visit the site. You can use volume counts that are a couple of years old. You can use the timing plans from your signal timing software. You can estimate the percent of Heavy Vehicles, the Arrival Type, the number of Buses Stopping, the Saturation Flow Rate, the Ped volumes, etc.. You can even use satellite imagery to get the geometric information if you don't have that handy. You can use the default values for any of the parameters you are not comfortable estimating. And when you are done you will generate a nice looking report with a complete set of Level of Service values for all of the lane groups.

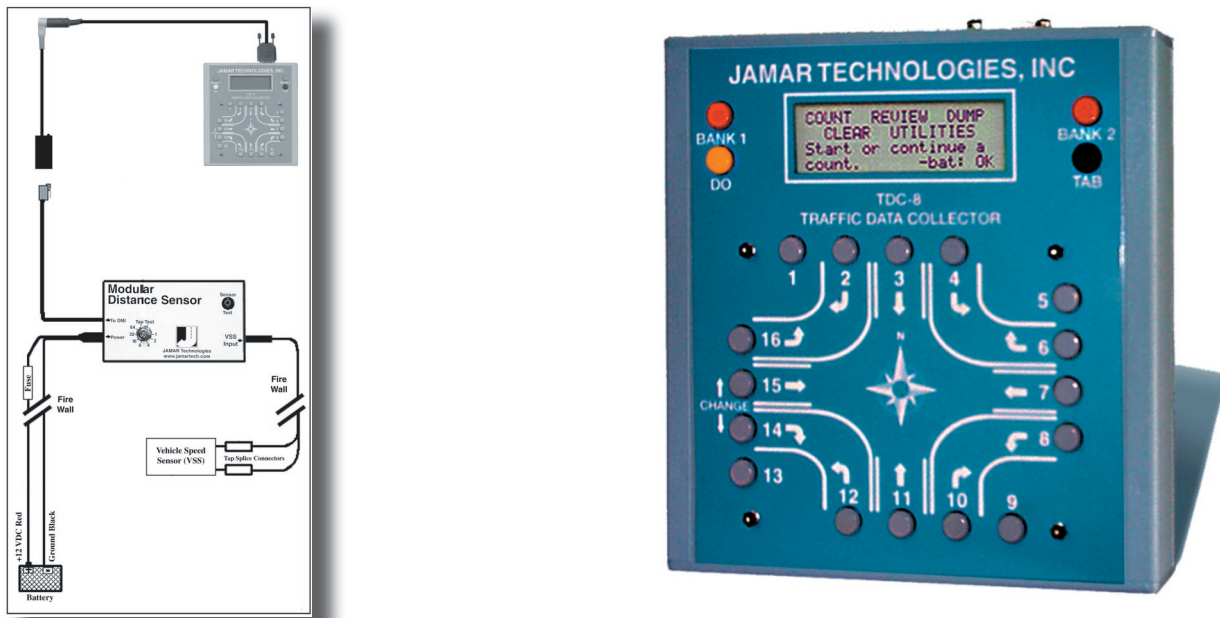
If this describes how you typically do LOS studies, and you see nothing wrong with it, then you are probably wasting your time reading this paper. There is no doubt that any procedure that requires you to go to the site to measure something is going to be more labor intensive than sitting in your office and using your "engineering judgement" to estimate the parameters.

If however you want to measure some of the input parameters to make the analysis as accurate as possible, then it becomes a different comparison. It isn't quite as easy to say that you don't have the time or the manpower to measure one or two of the major lane groups with a floating car methodology such as we describe in this paper.

## Three Systems to Measure Control Delay

This section of the paper will describe three different hardware systems to collect data in the field that can be analyzed to find control delay. They are all systems that were originally developed to do travel time and delay studies using *floating car* techniques; a vehicle is driven on a pre-determined route and data is collected that represents the average vehicle on the road at that time.

### System 1 - Transmission sensor and Jamar TDC-8 data collector:



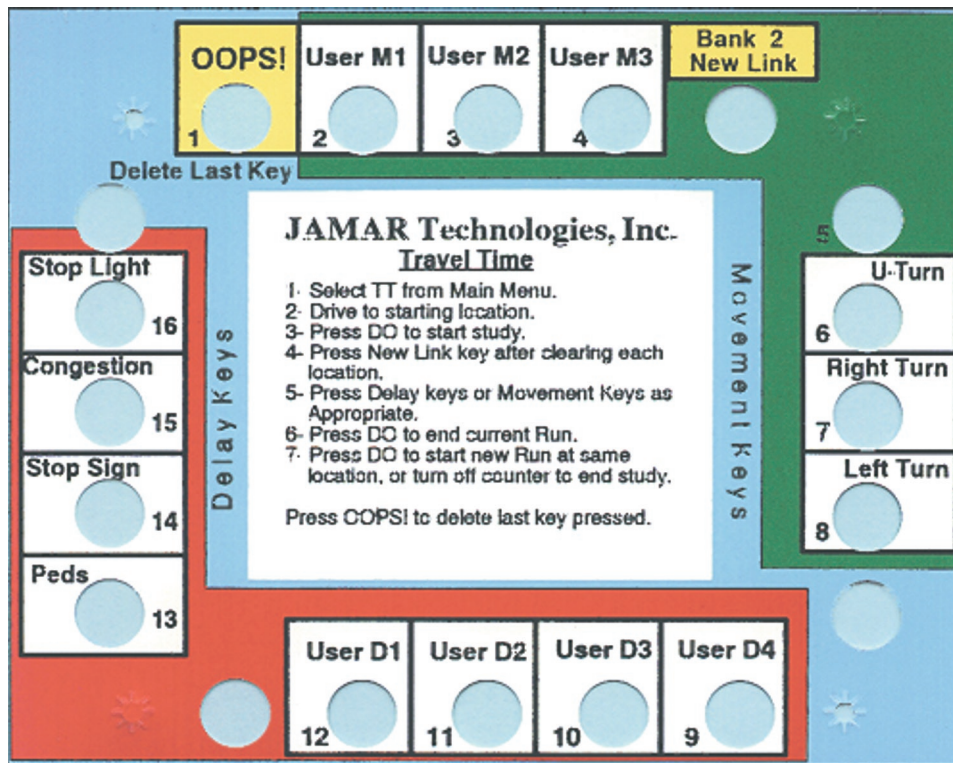
This system uses a transmission sensor that typically is installed in vehicles using Distance Measuring Instruments (DMIs). These sensors generate pulses that are proportional to the distance traveled by the vehicle. They are very accurate if installed properly; accuracies of one foot per mile are typical. The sensor is semi-permanently installed in a vehicle by connecting a wire to the Vehicle Speed Sensor (VSS) found in just about every vehicle. This wire is run to an interface box (the Modular Distance Sensor in the diagram above) that conditions the signal pulses and typically connects to a DMI, which counts the pulses. Every sensor/vehicle combination must be calibrated to convert the pulses into distances, which involves driving a known distance (usually around a thousand feet). The DMI counts the number of pulses it received while driving the calibration course and calculates the Calibration Constant for that vehicle. Users must re-calibrate the vehicles every year or so or whenever the tires are changed (which affects the calibration). This is all somewhat annoying, yet thousands of DMIs and sensor kits are sold yearly and if you happen to have such a vehicle you are half way to what you need to measure control delay data.

The TDC-8 is an instrument manufactured and sold by Jamar Technologies. It allows users to do eight common traffic engineering studies, including turning movement counts, intersection

and stop sign delay studies, spot speed studies, manual classification studies, saturation flow rate studies, and travel time studies. It is the last study listed that is of interest here. The TDC-8 connects to the transmission sensor just described (the TDC-8 takes the place of the DMI which is not needed). The pulses from the transmission sensor are counted by the TDC-8 and the number counted is stored each second in the memory of the TDC-8. Analysis software back in the office can take the second by second data and find the distance traveled and the speed of the vehicle. This is all that is needed to calculate the control delay.

This hardware package (TDC-8 and transmission sensor) has been sold by Jamar as part of a Travel Time and Delay system since 1988. Jamar sells a software package called PC-Travel for Windows which processes the data collected and generates reports and graphs to show travel times, average speeds, number of stops, total delays, fuel consumption and emission statistics.

If you already have a TDC-8 and have access to a vehicle with a transmission sensor installed then you have everything you need to collect control delay data. If you have one or the other of the two components needed, then you might want to get the missing component to complete the system. If you don't have either a TDC-8 or a vehicle with a transmission sensor then you may want to consider one of the other two options described in this paper.

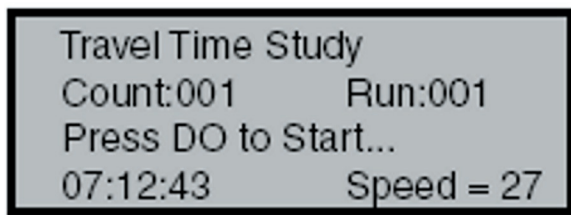


Shown here is the template that you use with the TDC-8 to collect travel time data, which you also use for LOS data. This snaps to the top of the TDC-8 and defines the way the keys on the TDC-8 are used. You only need to use two keys for LOS studies; the DO button to start and stop runs, and the New Link button to mark the stop bar.

Here are the steps needed to collect LOS data using a TDC-8 and a transmission sensor.

**1) Decide on the route for the study.** This may involve collecting data for one intersection or for 2 or 3 in a row. To simplify things we will assume a single intersection. Since normally you want to find out how bad things are (worst case) you want to identify the approach and lane that is likely to have the worst delays. This is usually pretty easy to identify. (*Route selection is discussed in more detail in the Conclusions section of this paper.*) You also would normally want to collect the data during the peak hour for the intersection (again to find the worst case situation). You want to collect as many runs as possible while the traffic is the heaviest.

**2) Connect the hardware.** Connect the cable from the Modular Distance Sensor to the TDC-8. See the diagram on page 8 to see how this is done.



**3) Turn on the TDC-8 and select the Travel Time study from the list of studies.** The TDC-8 reads the data from the Modular Distance Sensor and displays the time and speed on the screen as shown on the screen shot here. It is easy to tell if the hardware is working.

Drive to the beginning of the route, which should be well in advance of the intersection. You want to make sure that each run starts before the control delay starts.

Press the **DO** button to start the run. The TDC-8 starts storing the data in memory every second.

**4) Collect the data for the run.** Drive through the intersection, staying in the lane you previously selected. This may be a through lane or it may be a left turn lane. Drive with the traffic without any overly aggressive or passive behavior. When you go by the stop bar of the intersection, press the **New Link** button. Once you are through the intersection and back to a free flow speed (control delay is over), press the **DO** button to end the run.

**5) Turn around and collect data at the same intersection from the opposite direction.** You have to get back to the beginning of the route to do the next run so typically you would collect data in both directions and essentially do two LOS studies during one session.

**5) Collect as many sets of runs as possible.** The analysis software calculates the average control delay and the more data points you have the better the average will be. (*Determining the number of runs needed to get a good statistical average is part of the follow-up work for this paper.*)

The data stored in the TDC-8 is the speed of the vehicle for each second during each run. This is all that is needed to calculate the control delay and determine the LOS.



## System 2 - GPS Receiver and Laptop or PDA

The availability of low cost, yet very accurate GPS receivers has made this system a very popular option to collect travel time data in recent years, and it also can collect LOS data. The idea is simple. Most people know that a GPS receiver outputs latitude and longitude information, but most people don't know that they also output the speed of the receiver as well. If the GPS receiver is in vehicle driving down the road then the output of the GPS receiver will be the speed of the vehicle. The speed data is surprisingly accurate, with errors usually less than 1 MPH. Typically the data is output each second. This speed data is recorded by a laptop or PDA and analyzed in the office to find the control delay.

There are many, many different GPS receivers available, and most of them will work well to collect LOS data. There are three features that are required:

**1) Outputs data once per second.** Some low cost receivers save power by outputting data every three or five seconds. These do not provide the resolution needed for accurate LOS studies.

**2) Outputs data in a standard format, called NMEA.** This is a text based format supported by most software programs. Almost all receivers support this format, although often it is not the default format and must be selected somehow.

**3) Has an external antenna that can be mounted on the roof of the vehicle.** Many portable GPS receivers are not designed for use in a vehicle, they are designed to be carried around on hiking trips or used in small boats. You can get a signal while in a vehicle but it generally won't be as good as one where the antenna is magnetically mounted on the roof.

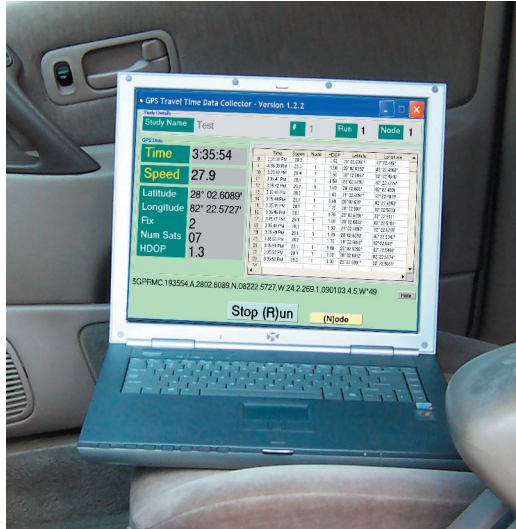
If you already have a GPS receiver, then check to see if it meets the three requirements above.



If so, then all you need is a laptop or PDA and you will have the hardware you need to do LOS studies. If you don't have a GPS receiver now then you can buy very inexpensive receivers (less than \$100) that are designed to be used in vehicles. A typical example is shown here. This is often called a mouse or hockey puck model. It consists of an integrated receiver/antenna that has a magnetic surface. It mounts on the roof of a vehicle. A cable runs into the cab of the vehicle and splits into two cables; one connects to a power source (either a cigarette lighter adapter plug or the mouse port of your laptop) and the other cable connects to the serial port of your

laptop or PDA. These low cost receivers are just as accurate as fancier receivers that cost five times as much (however, they aren't great to take on a hiking trip).

The GPS receiver generates the data while you drive the route, but you need a computer to process the data and store the data in a form that can be analyzed in the office. You can use a laptop or PDA for this. There are a few pluses and minuses to whether you should use a laptop or a PDA, but it generally comes down to personal preference and what you already have available.



You can use just about any laptop; you just need to be able to connect it to the GPS receiver you want to use. This isn't always as simple as it should be, but it almost always can be done. Newer laptops don't have standard serial ports any more; they have been replaced with USB ports. Fortunately there are many low cost USB to Serial converters available to solve this problem if your GPS receiver uses a standard serial port. Some GPS receivers now come with USB interfaces so this isn't an issue.

The software running on the screen is called GPS2LT and is available from Jamar Technologies. This software is normally used to collect travel time data, but as explained before, the data required for

LOS studies is identical to the data required for travel time studies, so this is exactly what is needed. Operation of the software is easy. You tap on keys to mark the beginning and end of each run. The screen shows the data coming from the GPS receiver so you know that everything is working.



You also can use just about any PDA to collect the LOS data, just about any Palm or Pocket-PC type PDA will work fine. Again, there often are tricks required to figure out how to connect the GPS receiver to the PDA (usually this requires a special cable between the GPS receiver and the PDA), but normally this isn't a major problem.

Here is an example of how to mount a PDA in a vehicle. The PDA clips into a holder that has a gooseneck arm that is bolted to the floor. The PDA can be positioned so it is easy for the driver or the passenger to operate the controls.

The software running on the PDA is called GPS2PDA and is available from Jamar Technologies. It is very similar to the software that runs on laptops except it doesn't show as much data on the screen, for obvious reasons. You tap on buttons on the screen to mark the beginning and end of runs, or you can use the pushbuttons on the bottom of the PDA.

Here are the steps needed to collect LOS data using a GPS receiver and PDA. The software shown is the GPS2PDA mentioned earlier.

**1) Decide on the route for the study.** This may involve collecting data for one intersection or for 2 or 3 in a row. To simplify things we will assume a single intersection. Since normally you want to find out how bad things are (worst case) you want to identify the approach and lane that is likely to have the worst delays. This is usually pretty easy to identify. (*Route selection is discussed in more detail in the Conclusions section of this paper.*) You also would normally want to collect the data during the peak hour for the intersection (again to find the worst case situation). You want to collect as many runs as possible while the traffic is the heaviest.

**2) Connect the hardware.** Mount the GPS receiver on the roof of your vehicle and snake the cable through a window. Connect the power cable to the cigarette lighter adapter and the serial cable to bottom of the PDA. Obviously this procedure may vary depending on the type of GPS receiver you use.

**3) Run the GPS2PDA software and verify the hardware is working.** The software reads the data from the GPS receiver and displays the time, speed, latitude, and longitude on the screen as shown on the screen shot here. It is easy to tell if the hardware is working.



Drive to the beginning of the route, which should be well in advance of the intersection. You want to make sure that each run starts before the control delay starts.

Tap the **Start Run** button to start the run. The screen changes to a green background and the software starts storing the data in the memory of the PDA.

**4) Collect the data for the run.** Drive through the intersection, staying in the lane you previously selected. This may be a through lane or it may be a left turn lane. Drive with the traffic without any overly aggressive or passive behavior. When you pass by the stop bar, tap the **Node** button. Once you are through the intersection and back to a free flow speed (control delay is over), tap the **Stop Run** button to end the run.

**5) Turn around and collect data at the same intersection from the opposite direction.** You have to get back to the beginning of the route to do the next run so typically you would collect data in both directions and essentially do two LOS studies during one session.

**5) Collect as many sets of runs as possible.** The analysis software calculates the average control delay and the more data points you have the better the average will be. (*Determining the number of runs needed to get a good statistical average is part of the follow-up work for this paper.*)

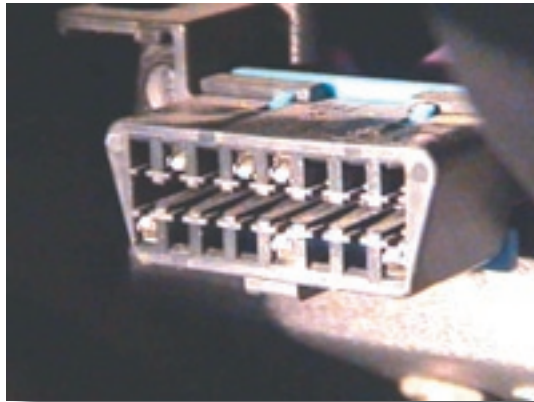
The data stored in the PDA is the speed of the vehicle for each second during each run. This is all that is needed to calculate the control delay and determine the LOS.

### **System 3 - OBD-II Interface with a Laptop or PDA**

This is the newest of the three systems described here, but in some ways is the best.

OBD is short for On Board Diagnostics and it is incorporated into all cars made after 1996. OBD-II is the specific data protocol that is utilized in all of these vehicles. All of the important details about the OBD scheme are standardized, fortunately. All OBD-compliant computers can provide data about emissions, fuel efficiency and (*most importantly for us*) the vehicle's speed.

The OBD-II system is the present culmination of the pollution control efforts of the California Air Resources Board (*CARB*) and the Environmental Protection Agency (*EPA*). The primary purpose of OBD is to electronically monitor your car's engine and fuel system to make sure that it's running as efficiently as possible. This, in effect, cuts down on harmful auto emissions. If anything monitored by OBD malfunctions, resulting in decreased efficiency, then the Check Engine light, or Malfunction Indicator Light (*MIL*), on your dashboard is illuminated.



The OBD connector is always the same; it must be located within a few feet of the driver, and it must be accessible without the aid of any tools. Here is a picture of an OBD connector. You probably didn't know it but you have one of these in your car (if it is newer than 1996).

Since the OBD connector can be easily accessed (*remember, no need for tools*), its use for LOS studies has some real advantages over the other methods of data acquisition described here. There is no need to attach a transmission sensor to your vehicle's wiring and there is no need to worry about poor GPS satellite reception.

## OBD Scantools

There are many engine components monitored by OBD, so your MIL could come on for many different reasons (*some are merely temporary glitches, while others could render your car immobile*). With an OBD scan tool, anyone (*not just mechanics*) can ascertain why the MIL has been turned on. Several companies have developed scan tools for this purpose. There are self-contained instruments that typically are expensive and others that interface to laptops or PDAs.



Shown here is a photo of a scantool manufactured by Harrison R & D. It has a cable to plug into the OBD connector in your vehicle and another cable that plugs into the serial port of your laptop or PDA. It sells for less than \$150 and comes with a complete software package to monitor the operation of your vehicle.

There also is a new interface protocol, called CAN (*Controller Area Network*) that will replace the current OBD-II in four or five years. There already are a few vehicles that use this new protocol. Harrison R&D makes a product called CANScan which supports this protocol. It looks identical to the OBDScan product shown here and uses the same cables and connectors; only the electronics inside are different.

The scan tool can monitor hundreds of different parameters in your vehicle, including the real time speed. Software can read the speed several times per second if needed. We've already seen in the previous section on GPS receivers that all you need to do to collect LOS data is to store the speed of the vehicle each second; this is easily done with an OBD scan tool and the proper software.

A scan tool based LOS data collection system has several advantages. It is very portable. You can use any vehicle built since 1996 to collect your data. The speed data is also very accurate; usually better than 1 MPH.

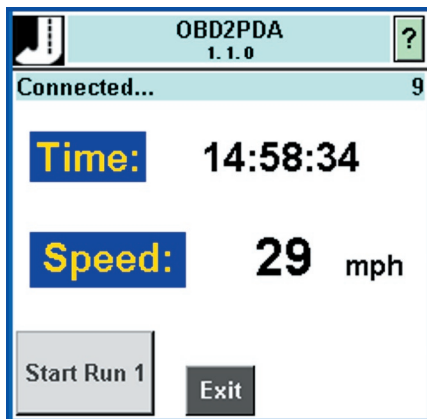
Jamar Technologies has software to work with laptops (OBD2LT) and PDAs (OBD2PDA) that interfaces to the Harrison Scantool. This software is normally used to collect travel time data but as we know by now can be used to collect LOS data as well.

Here are the steps needed to collect LOS data using an OBD scan tool and a PDA. The software shown is the OBD2PDA mentioned earlier.

**1) Decide on the route for the study.** This may involve collecting data for one intersection or for 2 or 3 in a row. To simplify things we will assume a single intersection. Since normally you want to find out how bad things are (worst case) you want to identify the approach and lane that is likely to have the worst delays. This is usually pretty easy to identify. (*Route selection is discussed in more detail in the Conclusions section of this paper.*) You also would normally want to collect the data during the peak hour for the intersection (again to find the worst case situation). You want to collect as many runs as possible while the traffic is the heaviest.

**2) Connect the hardware.** Mount the scan tool in your vehicle. Connect the OBD cable to the OBD connector in your car, and the serial cable to the bottom of the PDA.

**3) Run the OBD2PDA software and verify the hardware is working.** The software reads the data from the scan tool and displays the time and speed on the screen as shown on the screen shot here. It is easy to tell if the hardware is working.



Drive to the beginning of the route, which should be well in advance of the intersection. You want to make sure that each run starts before the control delay starts.

Tap the **Start Run** button to start the run. The screen changes to a green background and the software starts storing the data in the memory of the PDA.

**4) Collect the data for the run.** Drive through the intersection, staying in the lane you previously selected. This may be a through lane or it may be a left turn lane. Drive with the traffic without any overly aggressive or passive behavior. When you pass by the stop bar, tap the **Node** button. Once you are through the intersection and back to a free flow speed (control delay is over), tap the **Stop Run** button to end the run.

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The data stored in the PDA is the speed of the vehicle for each second during each run. This is all that is needed to calculate the control delay and determine the LOS.

## *Data Analysis in the Office*

Performing a Level of Service studies involves two parts. First you must collect the data in the field. The previous section of this paper described three hardware/software systems to do this. Second you must analyze the collected data to generate the LOS results. The software to do this is called PC-LOS and currently is being developed by the authors for Jamar Technologies. The next section of this paper will describe PC-LOS and how it calculates LOS.



The data shown in this example was collected at a very busy intersection in Pinellas County, Florida in late December, 2004. The image above shows this intersection. In this view you are looking northbound. The data was collected using the OBD-II system (OBD2PDA) described before. 13 runs were done starting at 10:20 in the morning and data was collected for one hour. The intersection chosen is very busy all day and these times were chosen to give some variability in the run times. The westbound, left turn lane was chosen since that lane typically has the largest delays. The OBD2PDA software generated 13 separate run files which were used in the study.

The driver collecting the data started each run well in advance of the intersection, approached the intersection on Main Street and merged into the left turn lane as early as possible, then made the left turn to head southbound on Keene Road. Once he was back up to a free flow speed he ended the run and made the first left turn he could and circled back to Main St a block east of the intersection and repeated the process. He did this for an hour, which resulted in 13 runs. The run files in the PDA were copied to the office computer automatically by the PC-LOS analysis software and then processed.

## Main Screen in PC-LOS

The screenshot displays the main interface of PC-LOS. At the top is a menu bar with 'File', 'View', 'Utilities', and 'Help'. Below it is a toolbar with icons for 'New', 'Open', 'Save', 'Read', 'Edit Run', 'Print', 'Stats', 'Prefs', 'StartUp', and 'Internet'. The main area is divided into three sections:

- Study Group: Main And Co1**: Contains fields for 'Name' (Main-Co1-LT-WB), 'Street Name' (Main Street & County Road 1), 'Critical Lane' (Left), and 'Direction' (WB). A 'Notes' field contains 'Weather, sunny and clear.' and a 'Help' button is present.
- Runs Used in This Study**: A table listing 13 individual runs with their respective metrics.
- Study Summary**: Displays key statistics such as 'Avg. Control Delay (sec)' (111), 'LOS Grade' (F), 'Stop Speed Threshold' (0), 'Avg. Stop Delay' (88), and 'Ratio of Control to Stop Delay' (1.26).

Run Title	Start Date	Start Time	Length (ft)	Control Delay (sec)	LOS Grade	Stopped Delay
Main-Co1-LT-WB-001	12/28/04	10:21	1715	136	F	114
Main-Co1-LT-WB-002	12/28/04	10:26	1827	20	B	0
Main-Co1-LT-WB-003	12/28/04	10:29	1617	24	C	9
Main-Co1-LT-WB-004	12/28/04	10:33	1652	147	F	132
Main-Co1-LT-WB-005	12/28/04	10:39	1616	154	F	130
Main-Co1-LT-WB-006	12/28/04	10:44	1682	59	E	44
Main-Co1-LT-WB-007	12/28/04	10:47	1505	204	F	162
Main-Co1-LT-WB-008	12/28/04	10:54	1511	184	F	154
Main-Co1-LT-WB-009	12/28/04	10:59	1500	28	C	10
Main-Co1-LT-WB-010	12/28/04	11:02	1422	189	F	159
Main-Co1-LT-WB-011	12/28/04	11:08	1596	54	D	39
Main-Co1-LT-WB-012	12/28/04	11:12	1459	168	F	153
Main-Co1-LT-WB-013	12/28/04	11:17	1410	71	E	44

This is the *Main* screen of PC-LOS. The software runs on any Windows based computer. It has the usual drop down menus at the top of the screen, along with a toolbar of commonly performed actions. The software recognizes the video resolution of the computer and adjusts the screen elements accordingly. The computer used for these screen shots was set to 1280 x 1024 pixels.

The primary job of PC-LOS is to allow you to quickly and easily create and manage LOS studies. Each study in PC-LOS is made up of a number of runs. Each run is a separate file that is stored on the computer. The run file contains the data collected in the field. Every run must start at roughly the same place, end at roughly the same place, go in the same direction, and use the same lane while going through the intersection. This is so all of the LOS statistics are based on equivalent data.

The screen is roughly broken into three parts; the Study Details near the top of the screen, the Run Information in the center of the screen, and the Summary Details near the bottom of the screen.



The top of the *Main* screen shows the Study Details. You enter the Study Name, the Street Name or Location and select the Critical Lane and Direction for the runs used in the study. You also can enter any Notes about this study in the space provided.

The center of the screen shows the runs used in the study. You see some of the parameters for each run; the Run Title (which is the name of the run file), the Start Date and Time, the Length of the run, and the calculated Control Delay and LOS. Also shown is the Stopped Delay for that run

Run Title	Start Date	Start Time	Length (ft)	Control Delay (sec)	LOS Grade	Stopped Delay
Main-Co1-LT-WB-001	12/28/04	10:21	1715	136	F	114
Main-Co1-LT-WB-002	12/28/04	10:26	1827	20	B	0
Main-Co1-LT-WB-003	12/28/04	10:29	1617	24	C	9
Main-Co1-LT-WB-004	12/28/04	10:33	1652	147	F	132
Main-Co1-LT-WB-005	12/28/04	10:39	1616	154	F	130
Main-Co1-LT-WB-006	12/28/04	10:44	1682	59	E	44
Main-Co1-LT-WB-007	12/28/04	10:47	1505	204	F	162
Main-Co1-LT-WB-008	12/28/04	10:54	1511	184	F	154
Main-Co1-LT-WB-009	12/28/04	10:59	1500	28	C	10
Main-Co1-LT-WB-010	12/28/04	11:02	1422	189	F	159
Main-Co1-LT-WB-011	12/28/04	11:08	1596	54	D	39
Main-Co1-LT-WB-012	12/28/04	11:12	1459	168	F	153
Main-Co1-LT-WB-013	12/28/04	11:17	1410	71	E	44

Below the list of runs are two buttons which are used to add and remove runs used in the study. There also is a button to edit the details of the run, including the control points which are used to define the start and end of the control delay.

At the bottom of the screen are the Summary Details that show the calculated Average Control Delay and final LOS for the study.

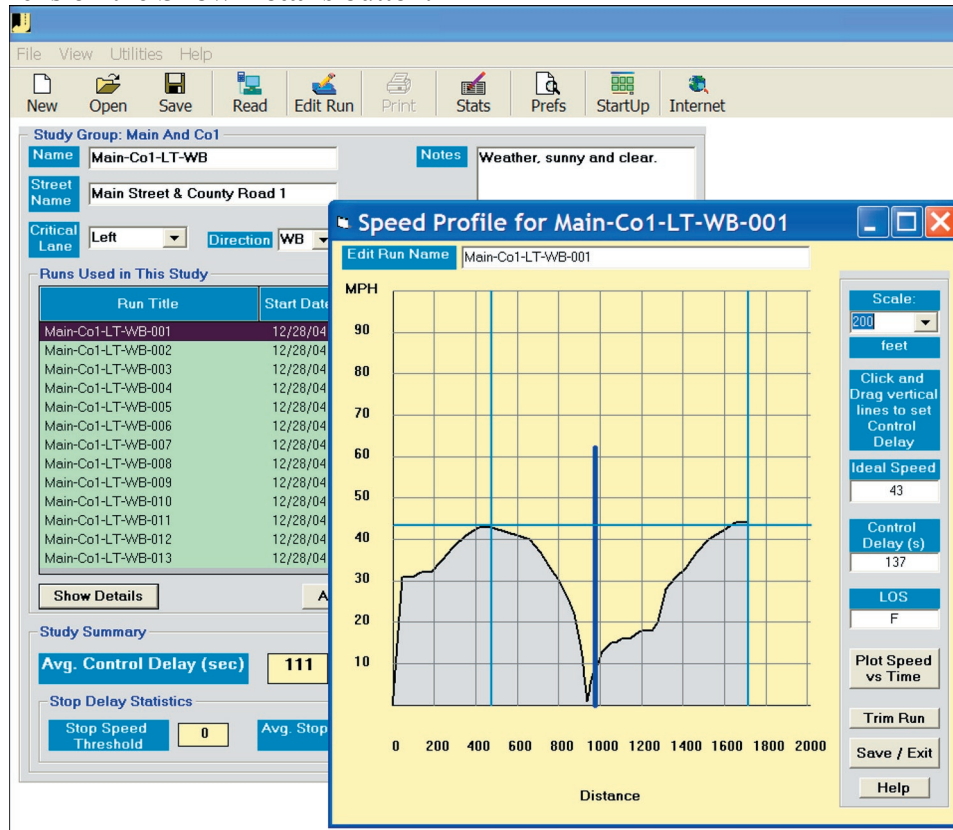
You can also show the Average Stop Delay and the Ratio of Control Delay to Stop Delay. The values for control delay used in the LOS tables

were developed from research that showed that this ratio is typically 1.3. You can check this assumption with your data. *Note: In this particular example, the ratio is 1.26 which is very close to 1.3, however other data sets show that this ratio can vary considerably.*

In a typical study analysis, this screen is simple to use. You use the **Add Runs** button to select the runs you want to use in the study. Then you edit the control points in each run to set the start and end of the control delay for that run (*this is described on the next page*). After all of the runs are edited, the software calculates the Summary Detail statistics, including the Average Control Delay and the LOS. You then can fill in the Study Details section at the top of the screen, save the study, and print the reports. It is very simple and intuitive and only takes a few minutes once you have the run files.

## Run Details Screen in PC-LOS

The *Main* screen just described gives a summary of the data in the study, including the Control Delay for each run. The Control Delay is found in the *Run Details* screen, which is shown when the user clicks on the **Show Details** button.



This is the *Run Details* screen for the first run in the study. The graph is a plot of the speed of the vehicle vs distance traveled. You can see that the vehicle was traveling at 30 MPH when the run started. The vehicle increased speed to about 40 MPH and then clearly ran into some congestion. The speed dropped to essentially zero and then increased up to about 42 MPH where it leveled out. This is a typical plot for a vehicle that ran into a red light at a signalized intersection.

The thick vertical line at 1000 feet shows a node, and usually is used to mark the stop bar for the approach. You can tell where you are relative to the intersection by noting the position of the node line. Here you see the typical pattern; the vehicle slowed down and stopped near the stop bar and then accelerated through the intersection. The node location was recorded in the field when the run data was collected.

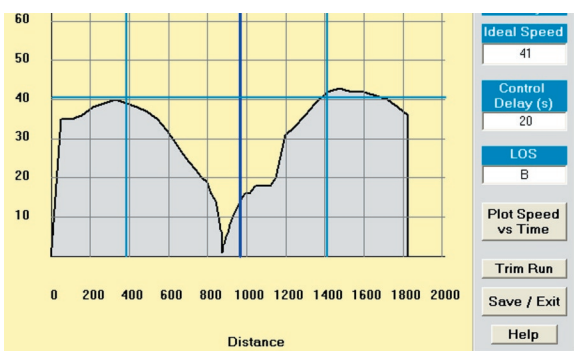
The two vertical lines, one at 460 feet and the other at 1700 feet show the *control points* and are used to mark the beginning and end of control delay for this run. You simply use your mouse to drag the lines to where you feel the control delay starts and stops. The software then calculates the control delay based on these settings. In this case the vehicle first started slowing down at about 460 feet so that is the start delay control point. The vehicle got back up to a free flow speed

at around 1700 feet so that is where the end delay control point should go.

The horizontal line, at 41 MPH, is the *ideal speed* used in the control delay calculation. This is the speed the vehicle would go if there were no congestion. This is initially found by averaging the speeds for the control points, but you can adjust the speed by dragging the line up or down.

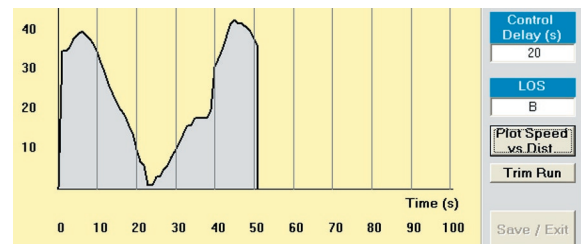
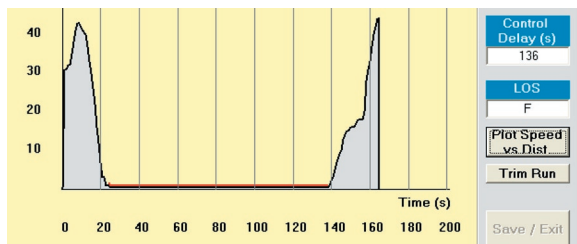
You can change the scale of the graph to make it easier to see using the **Scale** setting at the top right of the screen. This often helps makes setting the control points easier since you can spread the graph out if needed.

Setting the control points is just about the only task that requires any judgement when you run PC-LOS. You need to set the control points for each run in the study. Here are a few of the other runs in the study and comments about the control points:



This is run #2. It has almost the same shape as the first run, but the Control Delay is only 20 seconds compared to 137 seconds. This is because in this run the vehicle wasn't stopped for very long at the light, but it isn't obvious from this plot. If a vehicle stops for 3 seconds or 130 seconds the distance plot will still look the same.

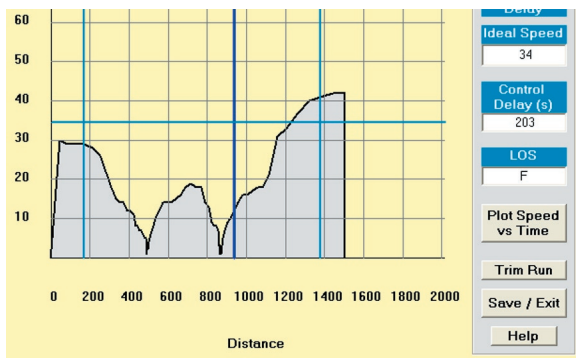
You have the option to show the graph as a Speed vs Time plot which would show the difference between the runs; just click the **Plot Speed vs Time** button on the right side of the screen.



Shown here are the same 2 runs as before, but in Speed vs Time mode. Run 1 is on the left and Run2 is on the right. You can see the long time spent stopped at the light in the first run compared to the much shorter time in the second.

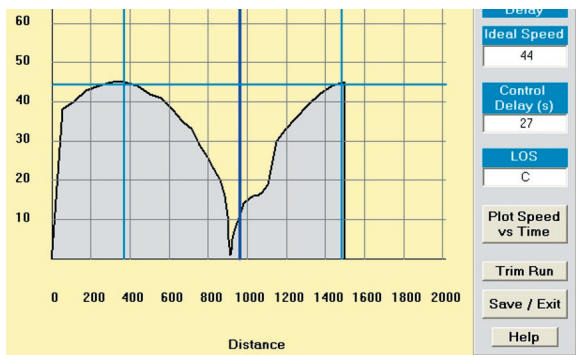
You can set the control points to mark the start and end of control delay on this graph as well; just drag the control points lines to the points on the graph you determine.

The Speed vs Distance plot is used as the default because it is very easy to pick the control points and the graph tends to be more compressed since there are no long stretches of data points when the vehicle isn't moving. Also, since all of the runs start in the same place and end in the same place, the graphs all have the same scale and can be compared to each other a little easier.

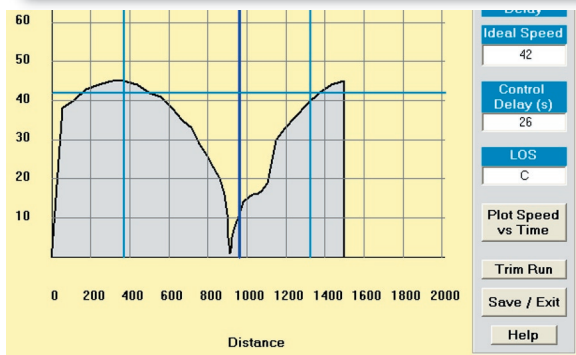


This is run #7. It has a slightly different look. You can see that the vehicle stopped once well short of the stop bar, moved ahead and then stopped again, before finally clearing the intersection. From the Control Delay value (203 seconds) you can see that this vehicle had to wait through two cycles (and this was at 10:47 in the morning!). It is pretty obvious where the delay started and ended for this run so marking the control points is easy.

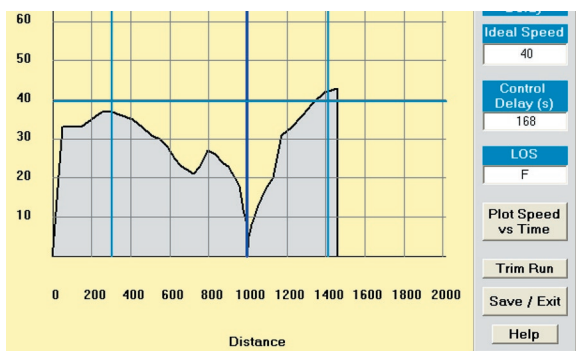
It may seem that the placement of the control points would have an effect on the value of the Control Delay. And this is certainly true. There is some judgement required and the results will vary a little depending on where the points are set, but not as much as you might think.



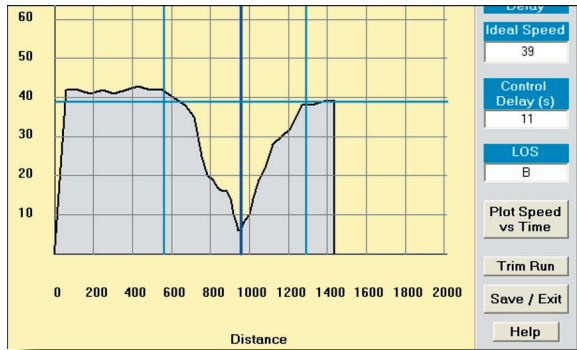
This is run #9. The plot looks very similar to the others we have seen. The Control Delay is 27 seconds, which for this intersection is pretty good. The ending control point is at the far right of the graph, right where the plot is starting to level off. This is the spot most people would place the control point.



This is the same run, but the ending control point is quite a bit to the left of the one shown above. Most people would agree that this control point is not set properly, and yet the Control Delay is 26 seconds, only 1 second different from the other (correct) value. As long as you are reasonably close to the proper value, the results will not vary much.



This is run #12. It shows a slower deceleration profile; the control delay clearly starts at around 200 feet while in most of the other runs the delay starts are around 400 feet. Still it is very easy to pick the point where the vehicle first felt the *friction* of the congestion at the intersection.



This is a run from a different study. It is included here to show what a run with no stop delay looks like. You treat this run just like the others. In this run the vehicle was cruising along, ran into some congestion approaching the intersection and had to slow down to about 10 MPH at the stop bar, but then accelerated up to the free flow speed. It never stopped so there was no stop delay. This is a good example of why the definition of LOS was changed to

be based on control delay instead of stop delay. I doubt the driver of this vehicle would say he experienced no delay going through this intersection.

As you can see from these examples, it usually is not difficult to pick the start and stop of the control delay; it only takes a few seconds to edit each run.

Once all of the control points in the runs are marked, you are essentially done. The software finds the average of all of the individual Control Delays for the runs in the study, this is the Average Control Delay Per Vehicle and is displayed on the **Main** screen. In our example, this is 111 seconds. The software uses this value to find the LOS value, which also is displayed. A value of 111 seconds is solidly in the LOS F category.

PC-LOS allows you to save the study so you can retrieve it at a later date. It also has several reports that you can print to show the results of the study.

## **Summary and Conclusions**

### **Summary**

The first part of this paper briefly described Level of Service and how it is defined by the concept of control delay. Control delay can be described as the total amount of time lost by a vehicle driving through an intersection. It is the difference between the time the vehicle actually took and the time it would have taken under ideal conditions. To measure control delay you must measure the time that a vehicle isn't going as fast as it would like to go. To do this you must measure two parameters, the speed of the vehicle (so you can tell when it is going slower than ideal) and the time (so you can tell how much delay there was). In other words you need to know the velocity profile of the vehicle, the speed of the vehicle on second by second basis.

Once you have the velocity profile you have what you need to do a Level of Service analysis. The velocity profile is used to find the actual delay experienced by the vehicle as it goes through the intersection. This is done by marking the two points that represent the start and end of the control delay. The actual time it took to travel between these two points, minus the time it would have taken under ideal conditions, is the control delay. A simple lookup table gives you the LOS.

The second part of this paper described three systems you can use to collect the velocity profile data required to perform Level of Service studies. These three systems basically collect the same type of data, the speed of the vehicle on a second by second basis. They use three different technologies, transmission sensor, GPS receiver, and OBD-II scan tool, but otherwise are very similar in the procedures you use and the results you get. A key feature of these systems is that the driver of the vehicle does not have to make any decisions about where or when the delay starts; he simply starts a run well in advance of where any delay might start and ends the run well after the delay ends. The analysis software is used to find the specific points where the delay starts and ends. This simplifies the data collection and also makes it safer.; the driver simply drives the route.

Which of these three systems you would choose to use for your data collection is more a matter of preference, convenience, and using what you already have available to you. If you have a GPS receiver now, or have other uses for it then that would be a logical way to go. If you already have a Jamar TDC-8 and have access to a vehicle with an installed transmission sensor, then that would be the logical approach.

The third part of this paper described PC-LOS, the software program designed to analyze the speed data collected in the field and generate LOS statistics. The software is very simple to use; your primary task is to select the runs you want to use in the study and mark the control points where the control delay begins and ends in each of those runs. The software shows you the velocity profile of each run and you use your mouse to mark the control points. Once this is done the software calculates the control delay for each run and then calculates the Average Control Delay, which is then converted to a LOS value.

## Conclusions

### The Problem with LOS

Level of Service is an important concept in traffic engineering, and LOS studies are going to be required for many years to come. Many engineers are unhappy with the state-of-the-art as defined by the current Highway Capacity Manual.

The definition of LOS was changed a few years ago to be based on control delay, which just about everyone would agree in principle is a good thing. It is intuitively more satisfying. The problem is that control delay is difficult to measure since it extends a considerable distance before and after the intersection.

The manual procedure suggested in the HCM use an old procedure that gives a rough estimate of stop delay, which then is converted to control delay, and hence to LOS, by using a factor of 1.3. This simply is bad engineering. Many engineers realize this, and appropriately don't want to use the manual procedure anymore.

Most engineers also realize that the intent of the HCM is not to go out and measure LOS. The suggested procedure in the HCM is a modeling technique that calculates LOS by using a series of equations that have input parameters that have evolved over the years to handle more and more complex situations. The result is the modeling has become so complicated that it is only practical to use computers to evaluate the procedures. This is fine. There is nothing intrinsically wrong with a system that is too complicated to be done by hand anymore. Traffic is complicated, so procedures to evaluate traffic are complicated.

The HCS software, which is designed to implement the procedure in the HCM, is free, reasonably well designed, and reasonably well supported, so this isn't a major problem. There are also many commercially available programs that incorporate the HCM procedures in their modeling, simulating, or optimizing software.

The problem is that the current HCM procedures make it too easy to do sloppy work. There are dozens of input parameters, most of which have default values that may or may not be reasonable for a given intersection. If a dedicated engineer truly wanted to do a rigorous LOS study and measure all of the parameters that can affect the accuracy of the calculations, he would be out of a job ten minutes after submitting the request for the manpower and money required. The result is that many, if not most, LOS studies are done with data that could not be defended if challenged (*is engineering judgement really a defense?*).

### **A Solution: Measure Control Delay Directly**

Because of the problems with the methodology in the HCM, some engineers have looked for alternative ways to do LOS studies. An obvious idea is to measure the control delay directly, since it is so well defined. Measure the control delay, look up the LOS, and you are done.

This logic leads to a problem, however. The only practical way to really measure control delay is to use a floating car methodology, since only a car driving in the traffic is exposed to the full gamut of the control delay before the intersection, at the intersection, and after the intersection.

To measure control delay you need to measure the speed of the vehicle at short, regular intervals (one second intervals works well), store this speed data, and then create a velocity profile of the vehicle (spd vs distance, or spd vs time, either work fine). With a little interaction from the user, the control delay is easily found.

It turns out that the hardware needed to collect this type of data is the same hardware needed to collect travel time and delay data, which typically is used to measure the effectiveness of an entire arterial, not isolated intersections. Jamar Technologies has manufactured and marketed travel time and delay systems since 1988. Others have developed similar systems on their own.

### **PC-LOS**

The authors, under contract with Jamar Technologies, modified the Jamar travel time system (which they developed and support) to develop a system to measure control delay and produce LOS statistics.

This system supports three different technologies to measure the data in the field; TDC-8/ transmission sensor, GPS receiver with a laptop or PDA, and an OBD-II scan tool with a laptop or PDA. These three systems give comparable results; the choice of which to use is primarily based on what equipment is already available.

The field software is the same software used in the travel time software. The data is collected and then transferred to an office computer running a software program called PC-LOS, which was developed specifically for this application.

PC-LOS is a Windows based program that is very simple to use. The primary task of the user is to select the runs to be used in the study and then mark the control delay points on each of those runs. This is easy to do since the software shows the velocity profile of the run on the screen; it is a simple matter to mark the points on the graph where the control delay starts and ends. The software calculates the control delay for each run and also for the entire study. You can save the data for future use and print a variety of reports.



## **Isn't This Just a Revamping of the Floating Car Technique Described Before?**

Yes. The PC-LOS system procedures described in this paper are very similar to the floating car methodology that has been around for years and as discussed earlier, is generally considered too difficult to use to be a viable alternative. We advocate using technology to replace the paper, pencil, and stopwatch, but in both cases you are directly measuring control delay by driving through the intersection. However there are significant advantages to the systems described here:

1) You only need one person in the car to collect the data. The driver only has to push 3 buttons for each run; one to start the run, one to mark the stop bar line, and one to end the run. Two of these button pushes can be done while the vehicle is stopped if desired. As long as the run is started before the control delay begins and ended after the control delay ends then it doesn't matter where the vehicle is when those buttons are pushed. You do have to push a button as you reach the stop bar, but this is not difficult since that is *all* you have to do at that moment (and this step is optional; it helps make reading the graphs a little easier but isn't needed for the data calculations at all).

2) No decisions about where the control delay starts or stops is made in the car. The driver simply drives the route (pressing those three buttons of course).

3) The data analysis back in the office takes a few minutes at most to do a complete study. The primary task is to select the run files created in the field and mark the start and end of control delay on each of those runs. The software does the rest.

4) The control delay calculation is much more accurate because the control delay points are much easier to mark looking at a detailed plot of the speed of the vehicle than while driving in the car. The data is typically collected at one second intervals so you can mark the start and stop of control delay to the nearest second. Also the speed, time, and distance measurements used in the calculations are inherently more accurate due to the technologies used. For example, the accuracy of the speed data generated by GPS receivers is typically on the order of 1 MPH or better.

In short, by adding the technology factor to the old methodology you go from a system that is labor intensive and not very accurate to one that is simple to use and very accurate.

In many ways what makes this system feasible now has nothing to do with the concept. It is the general availability of low cost yet accurate GPS receivers and OBD-II scan tools, coupled with the ubiquity of laptops and PDAs. Floating car methods may not have made sense ten years ago, but the economics have changed tremendously.

## **Perceived Problems With Floating Car Methods:**

Earlier in this paper the three methodologies commonly used to do LOS studies were briefly described. They all have pluses and minuses but only the floating car methods actually measure control delay directly. It would seem that this method would be more popular. Why isn't it?

There are two perceived problems with floating car methods:

### **1) It is too labor intensive:**

The first point, that measuring the data is labor intensive, is certainly true. You have to go to the site, drive through the intersection for an hour or more, and then analyze the data to get a result. Whether this is more labor intensive than other techniques is a matter of opinion.

Floating car methods using paper, pencil, and stopwatch clearly are very labor intensive, but with the use of computers and other technologies you can make the system much more efficient and easy to use.

The second method, the manual stop delay study, is comparable in use of manpower. However it doesn't give a real measure of control delay, it gives an estimate of stop delay. This method simply isn't appropriate any more since the concept of control delay was introduced.

The third method, using the HCM procedures, is more complicated to compare. You can do a minimal study with essentially no field work and generate LOS statistics, which clearly is less labor intensive (but at the price of dubious accuracy). Or you could follow the procedures in the HCM precisely and do several field studies and get very accurate results, which probably would be significantly more labor intensive. Our point is that it isn't as obvious as it may first seem.

### **2) It doesn't give enough data.**

This second objection is in some ways more difficult to evaluate. There are two primary problems with the data you get when measuring control delay with instrumented cars. ***One is that you only get one value of control delay for each run you do, and you need many runs before the data becomes statistically significant.***

This may or may not be a problem. It isn't clear how many runs you need (this will be a major part of the next phase of this project) but certainly more than just a few. It may be difficult to do enough runs during one peak hour period to be confident of the results. In the example shown in this paper 13 runs were done in a one hour period. This is probably sufficient but more work is needed to be certain.

*Another problem is that it isn't normally practical to measure control delay for all of the lane groups at an intersection.* If you use the HCM procedures you get a value for each of the lane groups and one for the entire intersection. It certainly is useful to be able to say “Yes, the LOS of two of the lane groups is F, but the overall LOS for the intersection is D.”

One option is to have two or more instrumented cars all collect data at the same intersection at the same time. Each car would measure two lane groups (go through the intersection one way, turn around and go through the same intersection from the opposite direction). Whether or not this is practical is another question. To answer this you have to consider how many man-hours it takes to collect the data you need for a LOS study now. Since it only takes one tech per car to collect the data needed for PC-LOS (plus the hardware for the car) and that tech can measure 2 lane groups during the same peak hour then if you are considering sending two techs to do a manual intersection stop delay study or a turning movement count you could argue that it is about a tie.

Ultimately, of course, you have to decide how many lane groups you need to measure. Sometimes one or two will be enough (to answer, just how bad is it out there?), sometimes it might be worthwhile to measure more. You have to decide if the extra data you get is worth the extra manpower to get it, something you do all of the time anyway.

### **How Can PC-LOS Help You?**

There basically are two ways you can use PC-LOS.

#### **1) Check the answers you get with your current system.**

You can use PC-LOS to see if some of the assumptions you made in your software are reasonable. Do the LOS analysis as you normally would and then measure one or two of the lane groups with PC-LOS to see how well they compare. You could use the results of PC-LOS, which you could consider as the more accurate, to tweak the settings in your software to make them match. For example, you might change the Saturation Flow Rate a bit to make the control delays match for those lane groups.

#### **2) Replace your current system with PC-LOS.**

You may find the results you get from PC-LOS are easier to understand, explain, and defend and you may decide to use it instead of what you use now. This is particularly true if you don't need to measure all of the lane groups and get an overall LOS for the entire intersection. It may actually take less time and manpower to measure one or two lane groups with PC-LOS than do an equivalent study with an HCM procedure.

## **What is Next?**

This paper describes the hardware and software systems to directly measure control delay in the field. The PC-LOS software is ready to be used, but there is still work we want to do:

### **1) Compare the results obtained with PC-LOS to other traditional procedures.**

Several beta testers of PC-LOS are currently helping with this testing, and we expect many more to help in the future. We are particularly interested in how much data you have to input into the existing software to get good results. There is only one way to do this. A few candidate intersections will be chosen and as much data as possible will be manually collected at the same time PC-LOS run data is collected. The manual data will include turning movement counts, saturation flow rates, pedestrians, bikes, buses, heavy vehicles, arrival types---as much as we can measure at one time with the group we bring.

### **2) Determine how many runs are needed to get a statistically significant result.**

There is some work on this in the literature for travel time run data. We need to adapt that work for this type of data collection. Hopefully we will be able to calculate the statistical significance based on the number of runs and the variability in the runs.

### **3) Adapt the system to work with other types of LOS studies.**

PC-LOS is specifically designed to find control delay for signalized intersections, but it can easily be modified to find the average speed used as the basis for arterial LOS. This support will be added to the software in the near future.

**[www.MeasureLOS.com](http://www.MeasureLOS.com)**

We are setting up a web site to report on the progress of the work we do with PC-LOS. At this site you can download the latest version of PC-LOS, which will be continually tweaked like all software over the next several years. You also can see the results of our testing and what other users have discovered. We plan to have a forum where users can discuss the software, HCM, and whatever else is relevant.

## **References:**

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## **Links:**

The following links may be useful if you wish to learn more about the topics discussed in this paper.

<b><a href="http://www.measurelos.com">www.measurelos.com</a></b>	Support site for PC-LOS (see description on page 28)
<b><a href="http://www.jamartech.com">www.jamartech.com</a></b>	Manufacturer of PC-LOS hardware and software, and other data collection systems.
<b><a href="http://www.gps2traveltime.com">www.gps2traveltime.com</a></b>	Support site for GPS based travel time hardware and software, including links to sources of GPS receivers and PDAs suitable for PC-LOS.
<b><a href="http://www.obd2tt.com">www.obd2tt.com</a></b>	Support site for OBD-II scan tool based travel time hardware and software, including links to sources of scan tools and PDAs suitable for PC-LOS.
<b><a href="http://trb.org">trb.org</a></b>	Transportation Research Board site, for information on the Highway Capacity Manual.
<b><a href="http://www.ite.org">www.ite.org</a></b>	Source for "Manual of Transportation Engineering Studies" Item TB-012 in the ITE Bookstore

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