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16. Abstract Federal and environmental transportation laws require that transportation projects conform to air quality goals in nonattainment areas. If the plan does not conform, funding for transportation could be delayed or withheld. Analysis tools are needed to better estimate the impacts of transportation projects on air quality.  This report documents the methodologies and data requirements for running the comprehensive modal emissions model (CMEM) and documents the results of a case study conducted in the El Paso, Texas, area. The report also discusses the advantages of using the CMEM software and suggests potential uses for the software in the El Paso area. The CMEM software predicts emissions from light-duty vehicles, automobiles, and small trucks. The model estimates emissions for light-duty vehicles under various operating conditions and is capable of predicting fuel consumption and second-by-second tailpipe emissions for various vehicle categories. The main purpose of the model was to estimate vehicle tailpipe emissions for various categories of vehicles, with consideration given to the length of time the vehicle is operating and vehicle operations such as accelerating, decelerating, idling, and cruising.					
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**EL PASO COMPREHENSIVE MODAL EMISSIONS  
MODEL (CMEM) CASE STUDY**

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Mobile Source Emission Modeling: Methods, Sensitivity, and Analysis of Assumptions

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# **EL PASO COMPREHENSIVE MODAL EMISSIONS MODEL (CMEM) CASE STUDY**

The Comprehensive Modal Emissions Model (CMEM) software was developed under the sponsorship of the National Cooperative Highway Research Program (NCHRP). A four-year research project was conducted by the College of Engineering - Center for Environmental Research and Technology (CE-CERT) at the University of California-Riverside and the University of Michigan-Lawrence Berkeley National Laboratory.

The objective of the research was to develop an emissions model that would predict emissions from light-duty vehicles (LDV), which are comprised of automobiles and small trucks. Researchers developed the model to estimate emissions from LDVs under various operating conditions. It is capable of predicting fuel consumption and second-by-second tailpipe emissions for various vehicle categories. The main purpose of the model was to estimate vehicle tailpipe emissions for various categories of vehicles, with consideration given to the length of time the vehicle is operating and vehicle operations such as accelerating, decelerating, idling, and cruising.

## **PROJECT DEVELOPMENT**

Development of the CMEM software was conducted in four major phases. A general description of the phases is outlined below:

- Phase 1 This phase consisted of various efforts including conducting a literature review focused on vehicle operating factors that affect emissions, collecting data sets pertaining to vehicle emissions and activity, and reviewing other emissions models (MOBILE and EMFAC). Additionally, researchers developed a vehicle emissions testing procedure and a small sample of vehicles was tested against this procedure.
- Phase 2 This phase consisted of conducting a test of a larger sample of vehicles, refining the model procedure through an iterative process, and validating model results.
- Phase 3 Data were further analyzed and the model was refined during this phase. Velocity/acceleration tables and vehicle categories were added to the model. A major component of this phase involved examining the interface between the developed model and existing modeling frameworks.
- Phase 4 This final phase involved finalizing vehicle category data, developing a graphical interface that was user friendly, and conducting workshops to disseminate the model to transportation and air quality professionals.

## CMEM MODELING APPROACH

The premise of CMEM is a physical, power-demand modeling approach. In this approach, the model breaks down the emissions process into components that reflect the physical operating and emissions characteristics of the vehicle. Each of the components is then modeled based on various parameters characteristic of the selected component. The parameters are specific to different vehicle categories and based on specifications associated to that vehicle type (e.g., vehicle mass, number of gears, number of cylinders, engine displacement, etc.).

There are several key factors why the physical, deterministic modeling approach was selected in developing the model. Factors such as vehicle technology, accessories on the vehicle, road grade, and maintenance all directly affect emissions levels of a vehicle. This modeling approach considers these factors. This modeling approach also allows integrating vehicles from various categories into an entire emissions inventory. Additionally, the model can be used at a microscale and macroscale level; it is relatively easily validated and calibrated, and it is different than a speed/acceleration matrix approach or emissions map approach in that it is not restricted to pure steady-state emissions events.

## MODEL STRUCTURE

The model itself does not predict emissions for specific makes and models of vehicles but rather estimates emissions for vehicle categories. Vehicle categories were derived based on groupings of vehicles with similar operating and technology characteristics. [Table 1](#) provides the vehicle categories used in CMEM.

Vehicle tailpipe emissions, quantified on a second-by-second basis, are derived as the product of fuel rates (FR), engine-out emission indices ( $g_{\text{emission}}/g_{\text{fuel}}$ ), and a time-dependent catalyst pass fraction (CPF). The formula is:

$$\text{tailpipe emissions} = FR \times \left( \frac{g_{\text{emission}}}{g_{\text{fuel}}} \right) \times CPF$$

Fuel use rates are measured in grams; engine-out emissions index is shown in grams of engine-out emissions per gram of fuel consumed, and catalyst pass fraction is the ratio of tailpipe to engine-out emissions.

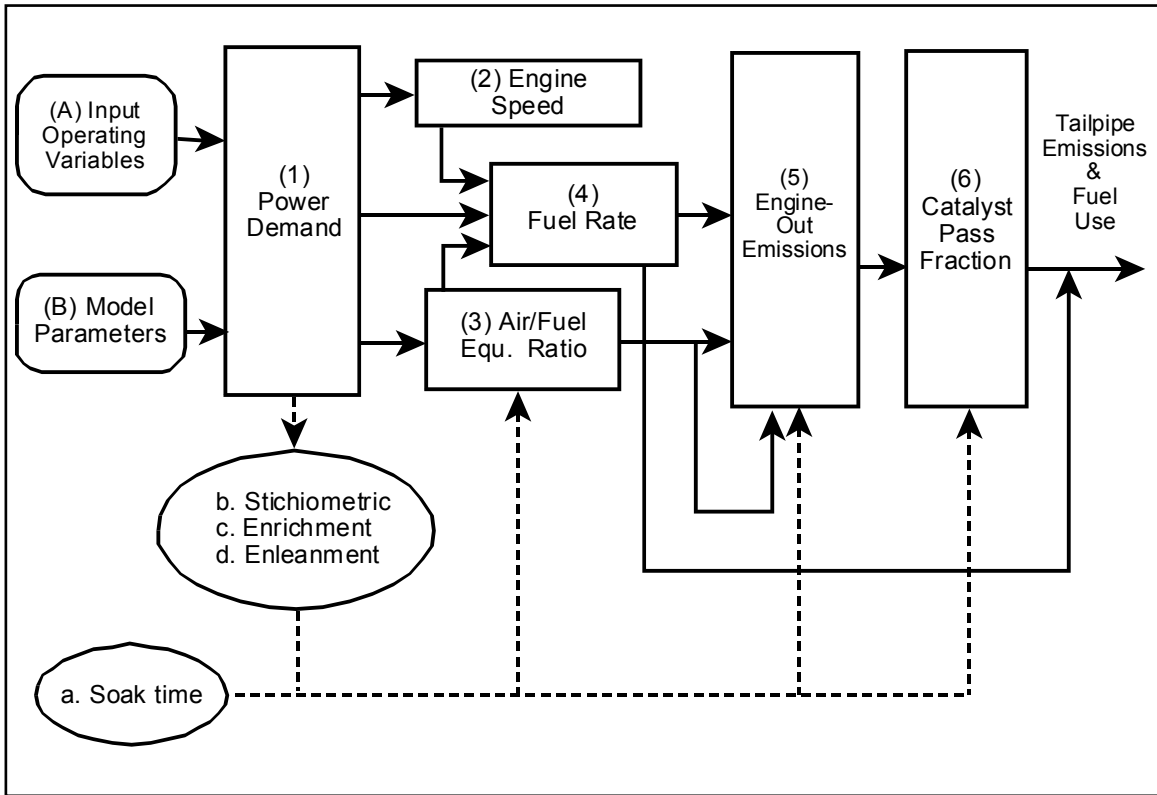
CMEM is comprised of six modules:

- engine power demand,
- engine speed,
- fuel/air ratio,
- fuel rate,
- engine-out emissions, and
- catalyst pass fraction.

The model requires two inputs (input operating variables and model parameters) and produces two outputs (tailpipe emissions and fuel consumption). [Figure 1](#) provides a schematic representation of the model, as shown in the CMEM User's Guide (1). The items shown in ovals represent four different operating conditions. The soak time ( $t_{\text{soak}}$ ) value is input by the user, and the model determines when the operating conditions change from a cold start mode to a fully warm operation condition. The power demand of the vehicle can affect the operating condition of the model, creating a change from stoichiometric to enrichment or enleanment. As shown in [Figure 1](#), these changes will impact the air/fuel ratio, engine-out emissions, and catalyst pass fractions.

**Table 1. CMEM Vehicle Categories.**

<b>Category #</b>	<b>Vehicle Technology Category</b>
<i>Normal-Emitting Cars</i>	
1	No catalyst
2	2-way catalyst
3	3-way catalyst, carbureted
4	3-way catalyst, fuel injected (FI), >50K miles, low power/weight
5	3-way catalyst, FI, >50K miles, high power/weight
6	3-way catalyst, FI, <50K miles, low power/weight
7	3-way catalyst, FI, <50K miles, high power/weight
8	Tier 1, >50K miles, low power/weight
9	Tier 1, >50K miles, high power/weight
10	Tier 1, <50K miles, low power/weight
11	Tier 1, <50K miles, high power/weight
24	Tier 1, >100K miles
<i>Normal-Emitting Trucks</i>	
12	Pre-1979 (<=8500 gross vehicle weight [GVW])
13	1979 to 1983 (<=8500 GVW)
14	1984 to 1987 (<=8500 GVW)
15	1988 to 1993, <=3750 loaded vehicle weight (LVW)
16	1988 to 1993, > 3750 LVW
17	Tier 1 Light-duty trucks (LDT) 2/3 (3751-5750 LVW or Alt. LVW)
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)
25	Gasoline powered, LDT (>8500 GVW)
40	Diesel powered, LDT (>8500 GVW)
<i>High-Emitting Vehicles</i>	
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich



**Figure 1. CMEM Structure.**

CMEM input parameters are divided into two main categories. The first main category is “Readily Available Parameters.” These input parameters are obtained from external sources such as automotive specifications and data sets compiled by the U.S. Environmental Protection Agency (EPA). Readily Available Parameters are further categorized into “specific vehicle parameters” and “general vehicle parameters.” The second main category is “Calibrated Parameters,” and as the name implies, these input parameters are calculated and calibrated from the data. This category is also divided into two sub-sets that are referred to as the “insensitive set” and “sensitive set.” Insensitive set data either are known in advance or have a relatively small impact on vehicle emissions. Sensitive set data, however, must be carefully determined. Sensitive set data also are further divided into three sub-sets: cold-start, hot stabilized catalyst, and enrichment parameters. [Table 2](#) provides a complete overview of the parameters and variables used in the CMEM.

**Table 2. CMEM Parameters and Variables.**

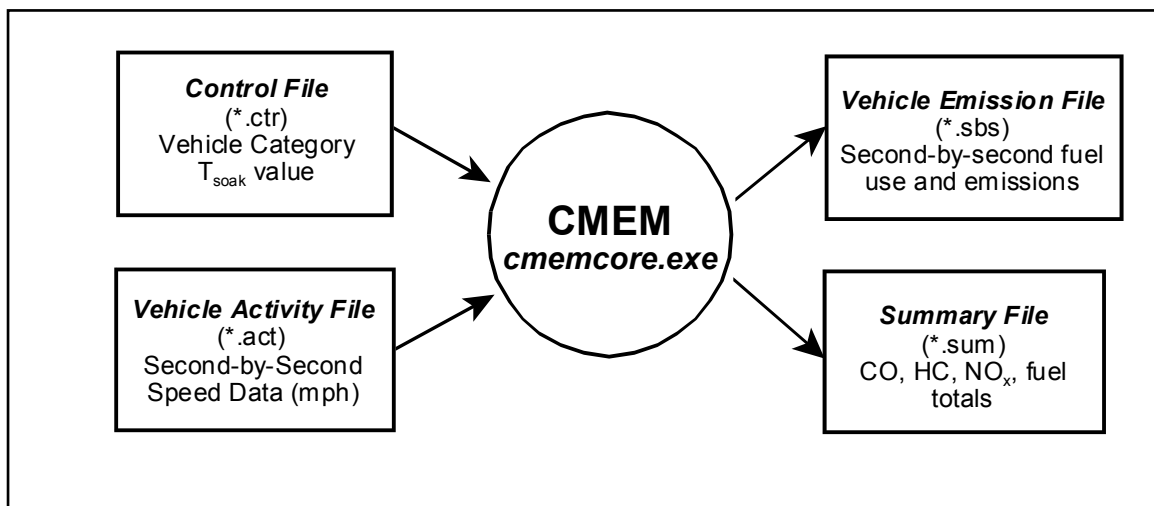
Readily Available Parameters	Calibrated Parameters	
<p><b><i>Specific Vehicle Parameters</i></b></p> <p>M - vehicle mass in lbs  V - engine displacement in liters  N<sub>c</sub> - number of cylinders  Trlhp - coastdown power in hp  S - eng spd/veh spd in rpm/mph  Q<sub>m</sub> - max torque in ft lbs  N<sub>m</sub> - eng spd in rpm @ Q<sub>m</sub>  P<sub>max</sub> - max power in hp  N<sub>p</sub> - eng spd in rpm @ P<sub>max</sub>  N<sub>g</sub> - number of gears</p> <p><b><i>Generic Vehicle Parameters</i></b></p> <p>O - indicated efficiency  g<sub>l</sub> - max drivetrain efficiency  R(L) - gear ratio</p>	<p><b><i>(Insensitive)</i></b></p> <p><b><i>Fuel Parameters</i></b></p> <p>k<sub>0</sub> - eng fri factor in kJ  g<sub>l</sub>, g<sub>b</sub> - drivetrain eff coefficients</p> <p><b><i>Engine-out</i></b></p> <p><b><i>Emission Parameters</i></b></p> <p>C<sub>0</sub> - CO enrich coefficient  a<sub>CO</sub> - EO CO index coef  a<sub>HC</sub> - EO HC index coef  r<sub>HC</sub> - EO HC residual coef  a<sub>1NO<sub>x</sub></sub> - NO<sub>x</sub> stoich index  a<sub>2NO<sub>x</sub></sub> - NO<sub>x</sub> enrich index  FR<sub>NO<sub>1</sub></sub>, FR<sub>NO<sub>2</sub></sub> - NO<sub>x</sub>FR threshold</p> <p><b><i>Enleanment Parameters</i></b></p> <p>hc<sub>max</sub> - max HC<sub>lean</sub> rate in g/s  hc<sub>trans</sub> - trans HC<sub>lean</sub> rate in g/SP  *SP<sub>th</sub> - HC<sub>lean</sub> threshold value</p>	<p><b><i>(Sensitive)</i></b></p> <p><b><i>Cold-start Parameters</i></b></p> <p>\$<sub>CO</sub>, \$<sub>HC</sub>, \$<sub>NO<sub>x</sub></sub> - cold start catalyst coefficients for CO, HC, and NO<sub>x</sub>  N<sub>cold</sub> - cold F/A equi ratio  T<sub>cl</sub> - surrogate temp reach stoich  CS<sub>HC</sub> - cold EO HC multplier  CS<sub>NO</sub> - cold EO NO multiplier</p> <p><b><i>Hot Catalyst Parameters</i></b></p> <p>'<sub>CO</sub>, '<sub>HC</sub>, '<sub>NO<sub>x</sub></sub> - hot max CO, HC, and NO<sub>x</sub> catalyst efficiencies  b<sub>CO</sub>, b<sub>HC</sub>, b<sub>NO</sub> - hot Cat CO, HC, and NO<sub>x</sub> coefficient  c<sub>CO</sub>, c<sub>HC</sub>, c<sub>NO</sub> - hot cat CO, HC, and NO<sub>x</sub> coefficient</p>
<p><b><i>Operating Variables</i></b></p> <p>Z - road grade  P<sub>acc</sub> - accessory power in hp  v - speed trace in mph  T<sub>soak</sub> - soak time (min)  SH - specific humidity (grams/lb)</p>	<p>r<sub>R</sub> - HC<sub>lean</sub> release rate in 1/s  r<sub>O<sub>2</sub></sub> - ratio of O<sub>2</sub> and EHC  N<sub>min</sub> - lean fuel/air equi ratio</p> <p><b><i>Soak-time Parameters</i></b></p> <p>C<sub>soak_CO</sub>, C<sub>soak_HC</sub>, C<sub>soak_NO</sub> - soak time eng coef for CO, HC, NO<sub>x</sub>  "soak_CO, "soak_HC, "soak_NO - soak time  Cat coef for CO, HC, NO<sub>x</sub></p>	<p>id - NO<sub>x</sub> Cat tip-in coefficient</p> <p><b><i>Enrichment Parameters</i></b></p> <p>N<sub>0</sub> - max F/A equi ratio  SP<sub>scale</sub> - SP threshold factor</p>



## RUNNING CMEM

CMEM software was developed to provide users with flexibility. Therefore, it is provided in two formats. One format allows the user to execute command-line statements in a DOS operating system, and the other allows the user to utilize the software with a graphical user interface, specifically Microsoft® ACCESS. The premise of the two formats is the same for both interfaces. Additionally, the model allows the user to analyze data in two forms: core model and batch model.

Core Model allows the user to produce emissions data for a specific vehicle category with specific activity data. The model uses two input files and produces two output files. [Figure 2](#) provides a graphical representation of the core model. For inputs, the model requires a control file that provides specific information as to the vehicle category and a  $T_{soak}$  value. Each vehicle category has multiple parameters that are assigned default values, and the model user is allowed to overwrite these default values if needed. The second input value is a vehicle activity file, which is a column-oriented data set. The minimum required data for this file is time (in seconds) and speed (in miles per hour [mph] or kilometers per hour [kph] depending on the control file set-up). Other fields that may be applied to the vehicle activity file include acceleration, grade, and secondary load activities such as the use of vehicle air conditioning.

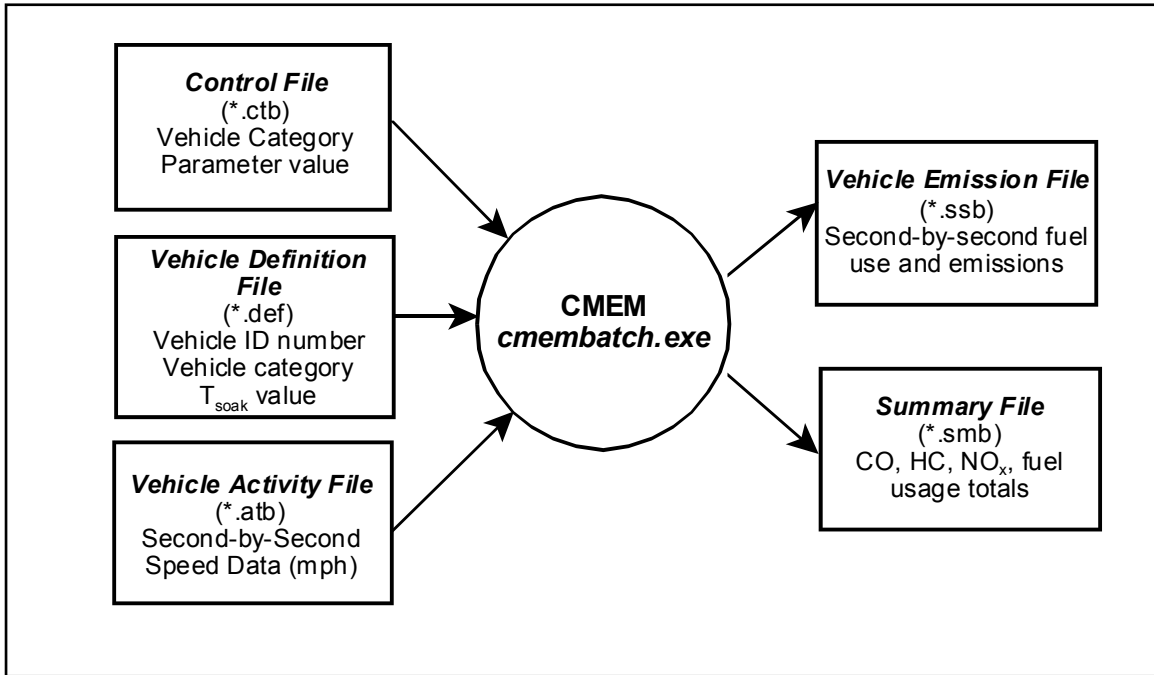


**Figure 2. CMEM Core Model Input/Output.**

The outputs produced by the core model include a summary file and a vehicle emissions file. The summary file provides column-oriented data detailing vehicle category parameters, length of route analyzed, fuel consumption (grams/mile), carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO<sub>x</sub>) emissions (grams/mile). The vehicle emissions file provides similar usage levels but supplies this information on a second-by-second basis.

Batch Model allows the user to produce emissions data for multiple vehicles (including those in different vehicle categories) with different trajectories as specified in the vehicle activity file. The model uses three input files and produces two output files. [Figure 3](#) provides a graphicsl

representation of the batch model. For inputs, the model requires a parameter control file, which provides model running parameters and the ability to overwrite vehicle category default parameters. In the vehicle definition file, the user provides a matrix correlating vehicle identification numbers, vehicle categories, and  $T_{soak}$  values. The final input is a vehicle activity file that is similar to the one used in the core model; however, it provides an additional column indicating which vehicle identification number correlates to the speed data.



**Figure 3. CMEM Batch Model Input/Output.**

Like the core model, the batch model produces a summary file and a vehicle emissions file. The summary file provides column-oriented data detailing vehicle category parameters, length of route analyzed, fuel consumption (grams/mile), and CO, HC, and NO<sub>x</sub> emissions (grams/mile). The vehicle emissions file provides similar usage levels but supplies this information on a second-by-second basis.

The model application is structured so that it may be run in a command-line mode in a DOS environment or using Microsoft<sup>®</sup> ACCESS in a Windows<sup>®</sup> environment. In the command-line mode, the input tables must be structured and saved in a specific format by the user. In Microsoft ACCESS, the CMEM application produces tables based on the data supplied by the user, and these tables serve as the inputs when the user performs certain actions.

## DATA COLLECTION

To supply input data for the CMEM software, it was necessary to collect data that supplied the specific information required by the software. The following will provide an overview of the data collection process, including the equipment needed, setup and use of the equipment, and the process used to reduce the raw data into a format that is usable by the CMEM software. In general terms, there are three key elements needed by the user to collect data needed to run the model—a vehicle, a Global Positioning Satellite (GPS) receiver, and a laptop computer. It is worth noting that there are various methods to collect the data, and this summary provides an overview of only one such method researchers used to collect data in El Paso, Texas, in August 2001.

As previously described, there are two key inputs to the CMEM software. These inputs are vehicle-related information that describes the vehicle category and any other parameters associated with that vehicle, and second-by-second speed data. Default values for various parameters are given for each vehicle category. Therefore, it is not required to determine values for all of the parameters, but that option is allowed if the model user desires to modify the settings. In addition to noting the vehicle type used in the data collection process, the user should also note  $T_{\text{soak}}$  value information.  $T_{\text{soak}}$  values are provided in the \*.ctr file when using the core model and in the \*.def file when using the batch model.

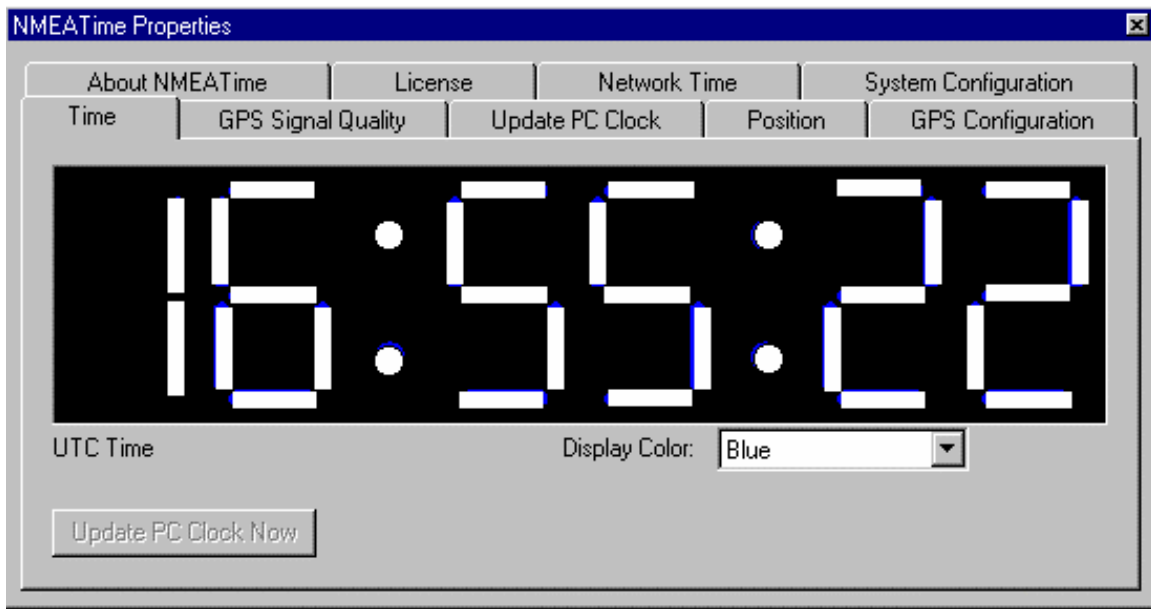
Second-by-second speed data may be obtained using different methods. In this case study, researchers used a GPS receiver in conjunction with a laptop computer to collect the speed data. The receiver used to collect data in this case study was a GPS 35/36 TracPak<sup>TM</sup> manufactured by the GARMIN Corporation. This particular GPS package collects various streams of data on a second-by-second basis. For this data collection effort, the streams obtained were:

- ***GPS Fix Data (GPGGA)*** - includes Universal Time Coordinated (UTC) time of position fix, latitude and longitude data, GPS reception quality, and antenna height;
- ***GPS DOP and Active Satellites (GPGSA)*** - includes number of satellites used in solution and horizontal, vertical, and position dilution values;
- ***GPS Satellites in View (GPGSV)*** - includes number of sentences to be transmitted, number of satellites in view, and satellite information; and
- ***Recommended Minimum Specific GPS/Transmit Data (GPRMC)*** - includes UTC time of position fix, latitude and longitude data, speed, course, and magnetic variation.

The primary data stream used to produce input for the CMEM software is the GPRMC stream. Manipulation of this raw data, which is discussed in following sections, is needed prior to input into the model.

The final component of the data collection “system” is a computer. For this effort, researchers used a laptop computer with a Microsoft® Windows® 95 operating system. The reason for using a laptop is that it provides the flexibility and compactness needed for use in a vehicle. For the data collection system to be effective, specific pieces of software were needed to accurately collect and archive the raw data. There were three specific software applications used, which are described below in the sequence they were applied in the data collection process.

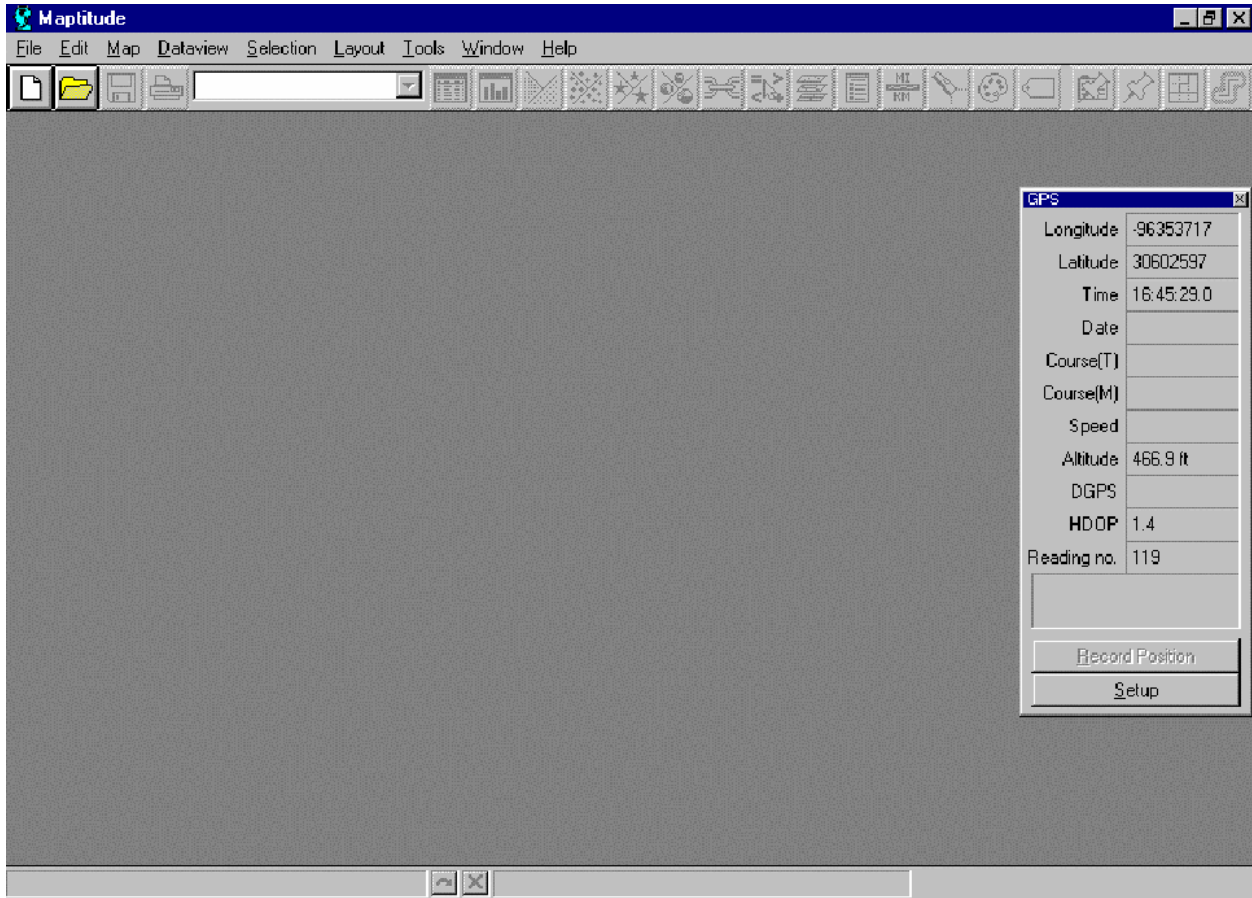
- **NMEATime**® is software that allows users to set a computer’s clock according to the atomic time standard. Time is updated either through a connection to the Internet, or in this case, via a GPS receiver. All of the four data streams mentioned above provide a time component to them. NMEATime® extracts this information and subsequently updates the computer’s internal clock. [Figure 4](#) provides a screen capture of the graphical interface.



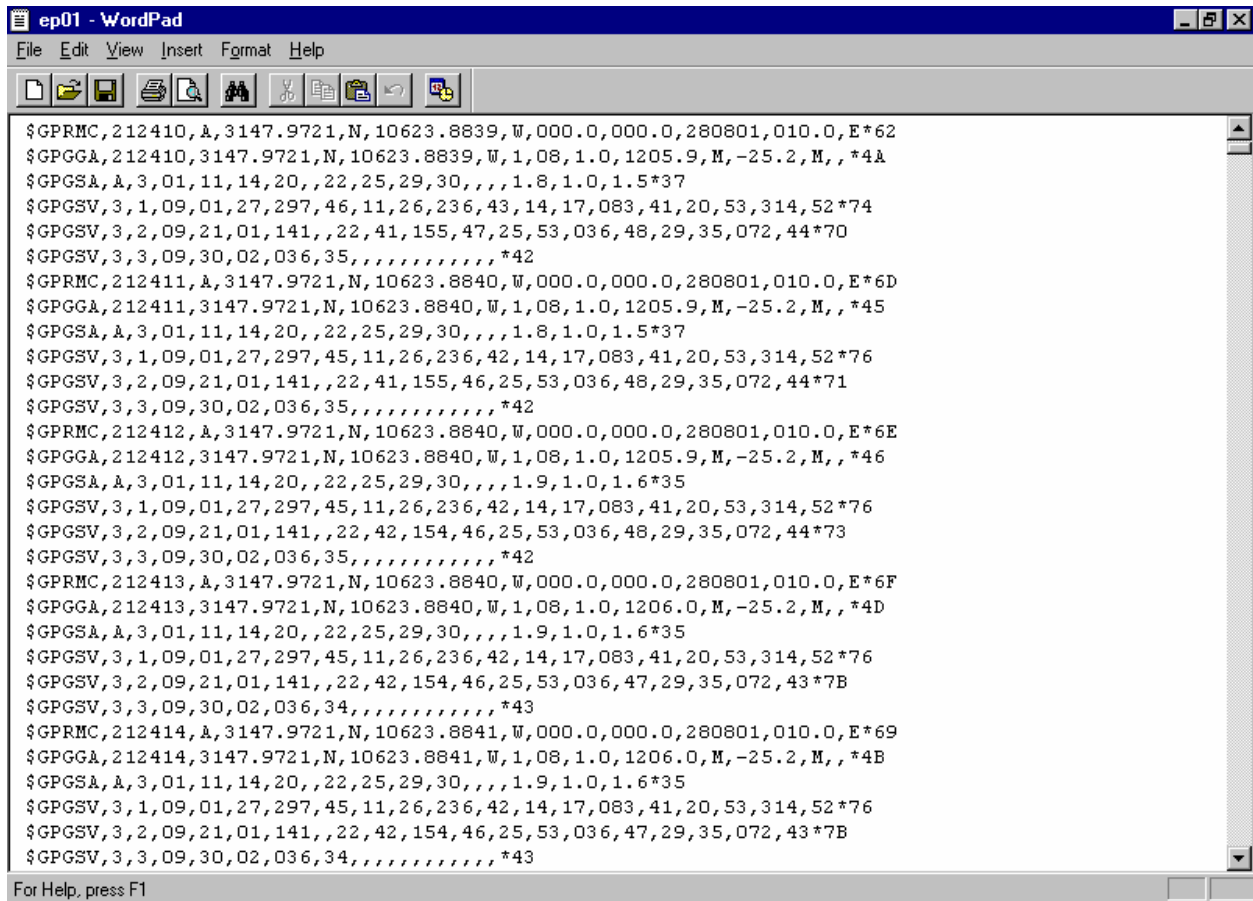
**Figure 4. NEMATime® Software.**

- **Maptitude**® is a GIS software program that has multiple applications. One of the applications is the ability to compile a GPS playback file. The GPS playback file archives the GPS data that are received by the unit. [Figure 5](#) provides a graphical view of the Maptitude® program capturing GPS transponder data. The data that are collected are saved in a comma-delimited text file. The text file contains the data streams discussed previously, and [Figure 6](#) provides an example of the output.
- **Runstart** is a simple FORTRAN program written by researchers at the Texas Transportation Institute (TTI) to identify when the true data collection begins. The logic for this is because the Maptitude® GPS playback file begins recording data on a second-by-second basis as soon as the file is created. The Runstart program allows the user to create a file name and note start points and end points, as well as enter

intermediate points of reference along a given route. Each time data are entered in the Runstart program, the data file gives that entry a time stamp. The time stamps can be matched against the time given in the GPS playback file to synchronize the true beginning and end points of the data collection run. Figure 7 provides a graphical view of the Runstart program with sample data entered, and Figure 8 shows the output of the data entered in Figure 7.



**Figure 5. Maptitude® Software Capturing GPS Data.**



**Figure 6. GPS Playback Data.**

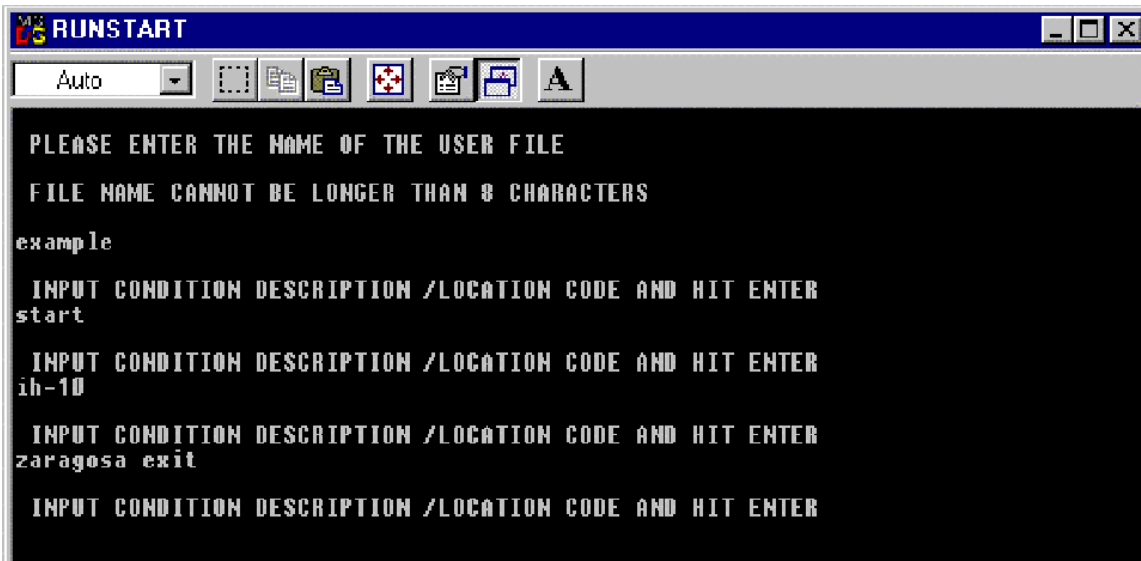


Figure 7. Runstart Screen Capture.

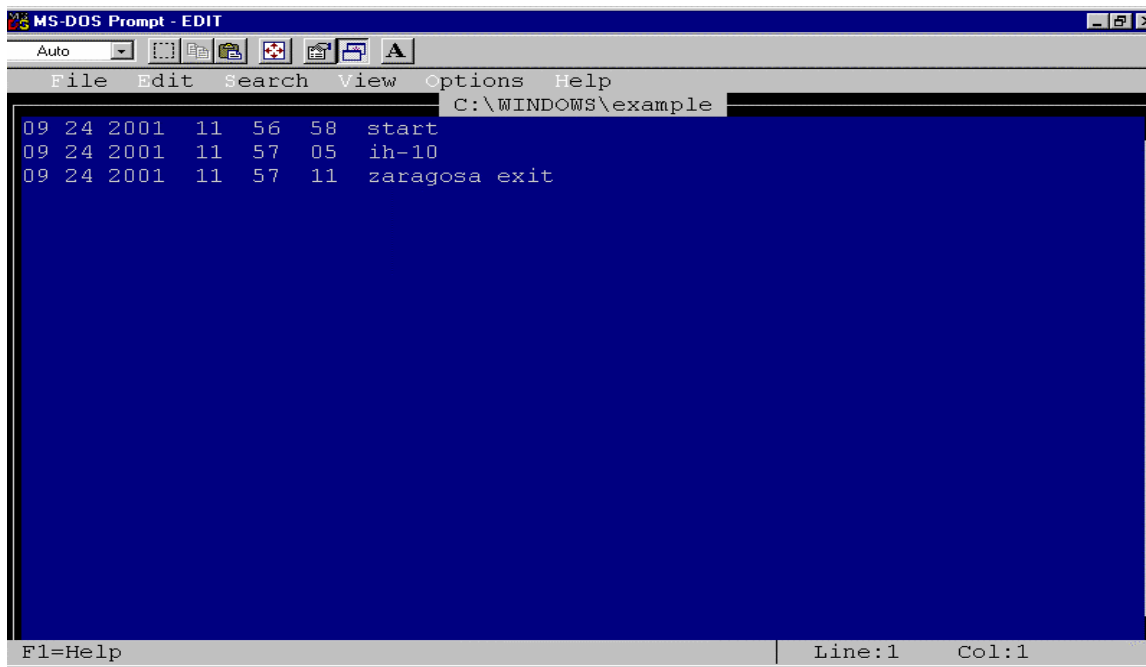


Figure 8. Runstart Example Output File.

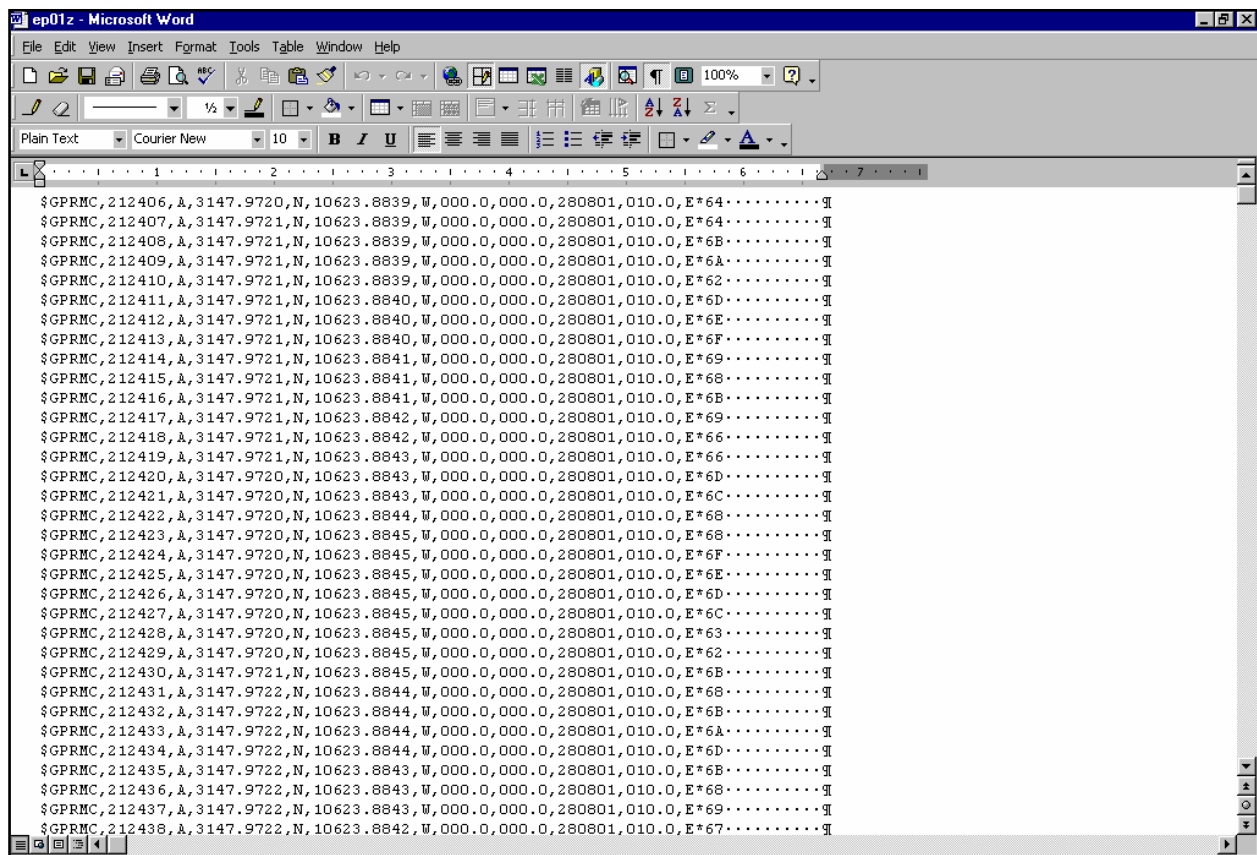
In [Figure 8](#), the first three columns of a line provide the date (MM DD YYYY); the second three columns provide the time (HH MM SS), and the final column is the text that was entered by the user. This sequence of data is repeated each time the user hits the “Enter” key.

## DATA REDUCTION PROCESS

The GPS playback file created using the GPS receiver and Maptitude<sup>®</sup> software included more data than were needed for input into the CMEM software. Therefore, it was necessary to reduce the raw data into a format that was usable by CMEM. There were two main issues that needed to be resolved for this to occur. The main issues were removing the extraneous data that were collected and converting the reduced data into a format that was recognizable to the CMEM model. Several steps were taken to accomplish this, and they will be explained in the following paragraphs. It is possible to reduce the raw data into a format that is usable as an input to CMEM by writing a program in packages such as FORTRAN or other programming languages.

The following provides a sequence of events that was used to reduce the raw data into a format that could be used as an input to the CMEM software batch mode.

1. The first step in the reduction process is removing the extra data collected by the GPS unit. The second-by-second speed data are needed for input information, and that information is found in lines that start with \$GPRMC (see [Figure 6](#)). All lines that do not begin with this sequence should be removed, leaving only lines of data that have a specific column dedicated to speed data (see [Figure 9](#)).



The image shows a screenshot of a Microsoft Word document titled "ep01z - Microsoft Word". The document contains a list of \$GPRMC GPS data lines. Each line follows the format: \$GPRMC,YYMMDD,A,LL.LL,LL.LL,N,LL.LL,LL.LL,W,SS.S,SS.S,E,A\*HH. The lines are numbered 1 through 38. The data includes coordinates (Latitude, Longitude), speed (SS.S), and heading (SS.S). The heading values are: 64, 64, 6B, 6A, 62, 6D, 6E, 6F, 69, 68, 6B, 69, 66, 66, 6D, 6C, 68, 68, 6F, 6E, 6D, 6C, 63, 62, 6B, 6B, 6A, 6D, 6B, 68, 68, 69, 67.

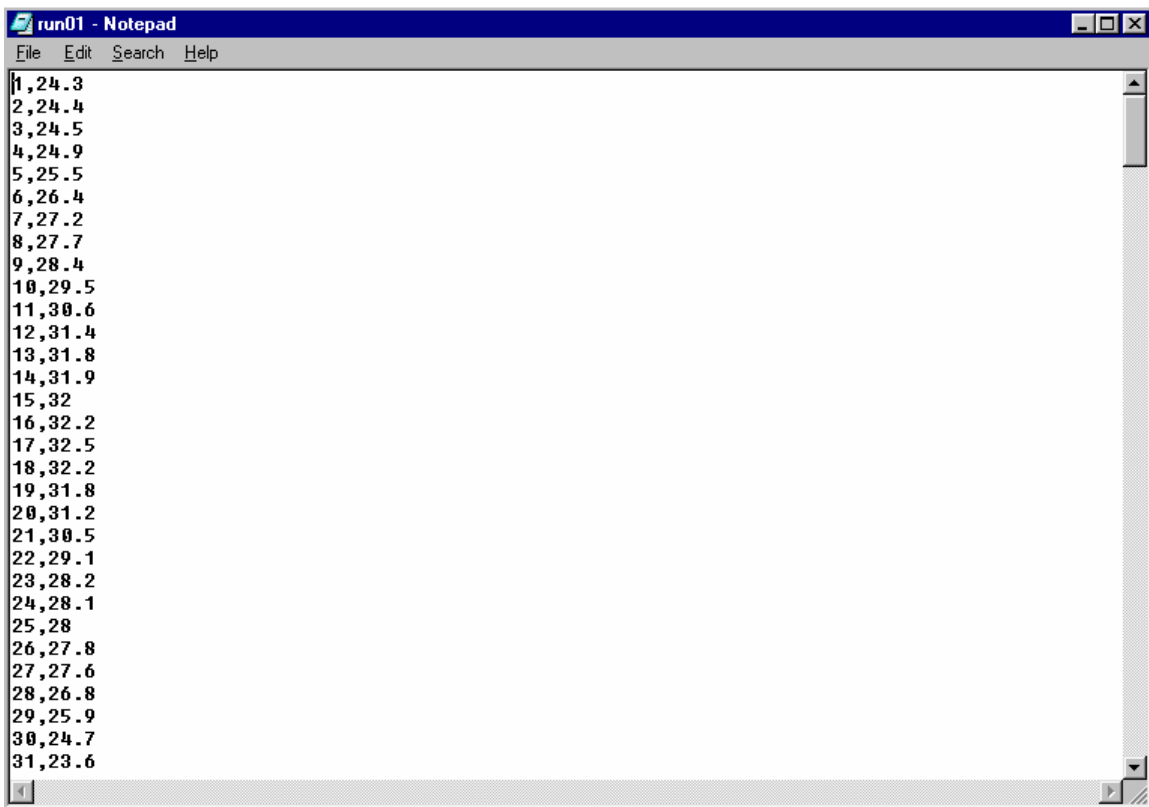
Figure 9. \$GPRMC GPS Data.

2. Next, open the corresponding Runstart output file (see [Figure 8](#) for an example) to note



when the true data collection period began and ended. These times are correlated to the times in the reduced GPS playback file. Any times in the playback file that are before the indicated start time in the Runstart output file are deleted. This process is also performed for any times that occurred after the indicated end time in the Runstart file. What remains is a series of \$GPRMC lines of data that matched the exact time the data collection run began and ended.

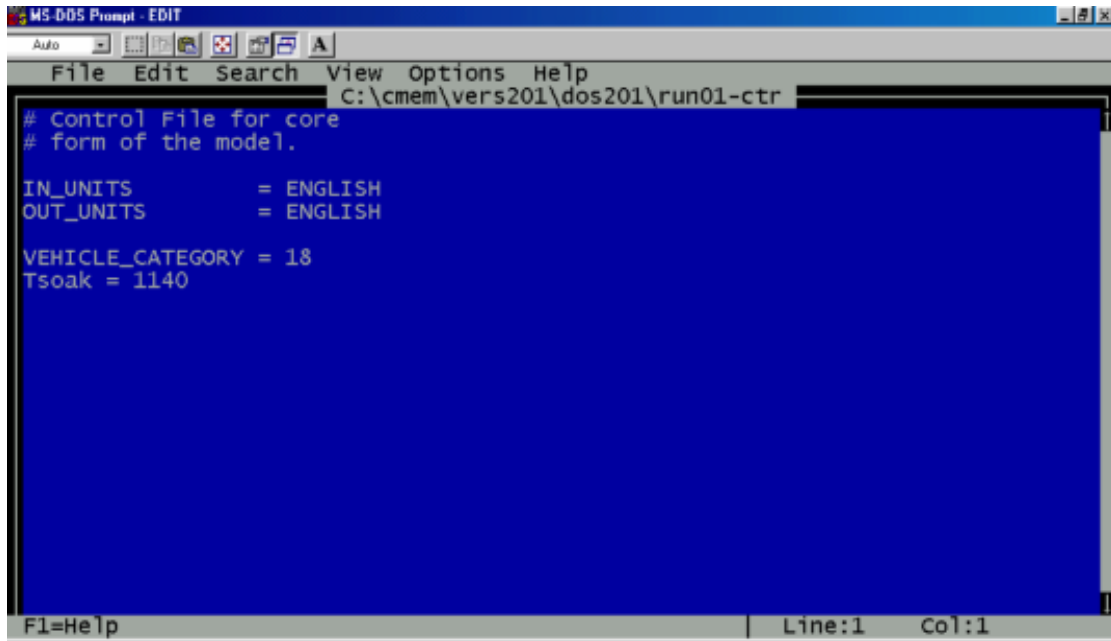
3. At this time, the raw data have been reduced to include only the \$GPRMC data for the time of the data collection run that was to be analyzed. Only the speed data are needed, so the column of data that contains this information is extracted from the playback file. This left a single column of speed data.
4. The GPS playback file collects speed in knots. Therefore, it was necessary to convert knots into mph using the conversion that 1 knot = 1.150778 mph. It is possible to use kph by designating this unit of measurement in the control (\*.ctr) file.
5. The final step in reducing the raw data was to assign a sequential number to each speed value. At this point, the data were saved as a comma-delimited ASCII text file. [Figure 10](#) provides an example of this.



**Figure 10. Reduced Data File.**

The data shown in [Figure 10](#) are in a format that is usable as the vehicle activity file (\*.act). As

mentioned previously, the other input required for the CMEM software is a control file (\*.ctr). Figure 11 provides an example of a control file.



```
MS-DOS Prompt - EDIT
File Edit Search View Options Help
C:\cmem\vers201\dos201\run01-ctr
# Control File for core
# form of the model.

IN_UNITS      = ENGLISH
OUT_UNITS     = ENGLISH

VEHICLE_CATEGORY = 18
Tsoak = 1140

F1=Help | Line:1 Col:1
```

**Figure 11. Example Control File.**

## Data Processing

The CMEM software has two methods to process data—the core model and the batch model. For this evaluation, researchers used the core model method. Additionally, the model may be run in either a DOS or Microsoft® Windows® operating system. In this evaluation, researchers used the DOS version of the software. The method used to process the two input files involved typing a command line argument. An example command line argument for the core model is:

*cmemcore example-ctr example-act*

The command line argument supplies three pieces of information. First, it identifies the model type, in this case the core model. Second, it supplies the name of the two input files needed for processing. In this scenario, the file names are “example-ctr” and “example-act.” After selecting the “Enter” key, the CMEM software processes the data and produces two output files. The file output extensions are \*.sbs and \*.sum. The \*.sbs file provides emissions output on a second-by-second basis, and the \*.sum file provides summary information. Examples of \*.sbs and \*.sum files are provided in Figures 12 and 13, respectively.

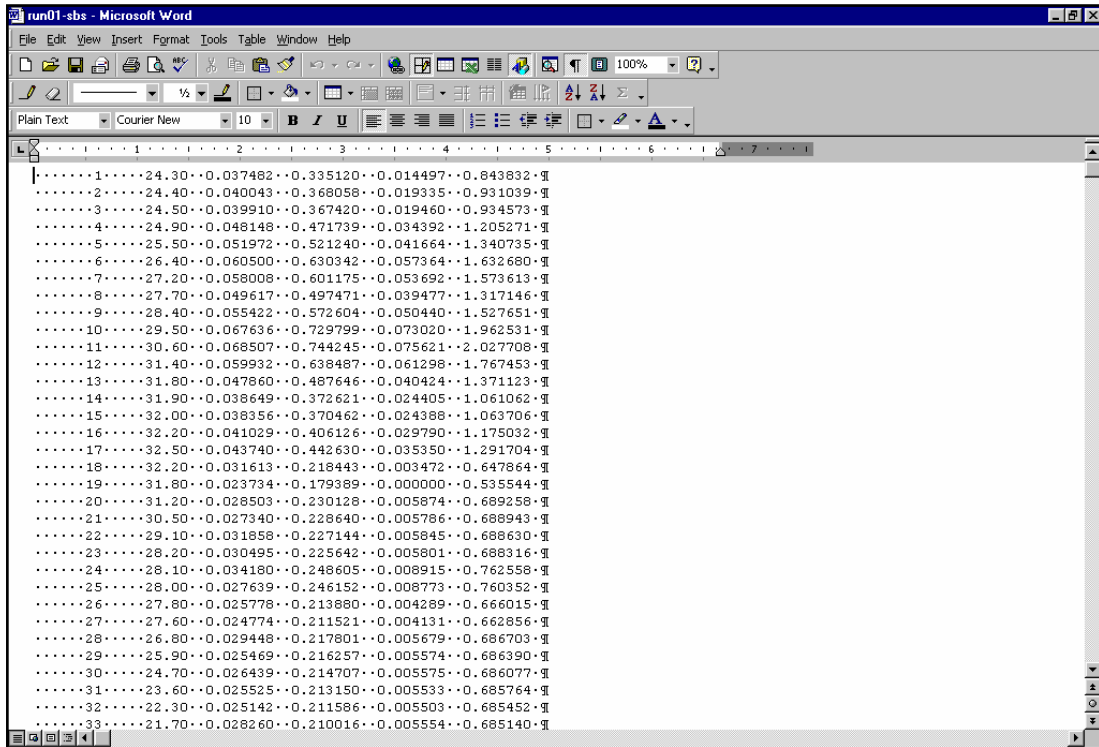


Figure 12. Example \*.sbs Output.

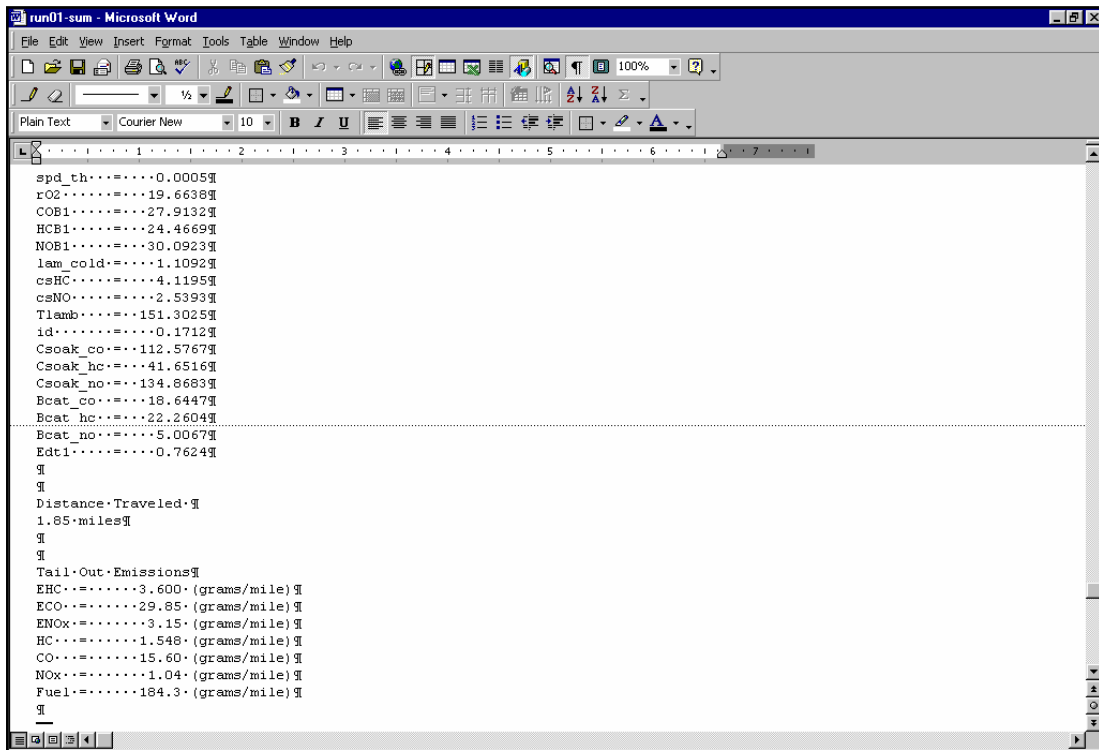


Figure 13. Example \*.sum Output.



## CASE STUDY OF EL PASO, TEXAS

El Paso, like many other urban areas in Texas and around the country, has been dealing with the problems related to air pollution for many years. There are various reasons for the air quality problems in El Paso, some of which are not exclusive to only El Paso. The city is partially surrounded by mountains that restrict the dispersal of pollutants, and the city receives, on average, less than 10 inches of rain a year. Additionally, wintertime inversions that trap emissions close to the ground and result in buildups of CO are common. However, unlike many other urban areas, a large industrial city (Juarez, Mexico) with relatively few emissions restraints lies just across an international border from El Paso.

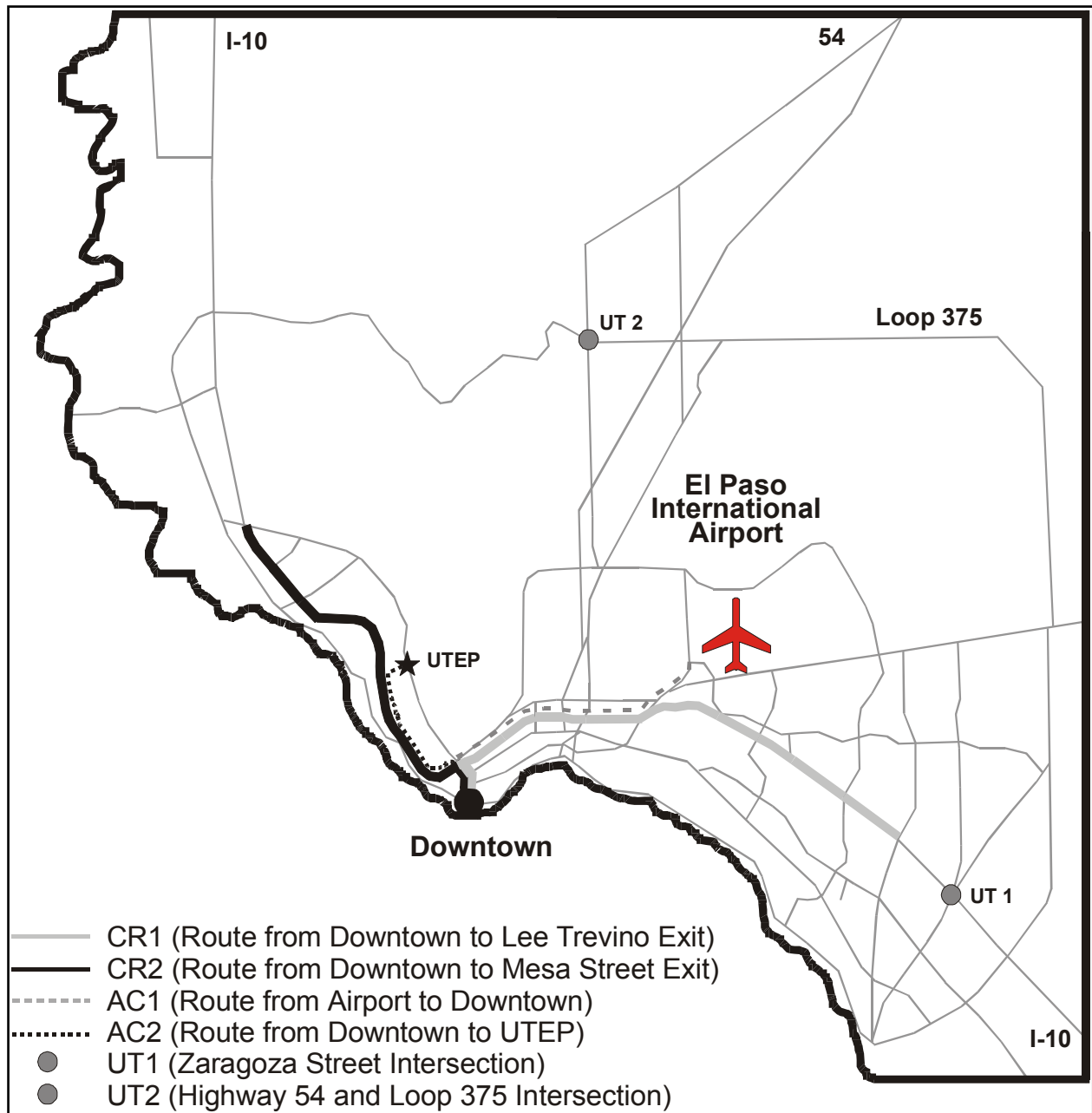
The pressure to improve air quality has come during a time when the region is experiencing high levels of growth. El Paso has a population of approximately 600,000 people, and Juarez has a population of nearly 1.2 million people. In addition to the growing population, there is a significant increase in traffic crossing one of the three international bridges connecting the two cities. This traffic is comprised of several groups including people who are commuting to work, tourists, and a large number of vehicles transporting commercial goods into or out of the U.S. The increasing population levels and the surge in the movement of goods through the region has resulted in higher volumes of traffic and congestion.

As a result, there has been a significant amount of research and planning activity in the region. These efforts are geared toward improving the overall air quality of the region. One potential method to assist in the monitoring of current emissions levels and evaluating potential emission-reducing strategies is the CMEM software.

During a three-day period in August 2001, TTI collected data in the El Paso area. Researchers collected nearly seven hours of speed data during this period. The number of miles covered during this time period was approximately 195 miles. The data were collected to accumulate speed data that could be input into the CMEM model and subsequently processed and analyzed. There were three specific scenarios identified as being useful in the research effort:

- commuter routes in the peak and off-peak direction,
- travel routes between activity centers, and
- traffic operation improvements.

Due to the numerous routes and corridors available in the region to evaluate, the extent of the evaluation is limited to two cases for each of the scenarios. The remainder of this section provides a description, summary, and analysis of the three scenarios. [Figure 14](#) provides a map that identifies the locations of the scenarios. The results provided in this section pertain to the emissions and fuel use of one vehicle. This section also provides a methodology for expanding the data to estimate the emissions and fuel use for each of the scenarios as well as results obtained by applying that methodology. Additionally, the [appendix](#) provides a series of figures that compare speed and emissions over a period of time for the various scenarios.



**Figure 14. El Paso Transportation Network.**

## COMMUTER ROUTES IN THE PEAK AND OFF-PEAK DIRECTIONS

To obtain a better understanding of the emissions produced during a peak period on a major commuter route, researchers collected data on the Interstate Highway (IH) 10 corridor. Data were collected for two separate segments of the corridor, as well as in the peak and off-peak directions. [Figure 14](#) graphically shows the locations of the two corridor segments. The routes were:

- **Commuter Route 1 (CR1)** - This corridor is comprised of the section of IH-10 from downtown El Paso to the Lee Trevino exit. Data were collected on this segment during the morning peak period. Therefore, eastbound traffic is considered the off-peak direction, and westbound traffic is considered the peak direction. The total one-way length of the route was approximately 10 miles.
- **Commuter Route 2 (CR2)** - This corridor is comprised of the section of IH-10 from downtown El Paso to the Mesa Street exit. Data were collected on this segment during the morning peak period. Therefore, eastbound traffic is considered the peak direction, and westbound traffic is considered the off-peak direction. The total one-way length of the route was approximately 7.5 miles.

Generally, traffic flow in the off-peak direction was free-flow for both CR1 and CR2. In a couple of instances, speeds were reduced to less than the posted speed limit because of a broken-down or abandoned automobile or road debris. In the peak direction for CR1, traffic was extremely heavy from the beginning of the route to the U.S. Highway 54 interchange. After this interchange, traffic flow improved, but the volume of traffic was still high. For CR2 in the peak direction, traffic was heavy and speeds were well below the posted speed limits near the Sunland Park interchange. After this merge area, the flows improved. The emissions and fuel usage levels associated with each of these routes are substantially different for the peak and off-peak directions, and are shown in [Table 3](#).

**Table 3. Commuter Route Summary Information.**

Route	Direction	Segment Length (miles)	Time	Avg. Speed (mph)	Emissions (grams)			Fuel Usage (grams)
					HC	CO	NO <sub>x</sub>	
CR1	Off-Peak	10.2	10:59	56	3.325	55.284	6.324	1461.7
	Peak		20:42	30	3.427	38.862	4.080	1615.7
CR2	Off-Peak	7.5	7:24	61	2.948	39.750	5.250	1108.5
	Peak		9:49	46	3.113	59.925	6.075	1177.5

CR1 had an increase in travel time from the off-peak to peak direction of nearly 90 percent, while the average speed over that segment decreased 46 percent. For CR2, the increase in travel time was less, at 33 percent. There was a decrease of 25 percent in the average speed for off-peak versus peak directions for CR2. The resulting change in fuel use for the two routes was 11 percent more for the peak direction for CR1 and 6 percent more for the peak direction on CR2.

The emissions output for the two commuter routes was less definitive. HC, CO, and NO<sub>x</sub> emissions in the CR2 peak direction showed increases over the off-peak direction. For CR2, HC emissions increased 6 percent, CO increased 51 percent, and NO<sub>x</sub> increased 6 percent. However, the output for CR1 showed decreases for CO and NO<sub>x</sub>. For CR1, HC showed a moderate increase of 3 percent from the off-peak to peak direction, while CO emissions decreased by 30 percent and NO<sub>x</sub> decreased by 35 percent.

### TRAVEL ROUTES BETWEEN ACTIVITY CENTERS

To obtain a better understanding of the emissions produced by vehicles, researchers collected data on two separate routes that linked specific activity centers in the El Paso area. They collected data for two separate routes, and Figure 14 graphically shows the locations of the two routes. The routes were:

- **Activity Center Route 1 (AC1)** – Roads between the El Paso International Airport and downtown El Paso comprised this route. The route began at the airport exit, traveling on Airway Blvd to IH-10. It then traverses IH-10 West to the downtown El Paso exit. This route was 8 miles in length.
- **Activity Center Route 2 (AC2)** – Roads between downtown El Paso and the University of Texas at El Paso (UTEP) comprised this route. This route began in the downtown area, traveled to IH-10 in a westerly direction, exiting at the Sun Bowl exit, and following the feeder road until the entrance to the UTEP campus. This route was 2 miles in length.

Table 4 provides summary information for both activity-center-to-activity-center routes that were analyzed.

**Table 4. Activity Center Route Summary Information.**

Route	Segment Length (miles)	Time	Avg. Speed (mph)	Emissions (grams)			Fuel Usage (grams)
				HC	CO	NO <sub>x</sub>	
AC1	8.00	19:51	24	3.760	55.440	3.360	1585.6
AC2	1.96	7:21	16	2.983	40.102	2.744	560.0



## TRAFFIC OPERATION IMPROVEMENTS

The El Paso area has various traffic operation improvements. Researchers decided that only one would be measured to determine its impact on emissions. Although researchers only analyzed one type of operation improvement, data were collected at two separate locations. The type of traffic operation improvement reviewed was a U-turn at a diamond interchange. For each location, researchers collected two sets of data. One set of data was collected using the U-turn as a method to change from traveling in the eastbound direction to the westbound direction. The second set of data was collected by making the same change of direction, but in this case, traveling through the traffic signals was the method to accomplish this change in direction. The locations were:

- **U-Turn 1 (UT1)** – This test was on Eastbound IH-10 at the Zaragoza Street intersection. In both of the data collection runs, data were collected from a point on the eastbound frontage road to a point on the westbound frontage road. Those points are the entryway to a video store on the eastbound side and the entrance to a restaurant on the westbound side. The total length between these points was 1.2 miles.
- **U-Turn 2 (UT2)** – This test was on Northbound U.S. Highway 54 at the Loop 375 intersection. In both data collection runs, data were collected from a point on the northbound frontage road to a point on the southbound frontage road. Those points are a restaurant entrance on the northbound side and the point where an exit ramp merged with the frontage road on the southbound side. The total length between these points was approximately 1.3 miles.

Table 5 provides summary information for each of the two locations. For both locations, the summary is further divided by the operation improvement measure used.

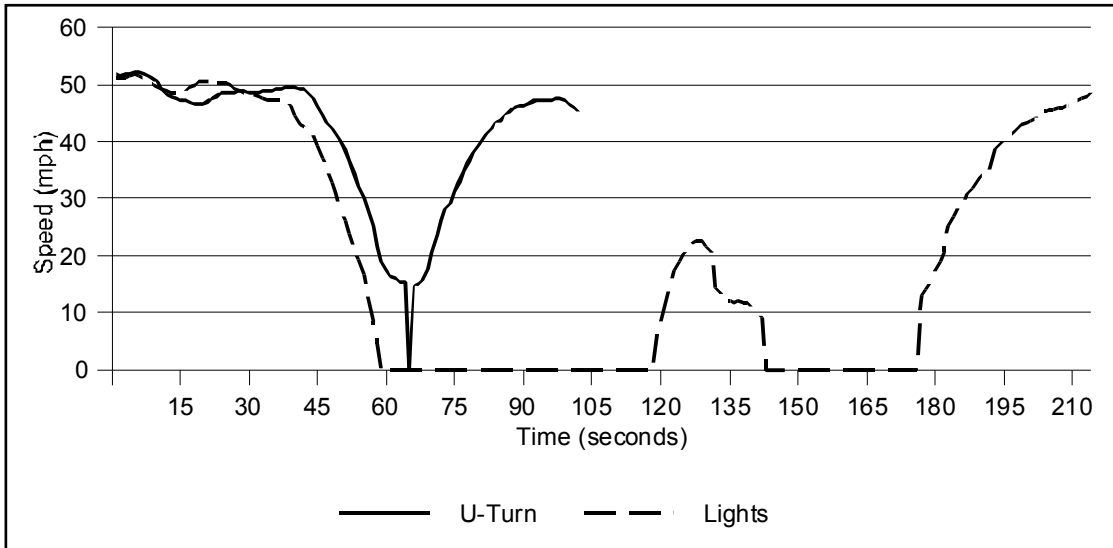
**Table 5. Traffic Operation Improvements Summary Information.**

Route	Operation Imp. Measure	Segment Length (miles)	Time	Avg. Speed (mph)	Emissions (grams)			Fuel Usage (grams)
					HC	CO	NO <sub>x</sub>	
UT1	U-turn	1.16	1:42	41	2.571	28.582	2.726	168.7
	Lights		3:36	19	2.717	35.252	2.285	260.7
UT2	U-turn	1.35	1:46	46	2.746	32.157	3.497	238.0
	Lights		2:28	33	2.726	29.282	2.592	252.5

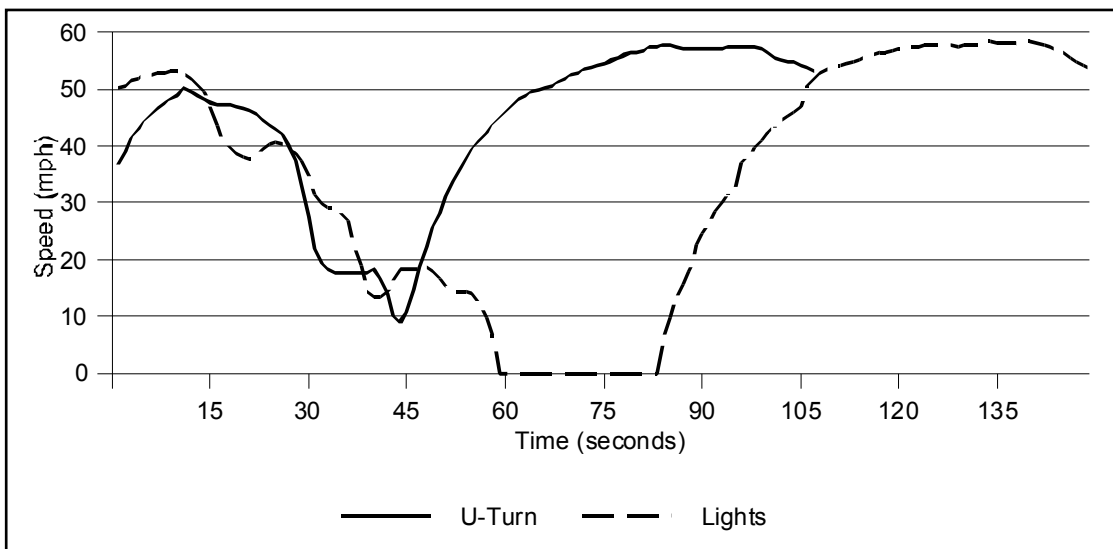
UT1 had an increase in travel time from the U-turn to light sequence of over 110 percent, while the average speed over that segment decreased 54 percent. For UT2, the increase in travel time was less, at 40 percent. There was a decrease of 28 percent in the average speed for the U-turn versus light sequence for UT2. Figures 15 and 16 provide a comparison of speeds by traffic

operation improvement measure for UT1 and UT2, respectively. The resulting change in fuel use for the two routes was 55 percent more for the light sequence for UT1 and 6 percent more for the same sequence on UT2.

For UT1, HC and CO emissions showed an increase when comparing the light sequence to the U-turn configuration, and a decrease in NOx emissions for the same comparison. HC increased by 6 percent; CO increased by 2 percent, and NOx decreased by 16 percent. For CR2, there was a decrease in emissions for HC, CO, and NOx. HC emissions decreased 1 percent; CO decreased 9 percent, and NOx decreased 26 percent.



**Figure 15. UT1 Speed Summary.**



**Figure 16. UT2 Speed Summary.**

## EXPANSION OF CASE STUDY DATA

The data collected for use with the CMEM model consisted of speed data for one particular category of vehicle. Additionally, CMEM estimates emissions for only LDVs. However, the composition of vehicles on a given roadway consists of more than one type of vehicle and more than just LDVs. Therefore, researchers expanded the following data to approximate the total emissions for all LDVs.

The first step in determining the distribution of vehicles is determining the percentage of LDVs and non-LDVs. For the El Paso area, approximately 8.7 percent of the vehicles are non-LDVs. Researchers distributed the remaining vehicles into the 26 vehicle categories, as shown in [Table 1](#). The researchers sorted these vehicles into the categories by using the decision trees supplied in the CMEM User’s Guide (Figures 5.5a and 5.5b). The decision trees require the total number of vehicles that fall within specific criteria ranges as an input. These inputs include items such as model year, mileage, and power/weight ratio. To provide a population of vehicles for input, researchers used vehicle registration information for the El Paso area. The registration information provided the numbers of vehicles by year and further disaggregated each year by passenger vehicle and light-duty trucks. [Table 6](#) shows the resulting distribution by percentage.

**Table 6. Distribution of El Paso Vehicles by Vehicle Category.**

Category Number	% of Population	Category Number	% of Population
1	1.9	14	2.4
2	2.4	15	4.05
3	5.1	16	4.05
4	12.1	17	6.9
5	14.8	18	0.8
6	0.6	19	1.4
7	0.8	20	2.8
8	4.1	21	3.1
9	7.3	22	1.1
10	6.4	23	1.0
11	12.1	24	0.0
12	2.2	25	0.5
13	1.7	40	0.4

The distribution of vehicles is not an exact replication of the conditions at the time the data were collected, but it represents an approximation of the composition of the vehicles on the roadways. As a result, the emissions generated by 91.3 percent of the vehicles (100 percent total vehicles - 8.7 percent non-LDVs) may be estimated. It should be noted that although the emissions generated by 91.3 percent of the vehicles may be estimated, this does not represent 91.3 percent of the total emissions. The non-LDVs may generate a disproportionately higher or lower level of a particular pollutant.

After researchers determined the distribution of vehicles by category, the speed data for each of the six scenarios (commuter routes, activity center routes, and traffic improvement measures) were processed again with the CMEM program. In this case, researchers created a control file for each of the 26 vehicle categories. For each scenario, the 26 control files and corresponding activity file (speed data) were processed using the CMEM core model. They multiplied output in the summary file by the scenario's segment length and the percent of the total vehicle population for each vehicle category to obtain the total amount of HC, CO, NO<sub>x</sub> emissions as well as the fuel used by each vehicle category of each scenario. [Table 7](#) provides an example of the output.

The information provided to this point, coupled with traffic volume counts, allows for the data collected for one vehicle to be expanded to multiple vehicles. [Table 8](#) provides a summary of the emissions and fuel use data as described in the preceding paragraph. The data in this [table](#) may be expanded by applying traffic count data for the areas where speed data were collected.

There were two problem areas identified while conducting the analysis. These problems involve the expansion of the data to a level that covers a specified time increment, for example, attempting to determine the amount of emissions during a peak hour. The following provides a summary of these issues:

- Traffic counts that are available are 24-hour, bi-directional counts. In the case of the commuter routes, the analysis examines the difference in pollutants emitted in the peak and off-peak directions. There is no way to accurately reduce the 24-hour counts to determine the number of vehicles traveling in each direction during the morning peak (or afternoon peak if needed) period. This information is needed to expand the data to a higher level and provide the detailed analysis, if needed. A potential scenario where CMEM might be useful is one where the data are collected and volume counts at specific points along the data collection route are gathered. Having the volume count information is crucial for the successful expansion of the CMEM output.
- Additionally, for the traffic operation improvements, there are typically no traffic count data collected for diamond interchanges. Counts are typically conducted away from the interchange, and determinations as to the number of turning movements cannot be made from the data. There are no data to show whether a vehicle that reversed direction made this change via going through the signals or through the U-turn. If a detailed turning movement study has been conducted for these interchanges, then the expansion of data would be possible.
- For any of the case studies, it would be prudent to have volume count data available in a time increment format. This count will allow the data to be applied to a higher level of detail and subsequently provide a more accurate analysis to be conducted.

**Table 7. Example of Summarized CMEM Output.**

Vehicle Category	Tsoak	Segment Length (miles)	Percent of Vehicle Pop.	HC (grams/mile)	HC (total)	CO (grams/mile)	CO (total)	NOx (grams/mile)	NOx (total)	Fuel Use (grams/mile)	Fuel Use (total)
1	1140	7.5	1.90%	7.30	1.04	67.29	9.59	1.68	0.24	156.50	22.30
2	1140	7.5	2.40%	2.14	0.39	30.79	5.54	2.36	0.42	127.80	23.00
3	1140	7.5	5.10%	0.77	0.29	13.99	5.35	1.09	0.42	90.40	34.58
4	1140	7.5	12.10%	0.57	0.52	9.90	8.98	0.94	0.85	95.40	86.58
5	1140	7.5	14.80%	0.58	0.64	10.91	12.11	0.85	0.94	103.10	114.44
6	1140	7.5	0.60%	0.39	0.02	8.58	0.39	0.94	0.04	95.00	4.28
7	1140	7.5	0.80%	0.43	0.03	6.44	0.39	0.87	0.05	93.20	5.59
8	1140	7.5	4.10%	0.23	0.07	5.28	1.62	0.48	0.15	91.20	28.04
9	1140	7.5	7.30%	0.31	0.17	4.30	2.35	0.49	0.27	87.60	47.96
10	1140	7.5	6.40%	0.19	0.09	4.19	2.01	0.52	0.25	90.00	43.20
11	1140	7.5	12.10%	0.24	0.22	5.48	4.97	0.38	0.34	100.20	90.93
12	1140	7.5	2.20%	3.29	0.54	65.60	10.82	3.31	0.55	201.90	33.31
13	1140	7.5	1.70%	2.16	0.28	40.22	5.13	2.38	0.30	160.90	20.51
14	1140	7.5	2.40%	0.81	0.15	13.98	2.52	1.50	0.27	123.40	22.21
15	1140	7.5	4.05%	0.66	0.20	12.91	3.92	1.04	0.32	117.50	35.69
16	1140	7.5	4.05%	0.76	0.23	12.40	3.77	1.59	0.48	152.40	46.29
17	1140	7.5	6.90%	0.34	0.18	7.58	3.92	0.72	0.37	130.60	67.59
18	1140	7.5	0.80%	0.42	0.03	7.99	0.48	0.81	0.05	157.00	9.42
19	1140	7.5	1.40%	0.83	0.09	11.65	1.22	2.38	0.25	121.40	12.75
20	1140	7.5	2.80%	1.95	0.41	28.29	5.94	1.45	0.30	105.20	22.09
21	1140	7.5	3.10%	2.13	0.50	16.27	3.78	1.02	0.24	111.30	25.88
22	1140	7.5	1.10%	3.00	0.25	27.27	2.25	2.75	0.23	126.20	10.41
23	1140	7.5	1.00%	6.27	0.47	92.79	6.96	0.54	0.04	124.70	9.35
24	1140	7.5	0.00%	0.30	0.00	7.91	0.00	0.55	0.00	102.50	0.00
25	1140	7.5	0.50%	0.83	0.03	11.91	0.45	2.47	0.09	203.90	7.65
40	1140	7.5	0.40%	0.17	0.01	0.17	0.01	0.33	0.01	132.50	3.98
<b>Totals</b>			<b>100.00%</b>	<b>6.82</b>		<b>104.48</b>		<b>7.48</b>		<b>828.03</b>	

Emissions Totals = Segment Length \* Grams/Mile (HC, CO, NOx, and Fuel Use) \* Percent of Vehicle Population

**Table 8. Total Emissions and Fuel Use.**

Route	Direction	Segment Length (miles)	Emissions (total grams)			Fuel Use (total grams)
			HC	CO	NO <sub>x</sub>	
CR1	Off-Peak	10.20	8.28	121.42	8.44	1020.26
	Peak		8.80	101.69	6.55	1140.98
CR2	Off-Peak	7.50	6.08	86.65	6.73	773.56
	Peak		6.82	104.48	7.48	828.03
AC1	N/A	8.00	9.72	113.08	5.97	1083.35
AC2	N/A	1.96	5.75	65.46	3.24	391.24
UT1	U-turn	1.16	4.36	39.16	2.24	120.54
	Lights		5.14	46.00	2.17	184.39
UT2	U-turn	1.35	5.03	43.77	2.93	168.24
	Lights		5.29	48.05	2.52	180.54

Without having specific volume counts for the case studies, it is still possible to generate an estimate of the changes in emissions and fuel used for the case studies. To develop these estimates, hypothetical values for volumes may be used. The following will provide an example of the changes in emissions and fuel use for the traffic operation improvement case study, UT1.

Volume of Vehicles = 1000

U-turn	HC	4.36	*	1000	=	4360
	CO	39.16	*	1000	=	39,160
	NO <sub>x</sub>	2.24	*	1000	=	2240
	Fuel Use	120.54	*	1000	=	120,540
Lights	HC	5.14	*	1000	=	5140
	CO	46.00	*	1000	=	46,000
	NO <sub>x</sub>	2.17	*	1000	=	2170
	Fuel Use	184.39	*	1000	=	184,390

Based on these totals for a population of 1000 vehicles, the difference in the amount of emissions and fuel use can be estimated. The differences are:

HC	5140	-	4360	=	780	(17.9 Percent Increase)
CO	46,000	-	39,160	=	6840	(17.5 Percent Increase)
NOx	2170	-	2240	=	-70	(3.1 Percent Decrease)
Fuel Use	184,390	-	120,540	=	63,850	(53.0 Percent Increase)

For this particular case study, the analysis investigated the impact that U-turns might have at a diamond interchange. Comparing the emissions and fuel use for the two alternatives reveals that vehicles using the lights to reverse direction will have higher levels of HC and CO emissions when compared to vehicles using the U-turns. Additionally, there is a significantly higher amount of fuel use with the light alternative, while there is a slight reduction in NOx emissions. These totals are for LDVs only.





## CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION

As the previous sections have shown, the CMEM software is a useful tool for estimating the emissions and fuel usage of LDVs. For this analysis, the software estimated the emissions and fuel use of one vehicle. However, it is possible to expand the data to obtain an approximation of the amount of emissions by a larger vehicle population.

### IMPLEMENTATION IN THE EL PASO AREA

There are numerous proposed or planned projects in the El Paso metropolitan area that could be analyzed with the CMEM software to determine the impact that the particular improvement has on emissions levels. In most instances, all of the following scenarios may be analyzed by examining specific locations within the city that already have these measures in place. For example, data could be collected at a location where there is a grade-separated railroad crossing and at another location where there is no grade separation. This comparison can provide a general analysis of the measure and its effectiveness. However, depending on the location, there may be certain site-specific elements (e.g., geometric configuration, high/low traffic generating businesses, etc.) that make a comparison between sites less accurate. To obtain an accurate determination on the effectiveness of an improvement, it may be best to collect data before and after an improvement is implemented. Performing before and after studies of a specific area being improved is the best method to determine the improvement's effectiveness in terms of emissions and fuel use.

The El Paso Metropolitan Planning Organization (MPO) recently adopted the 2025 Metropolitan Transportation Plan (MTP). The MTP, which is a tool that metropolitan areas use to plan future transportation, allows the urban area to become eligible for federal funding of transportation-related projects. The MTP itself outlines a considerable number of projects that could serve to benefit the urban area in various manners. The following provides a brief overview of several project types included in the MTP and are candidates for analysis using the CMEM software.

- ***Grade-Separated Overpasses at Railroad Crossings*** – The 2025 MTP includes 27 projects related to railroad crossing, with a majority of them being grade-separated overpasses. Due to the frequency of rail traffic in the area and the amount of congestion created as intersections are obstructed, grade-separated crossings are measures that are being investigated to help reduce congestion levels and additionally reduce emission levels. CMEM software could assess the effectiveness of this measure by comparing emissions levels prior to and after building a grade-separated overpass. This analysis could be useful to decision makers when determining whether or not to build additional grade-separated overpasses.
- ***Redesigning Traffic Patterns*** – The El Paso 2025 MTP provides a specific example where two streets become one-way pairs. In this example, Montana Ave., west of Paisano Dr., would carry eastbound traffic, and Yandell St. would carry westbound traffic. This modification can improve the flow of traffic and improve safety by reducing the number of conflicting turning movements along the corridor. Conducting

before and after studies of the conditions on these two corridors could provide information on the specific results that this type of measure provides.

- ***Turn Lanes and Turn Extensions*** – There are approximately 250 locations in the El Paso County area where turn lanes, auxiliary lanes, and turn lane extensions are proposed. This area also includes continuous left-turn lanes. Turn lane modifications assist in reducing the idle time that vehicles spend at intersections, which subsequently helps reduce the amount of emissions. One of the major causes of vehicle-created air pollution is time spent stopped and idling at intersections.
- ***Traffic Signal Timing Coordination*** – Currently, the City of El Paso operates the Transportation Management Control Center, which, among other things, interconnects and controls 265 traffic signals. The center is designed to allow for adjusting and retiming signals according to current traffic conditions. These adjustments allow traffic signal phasing to be modified to reduce congestion-associated delays at signalized intersections. The MTP plan includes projects that would increase the number of intersections connected to the center. As with the other measures, conducting before and after studies of this measure would provide data that would be useful in determining the effect that it has on emissions and fuel use.

## CONCLUSIONS

The CMEM software predicts fuel consumption and second-by-second tailpipe emissions of various categories of vehicles operating under different conditions. As shown in the preceding analysis, using basic features of the software allows for comparisons of operating conditions on selected transportation facilities. By comparing selected roadway segments operating in various conditions, an analysis of vehicle fuel consumption and emissions may be conducted. Depending on how the data collection is structured, the user can approximate the effectiveness of implementing emissions reduction strategies. This analysis tool can be used as part of the process of deciding where to make improvements to the transportation system.

One of the advantages of the software is that it requires very little in terms of input to run the model. It allows the flexibility of performing a more detailed analysis by modifying the vehicle parameters. These modifications would generate a more specific output for a particular vehicle rather than a class or group of vehicles. The main input to the model is the speed data, and the equipment needed to do this is modest. Another advantage to the equipment is that it is transferable to other vehicles. After assembling a package of equipment, the user can transfer the equipment and use it in multiple vehicles. This flexibility is an attractive feature of the system.

## REFERENCES

1. Barth, M., A. Feng, T. Younglove, G. Scora, C. Levine, M. Ross, and T. Wenzel. "Comprehensive Model Emissions Model (CMEM), Version 2.0 Users Guide." Research report prepared by the University of California – Riverside, Riverside, CA, November 30, 1999.



**APPENDIX**  
**SPEED AND EMISSIONS COMPARISONS**



The charts in the following appendix show the comparison between speed and HC, CO, and NOx emissions for the scenarios in the El Paso transportation network.

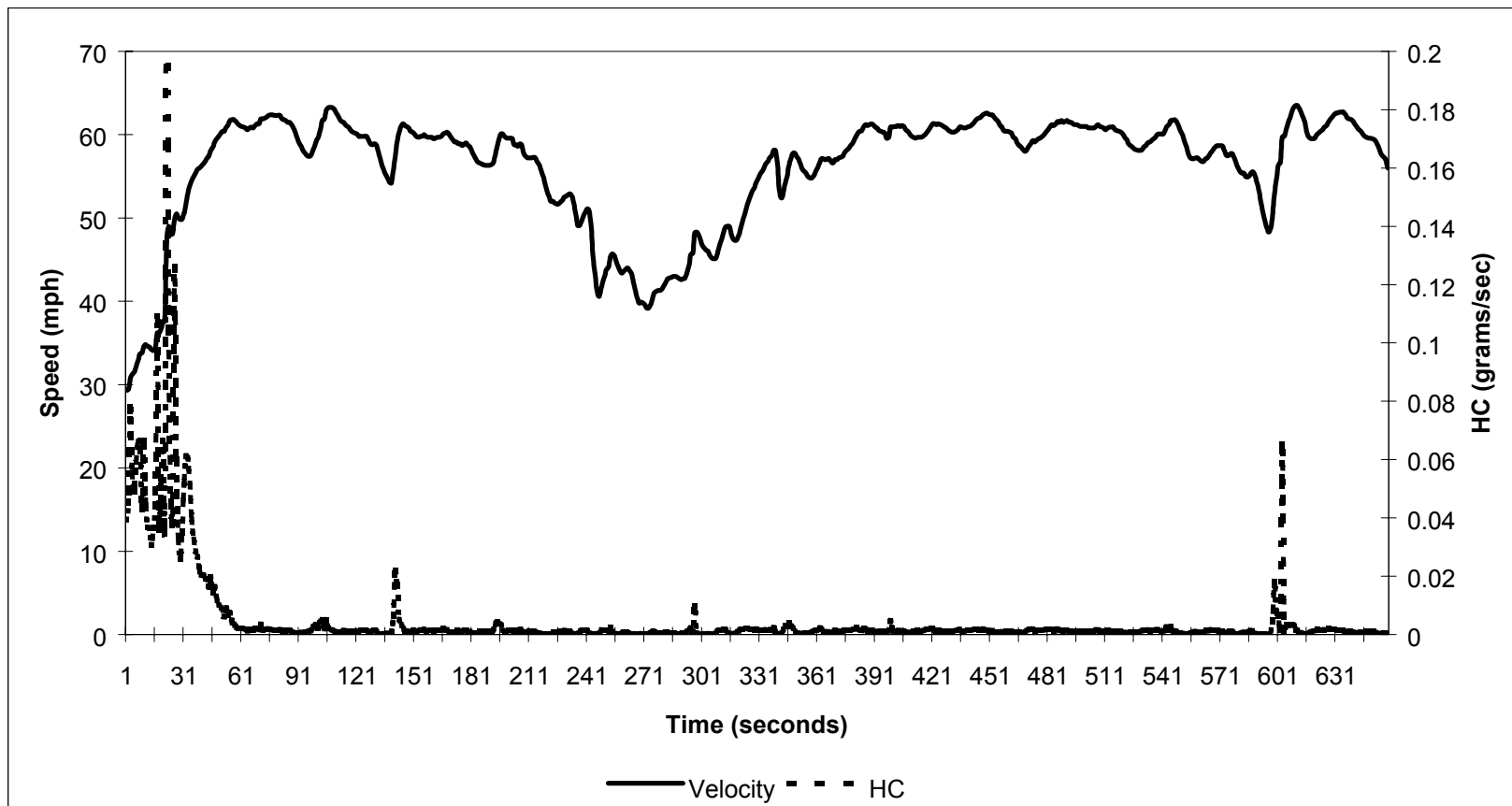
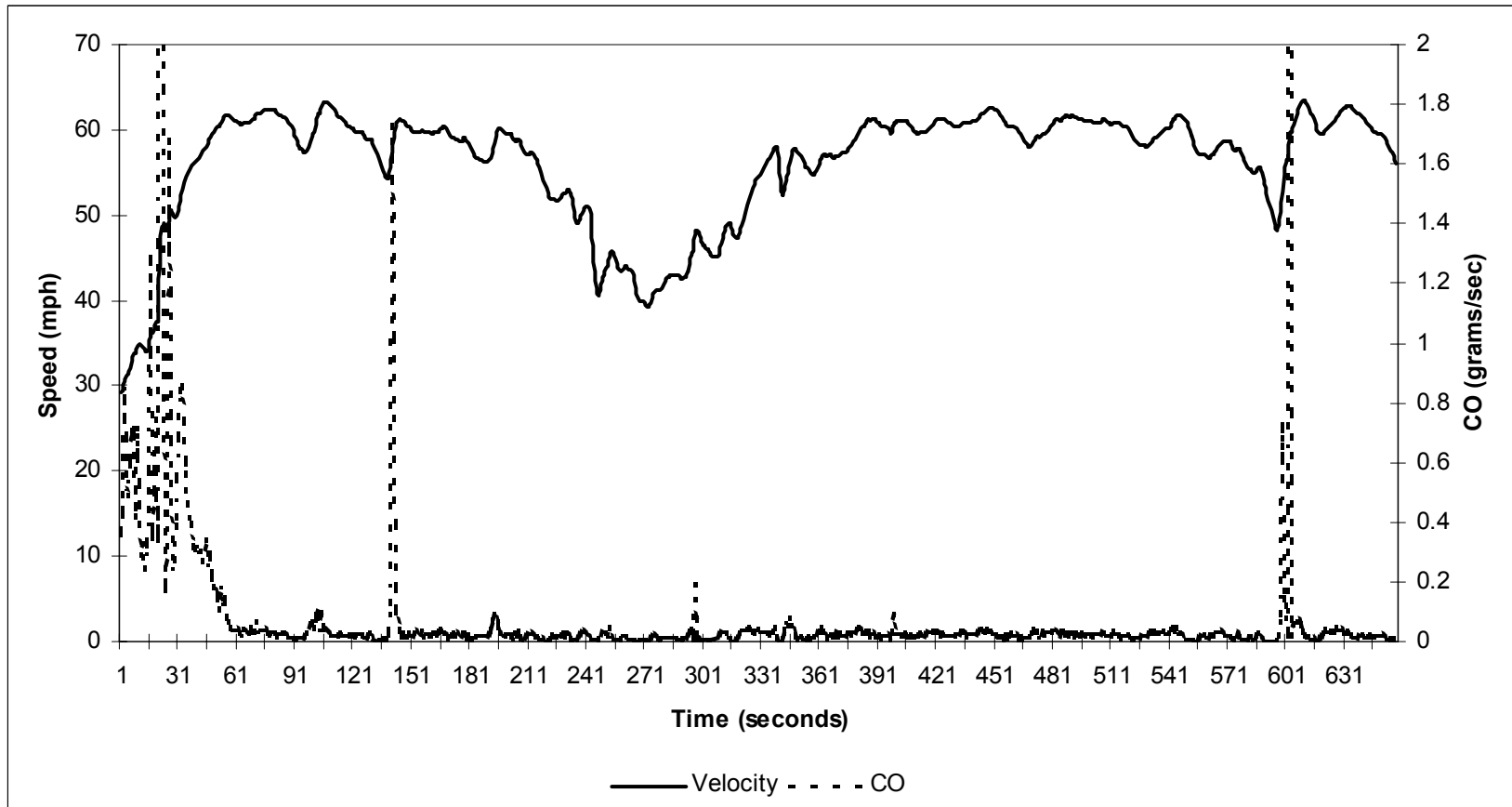


Figure 17. CR1 Speed-HC Comparison (Off-Peak Direction).





**Figure 18. CR1 Speed-CO Comparison (Off-Peak Direction).**

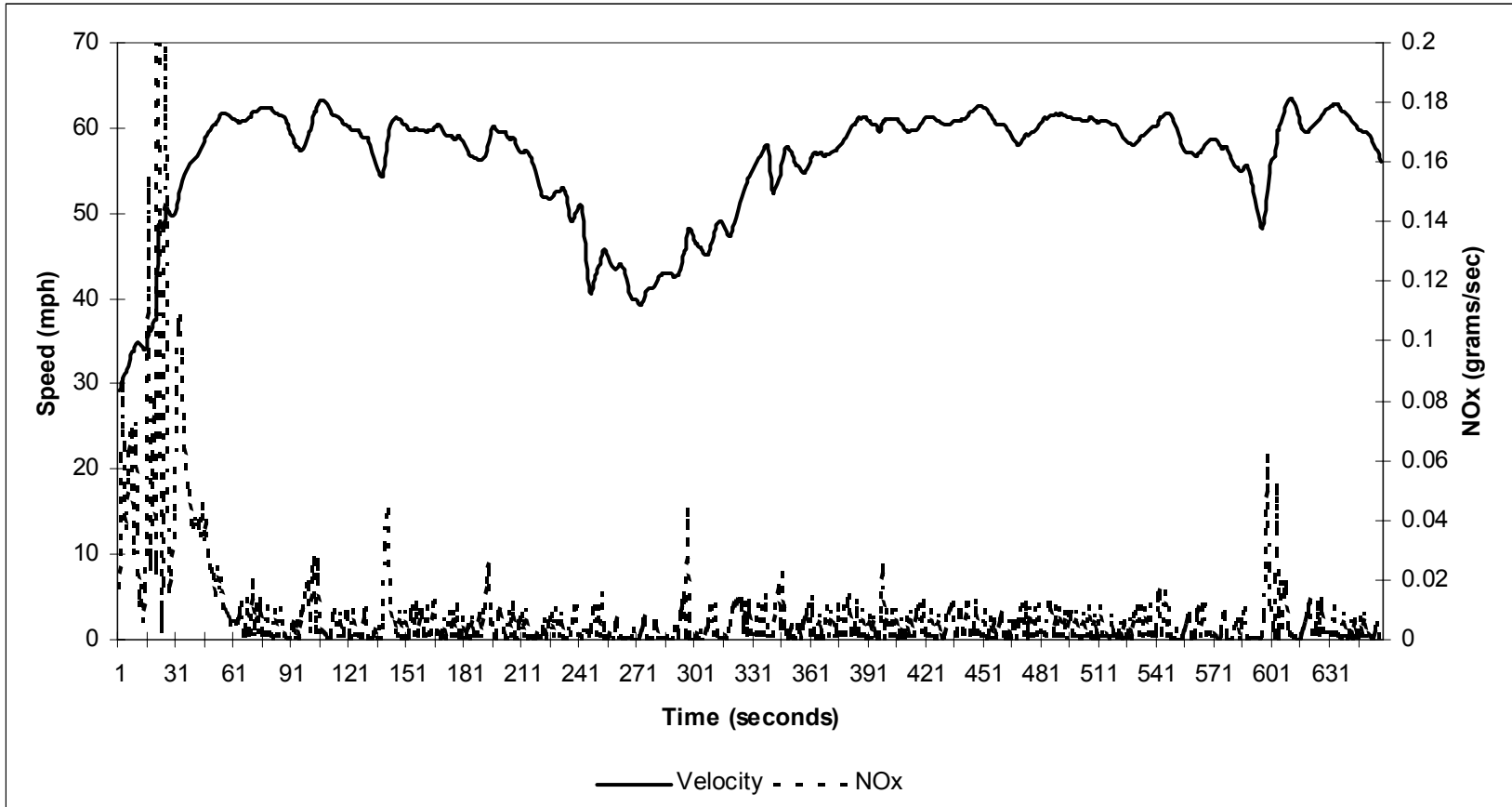


Figure 19. CR1 Speed-NOx Comparison (Off-Peak Direction).

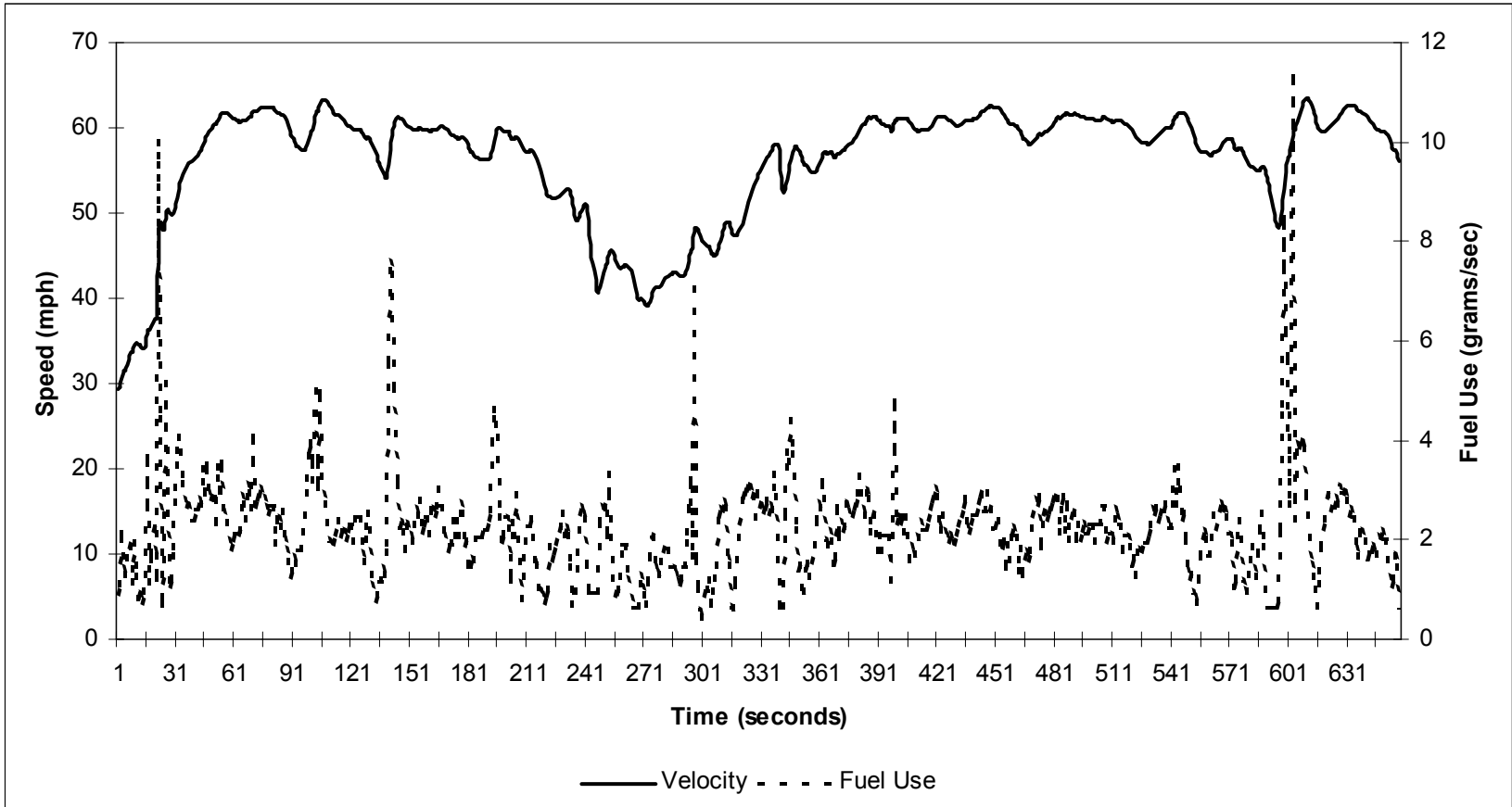


Figure 20. CR1 Speed-Fuel Use Comparison (Off-Peak Direction).

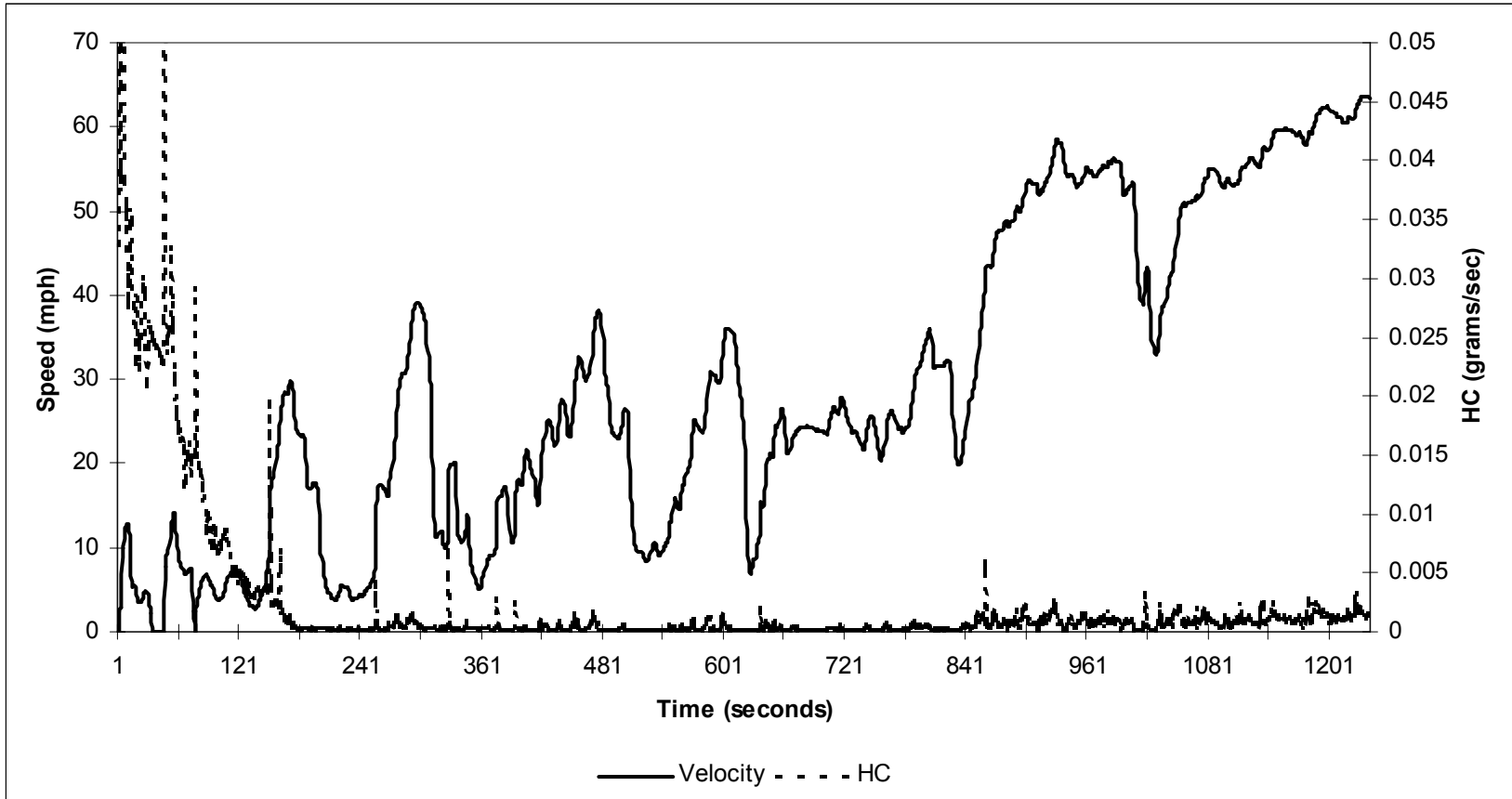
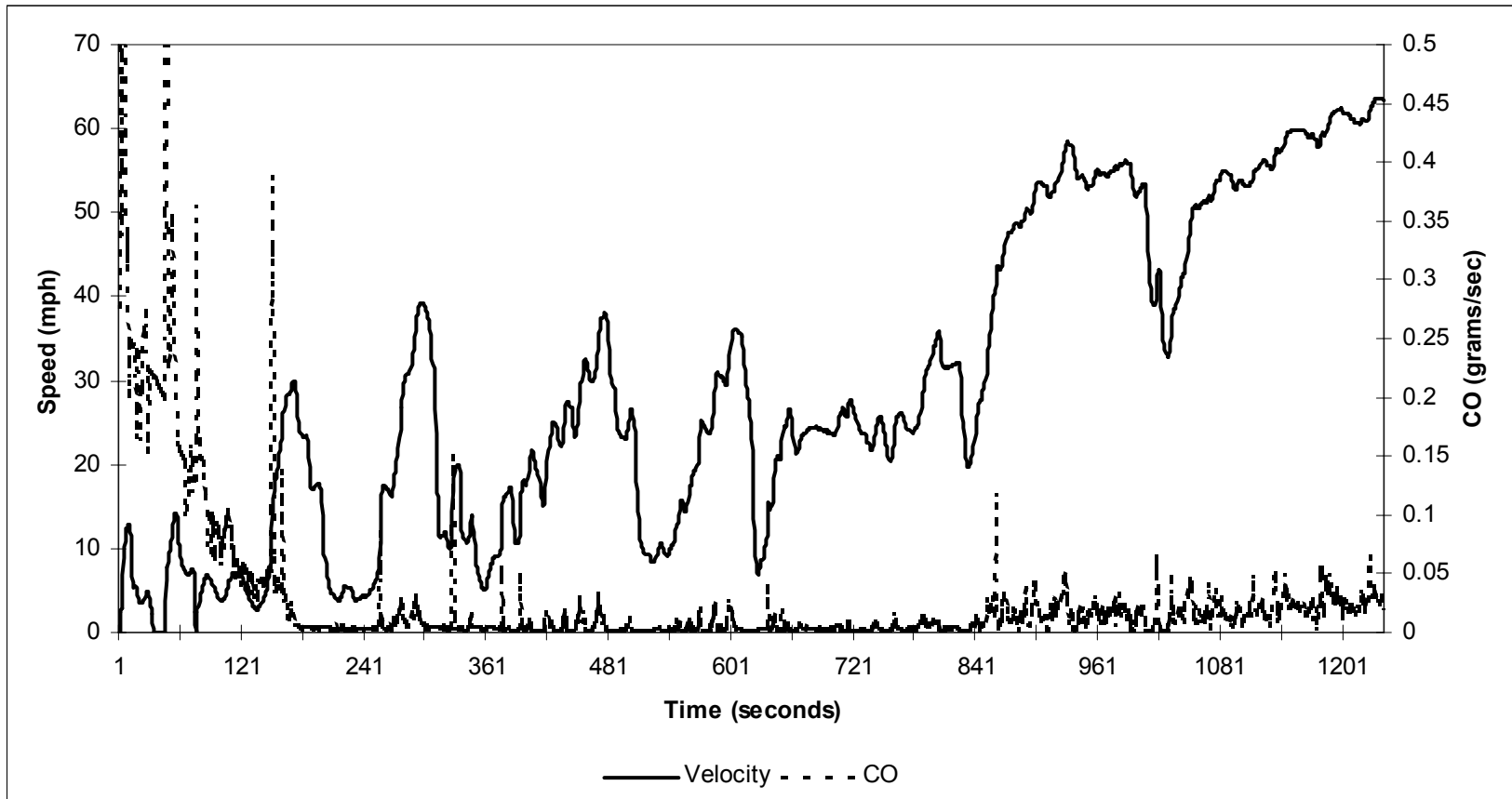


Figure 21. CR1 Speed-HC Comparison (Peak Direction).



**Figure 22. CR1 Speed-CO Comparison (Peak Direction).**

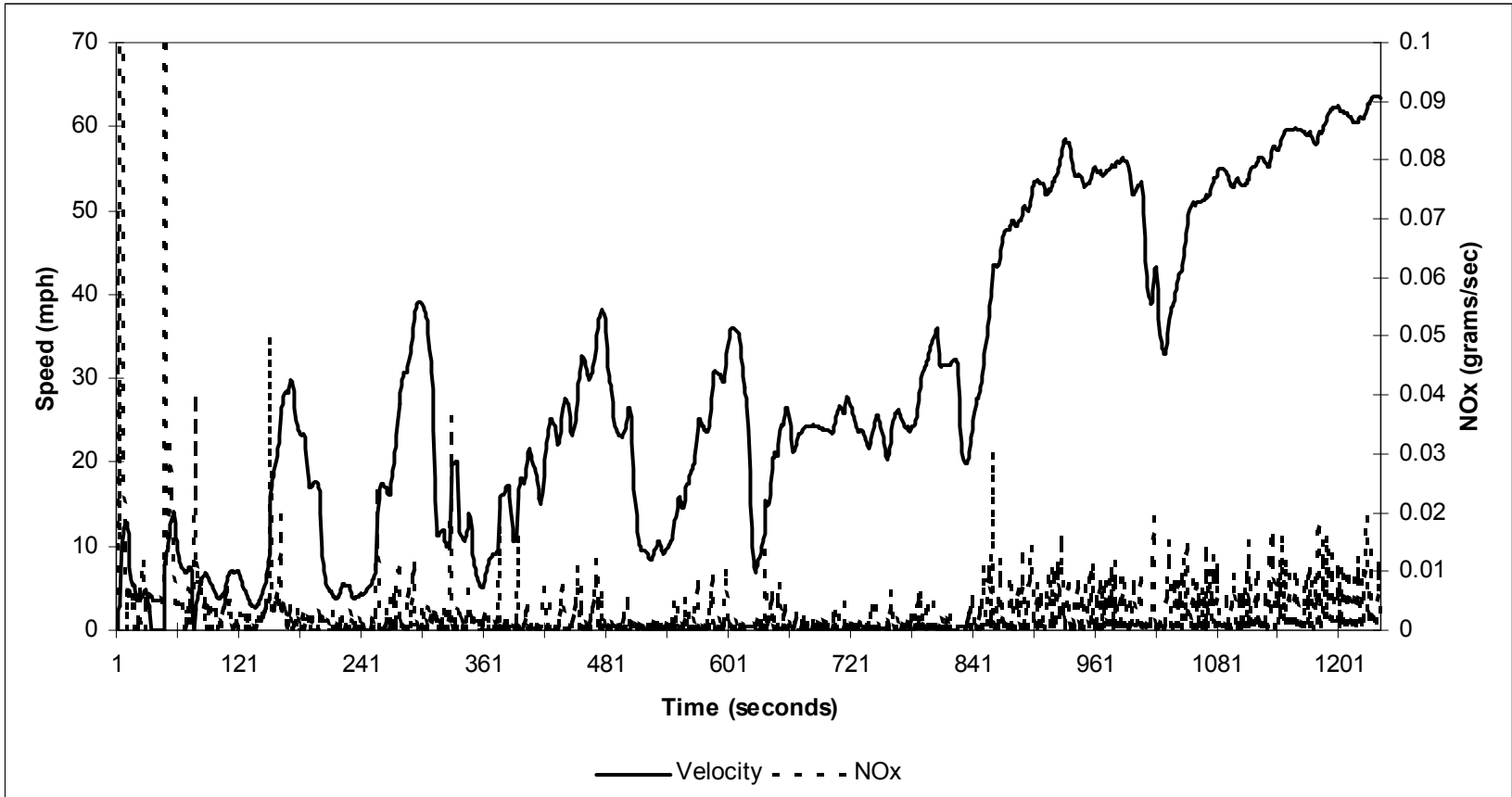


Figure 23. CR1 Speed-NOx Comparison (Peak Direction).

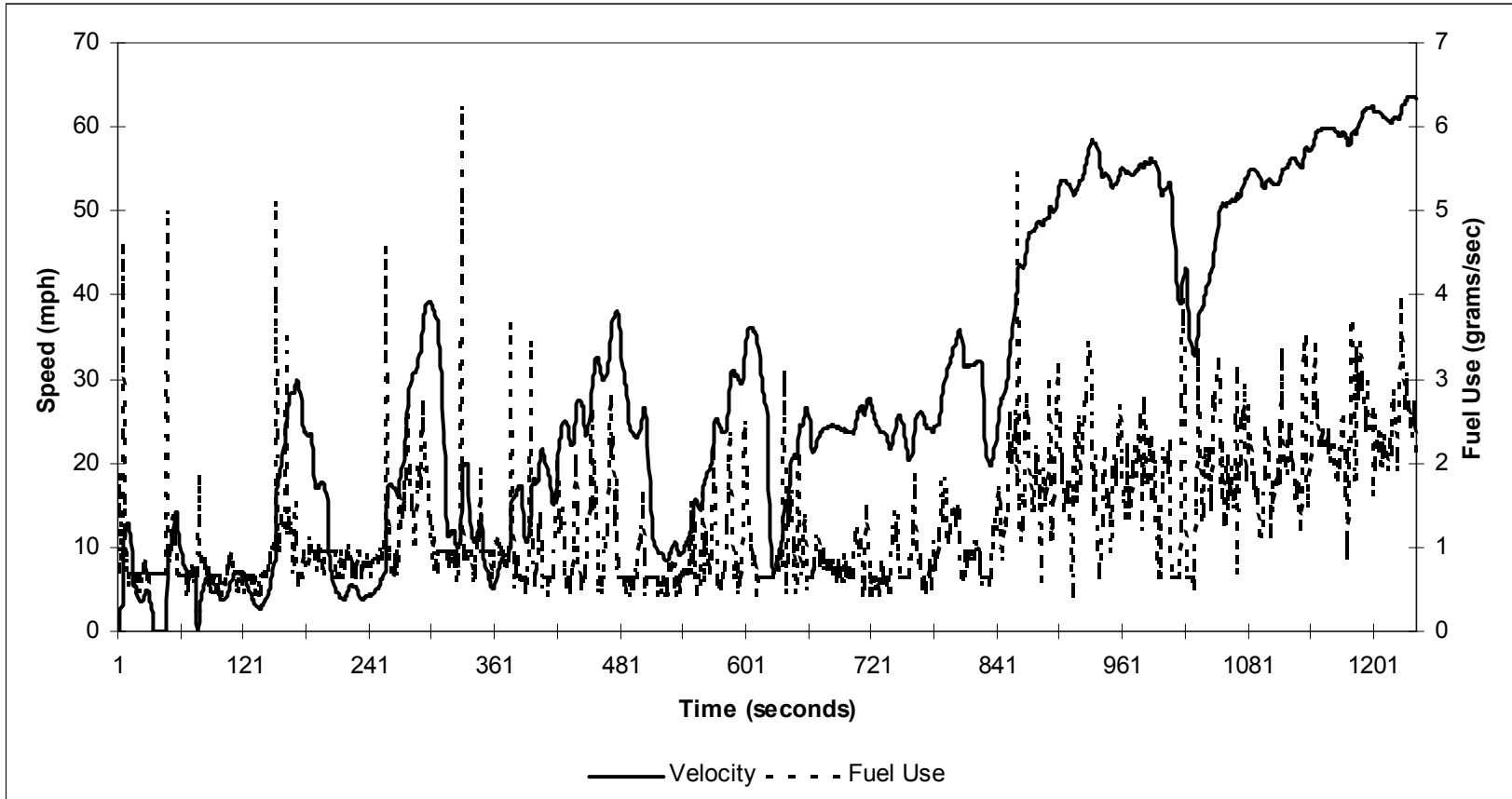


Figure 24. CR1 Speed-Fuel Use Comparison (Peak Direction).

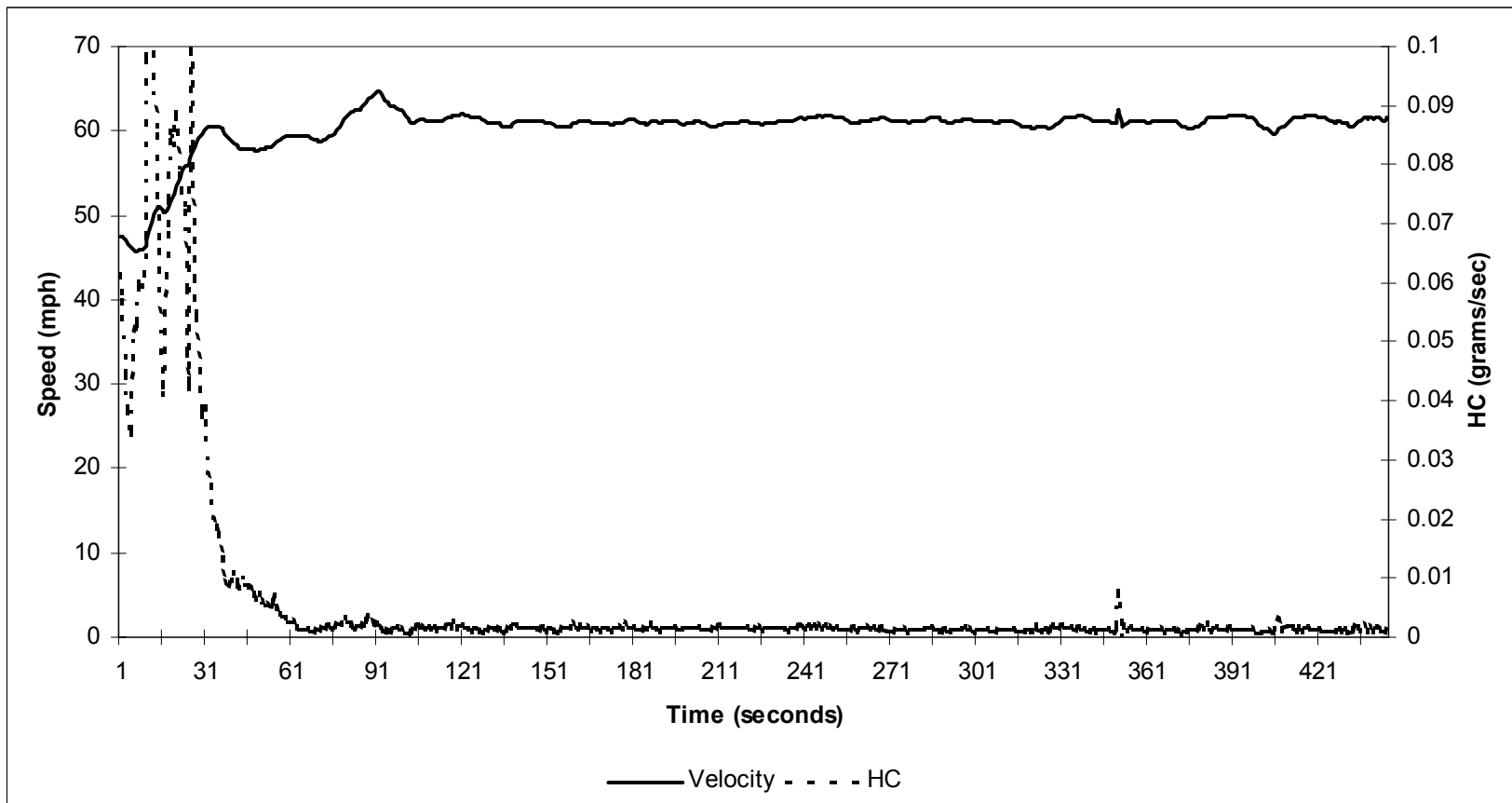


Figure 25. CR2 Speed-HC Comparison (Off-Peak Direction).



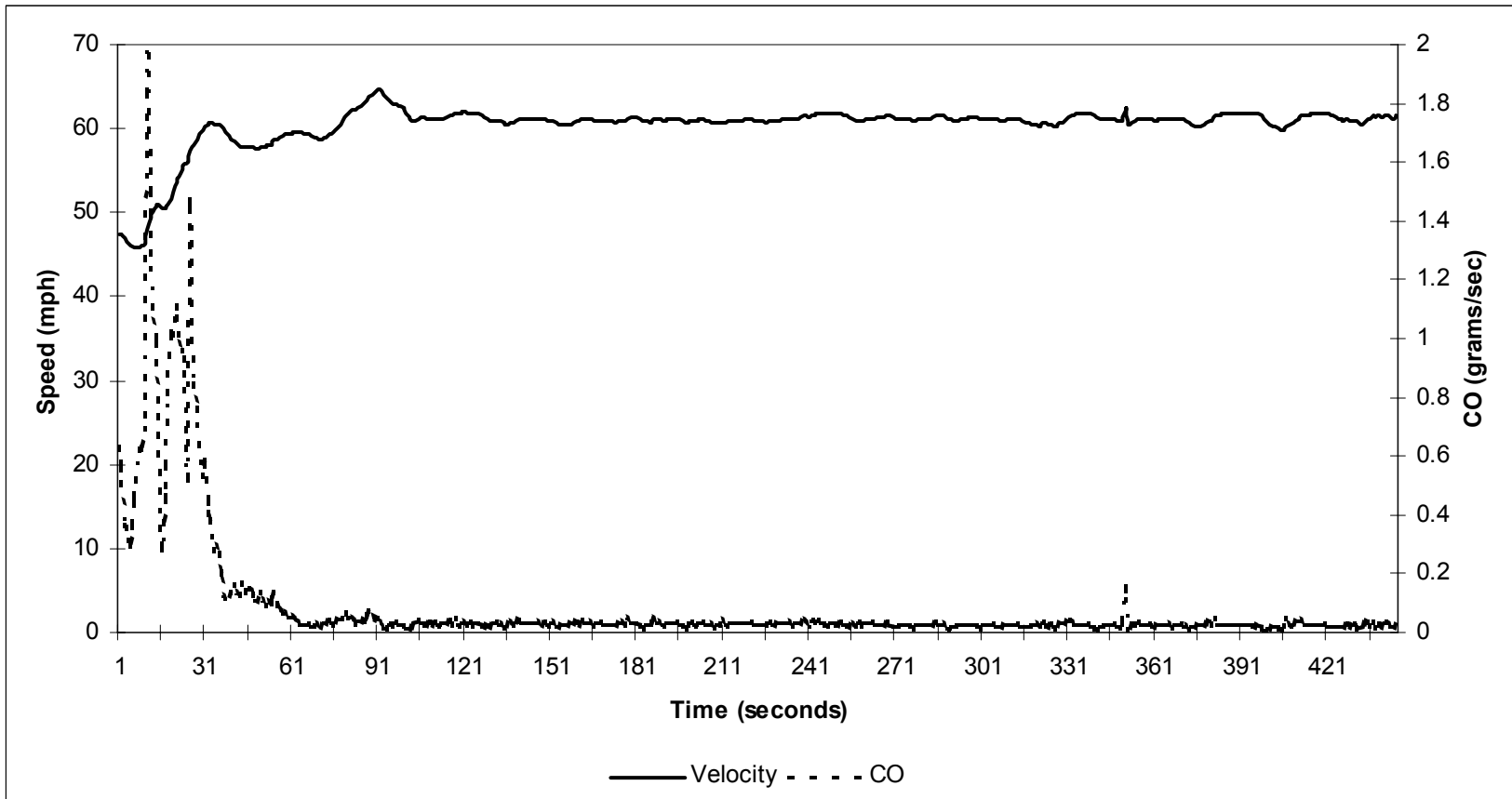


Figure 26. CR2 Speed-CO Comparison (Off-Peak Direction).

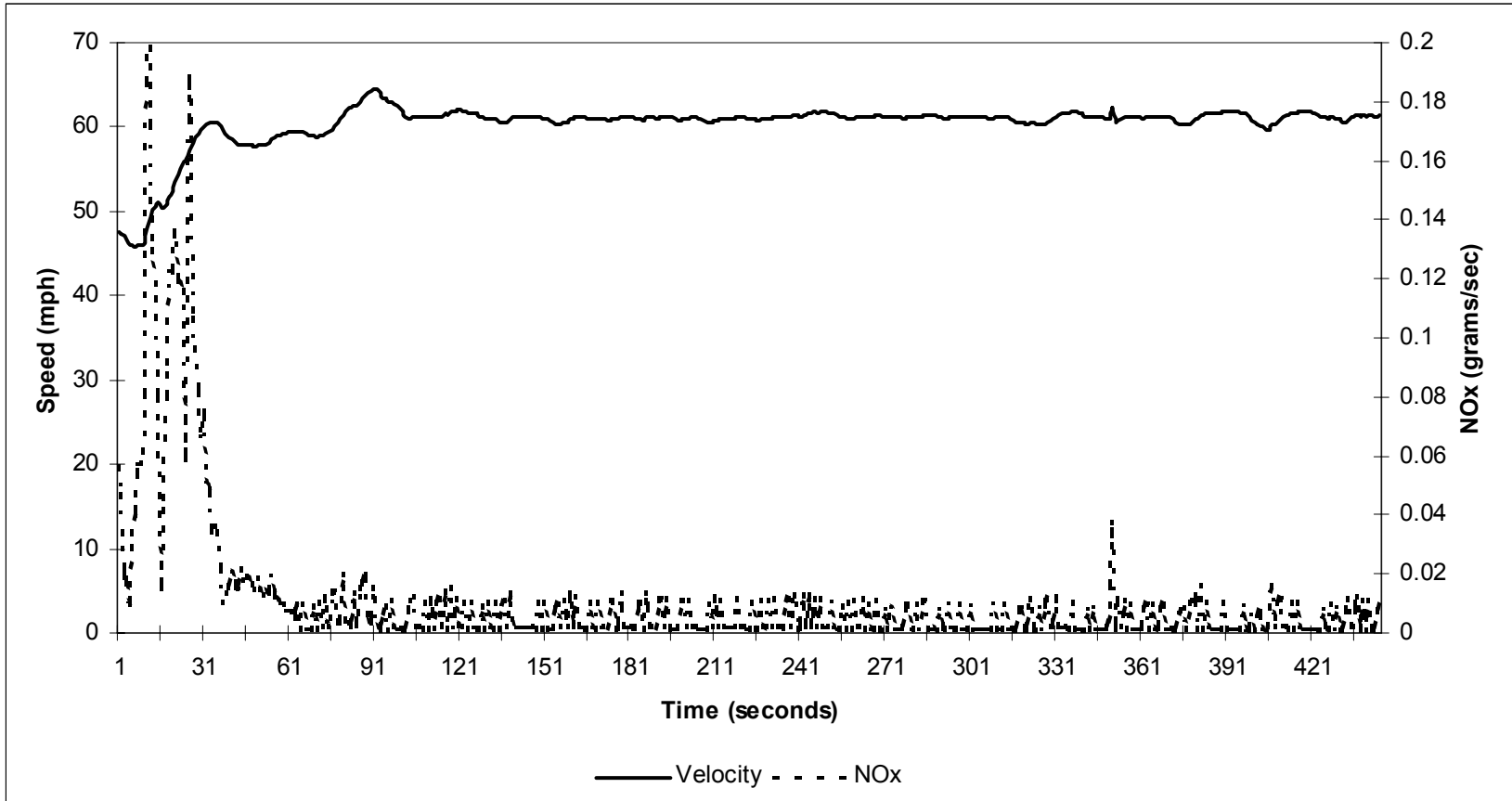


Figure 27. CR2 Speed-NOx Comparison (Off-Peak Direction).

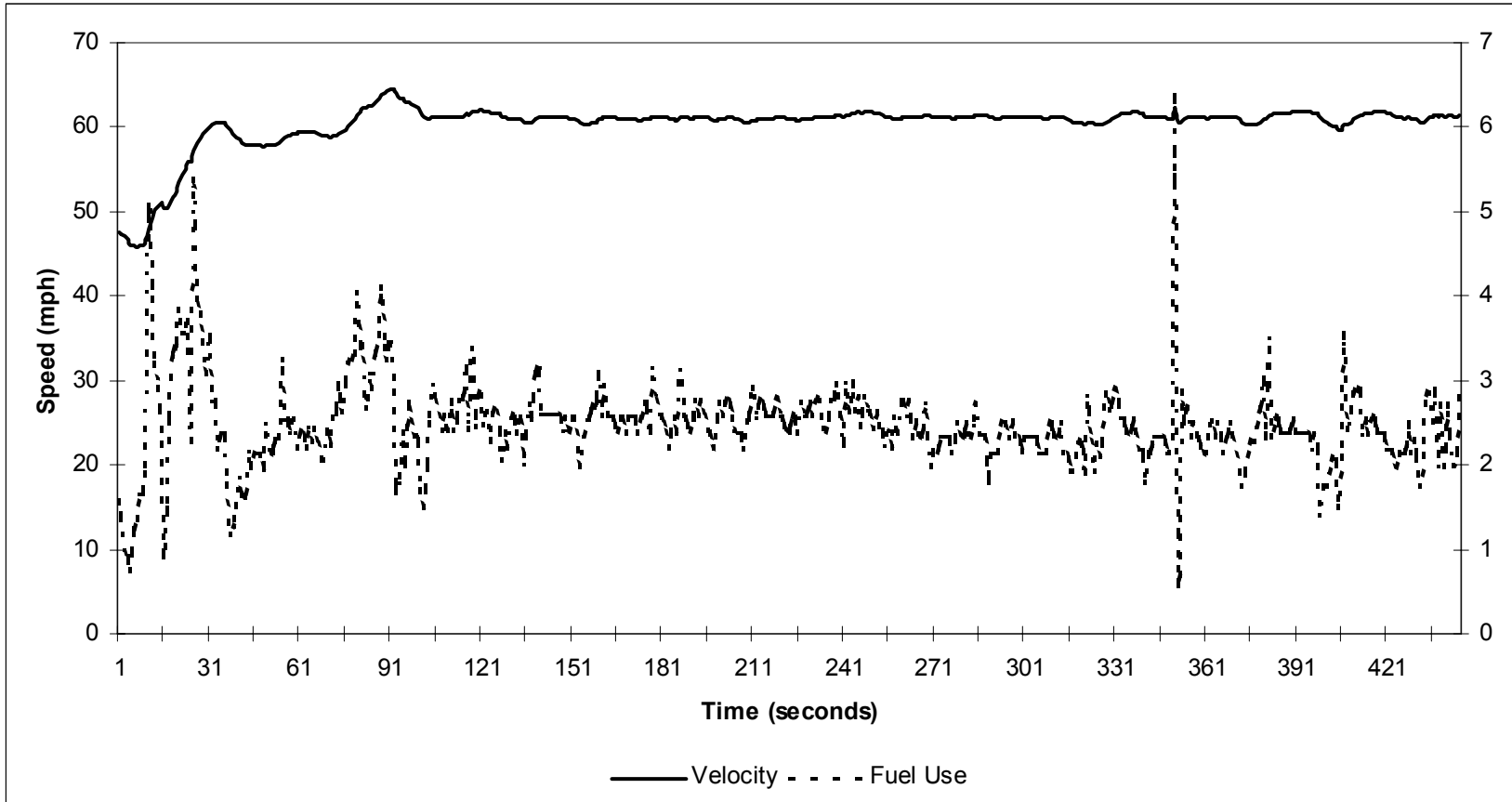


Figure 28. CR2 Speed-Fuel Use Comparison (Off-Peak Direction).

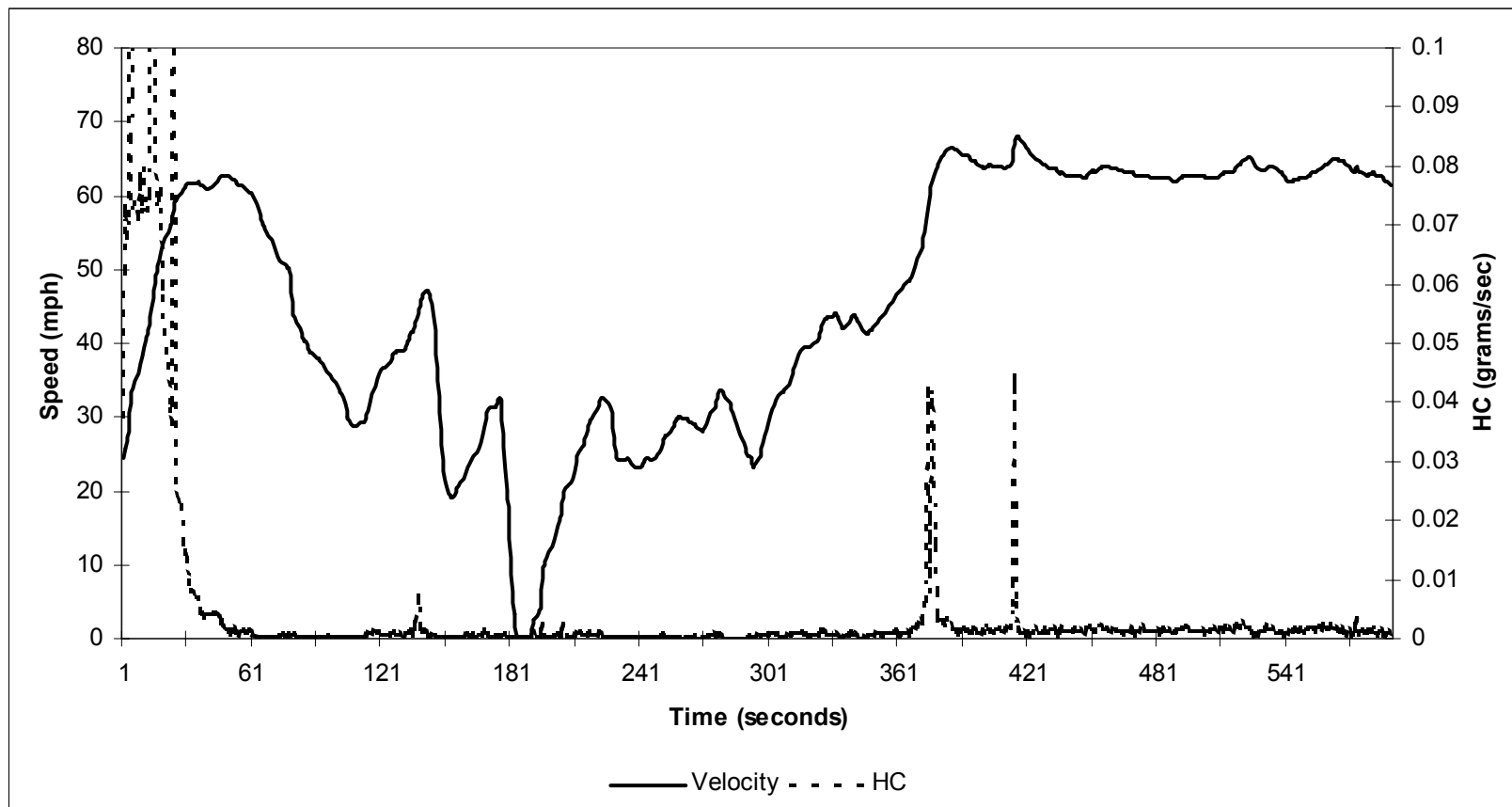


Figure 29. CR2 Speed-HC Comparison (Peak Direction).

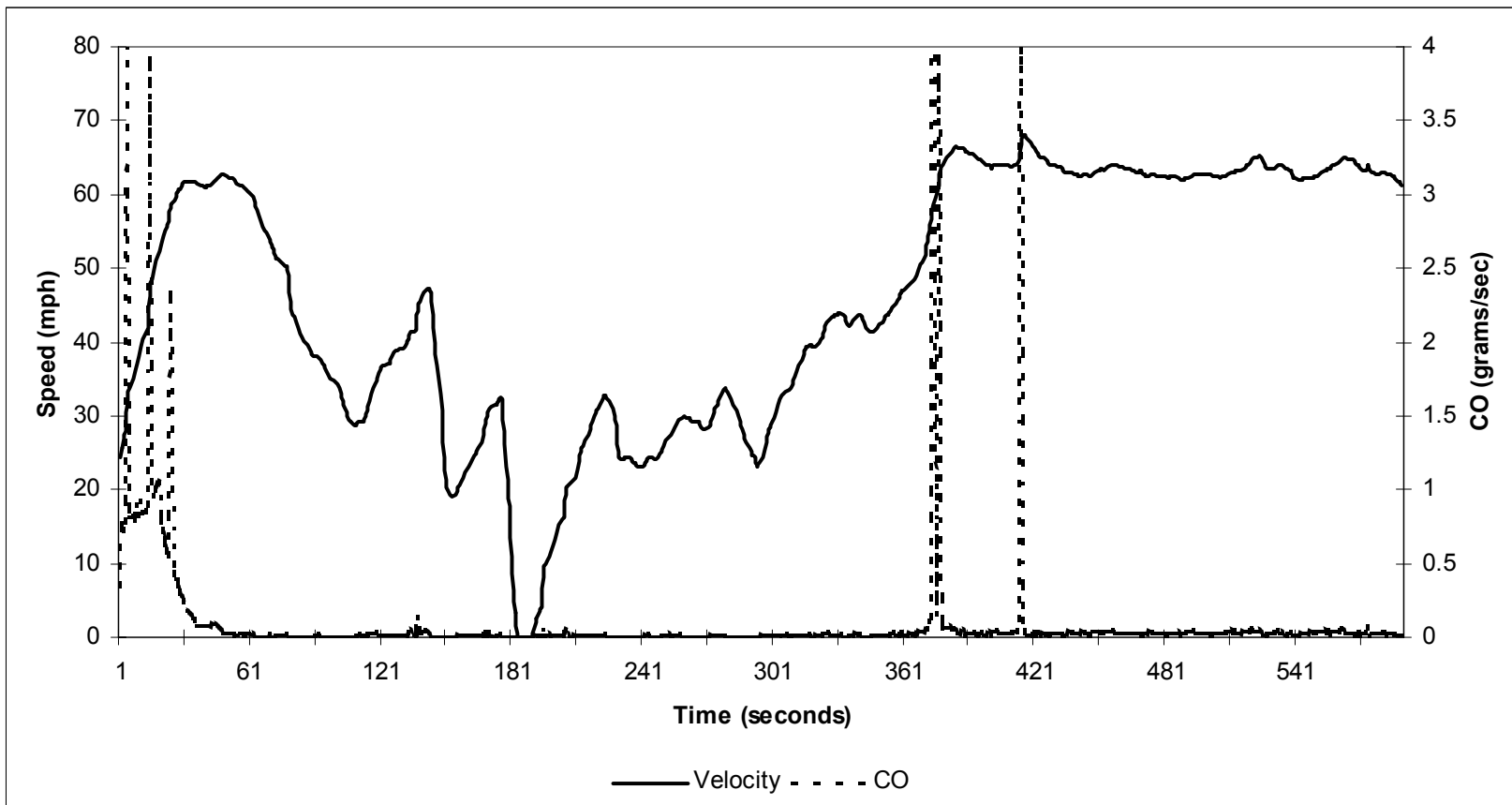


Figure 30. CR2 Speed-CO Comparison (Peak Direction).

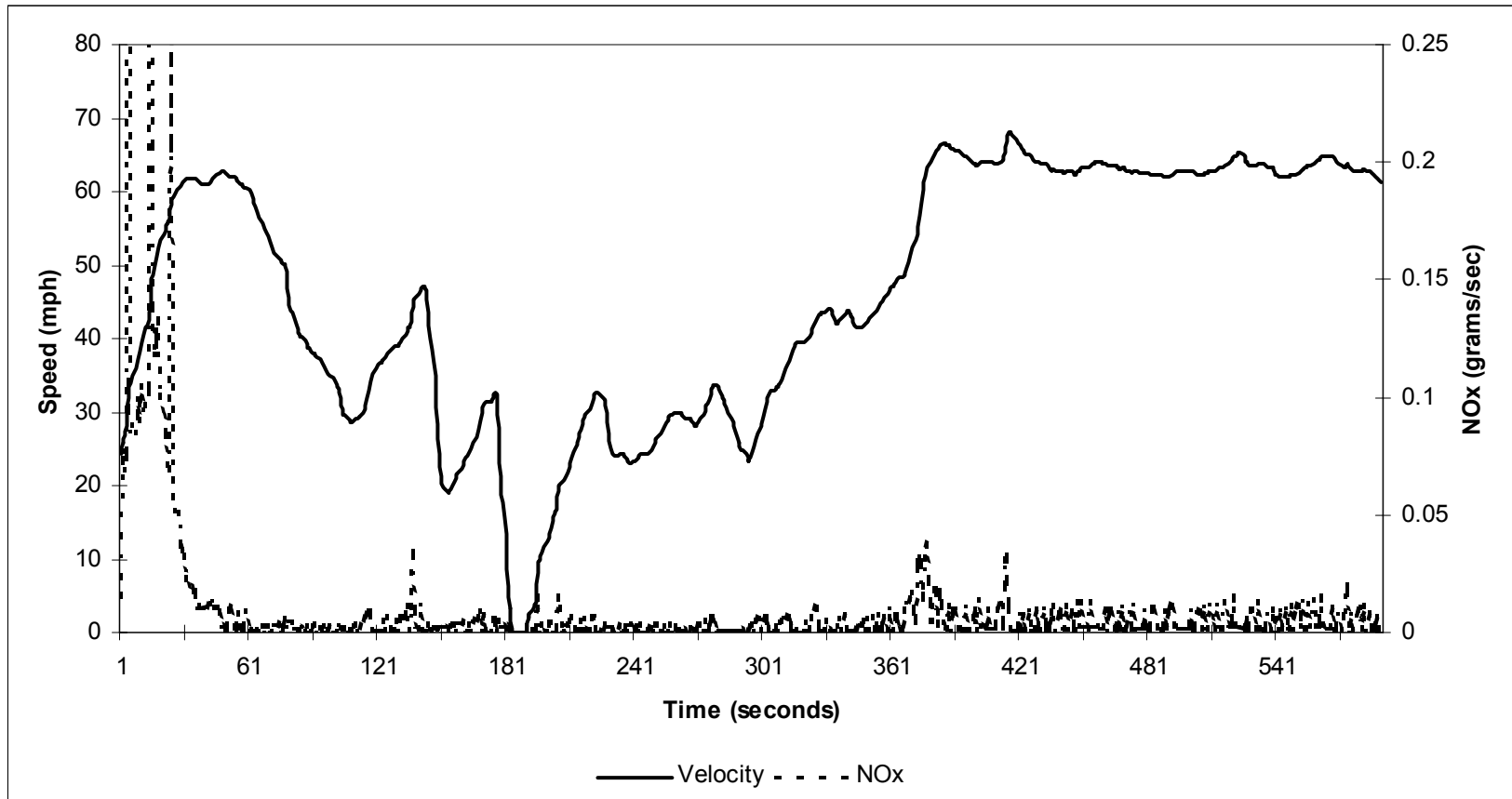
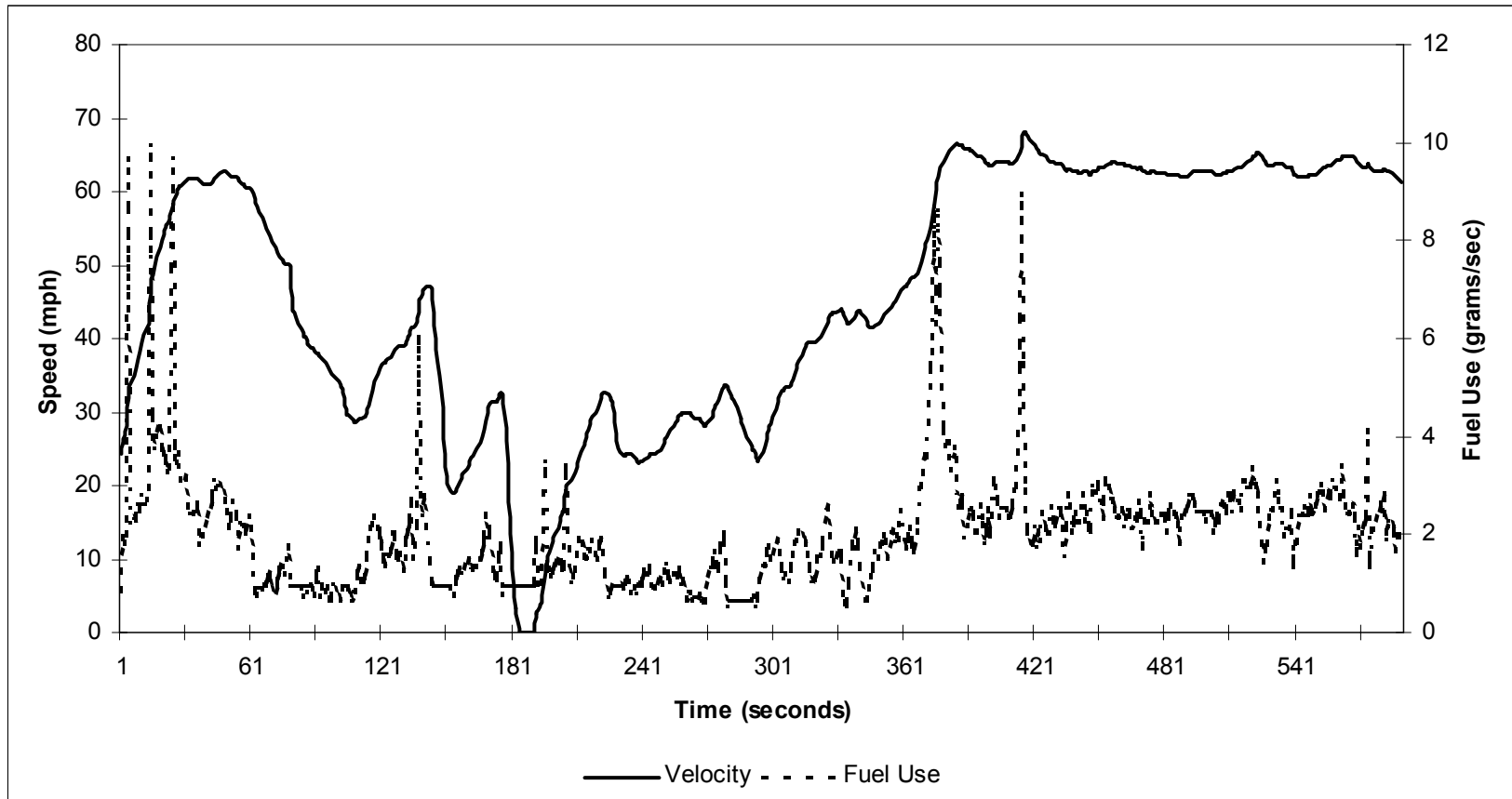


Figure 31. CR2 Speed-NOx Comparison (Peak Direction).



**Figure 32. CR2 Speed-Fuel Use Comparison (Peak Direction).**

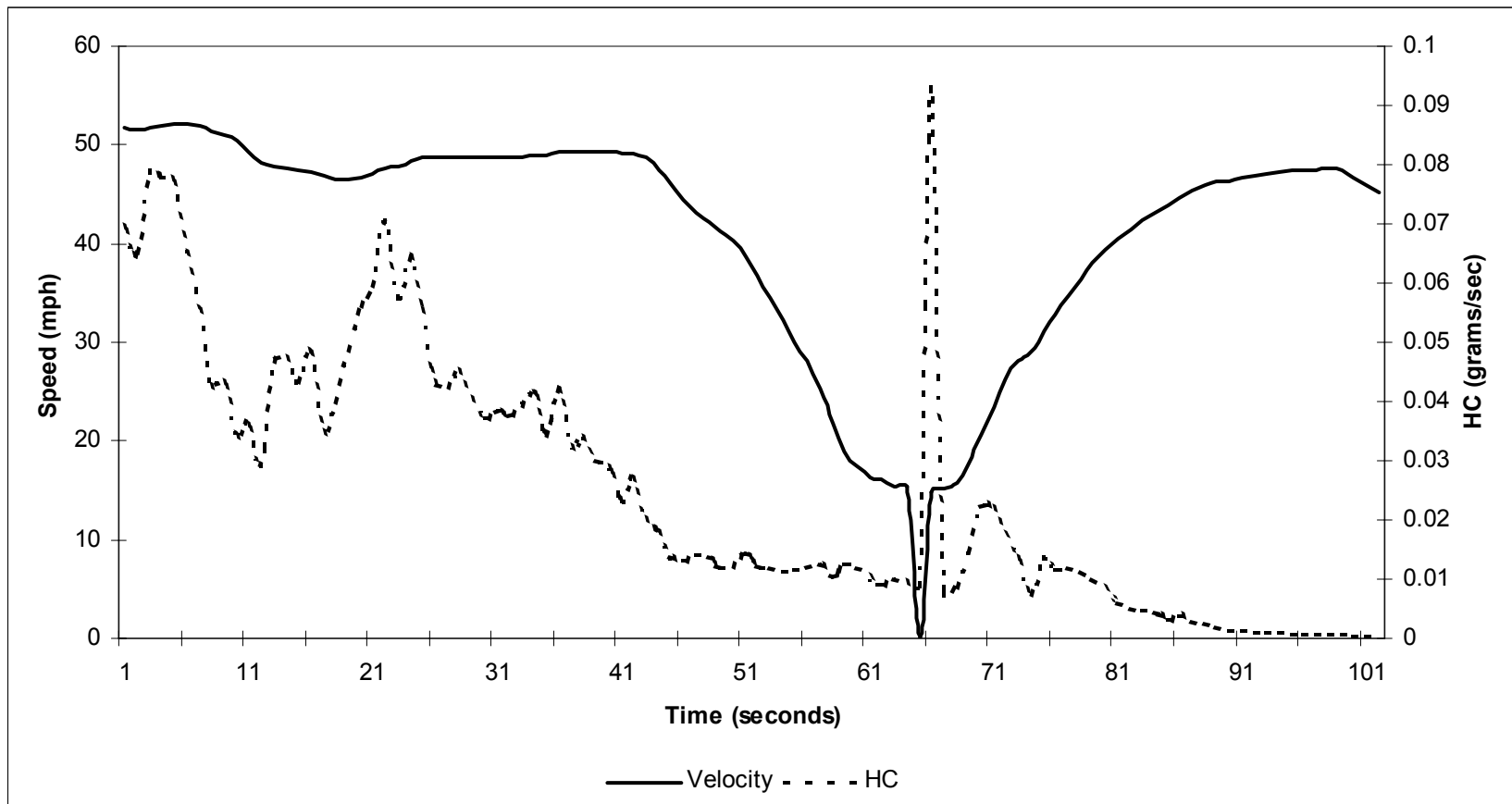


Figure 33. UT1 Speed-HC Comparison (U-Turn).



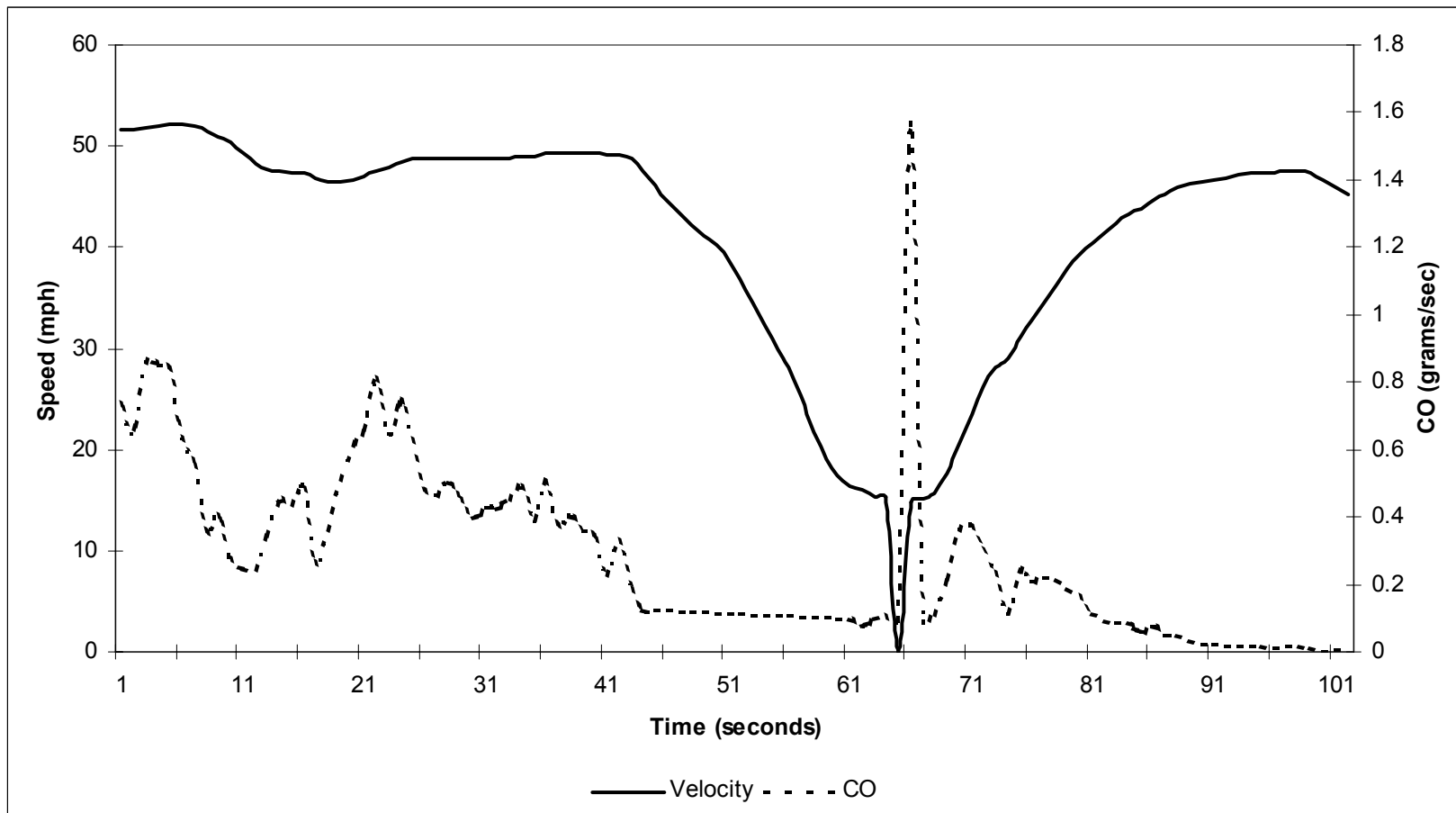


Figure 34. UT1 Speed-CO Comparison (U-Turn).

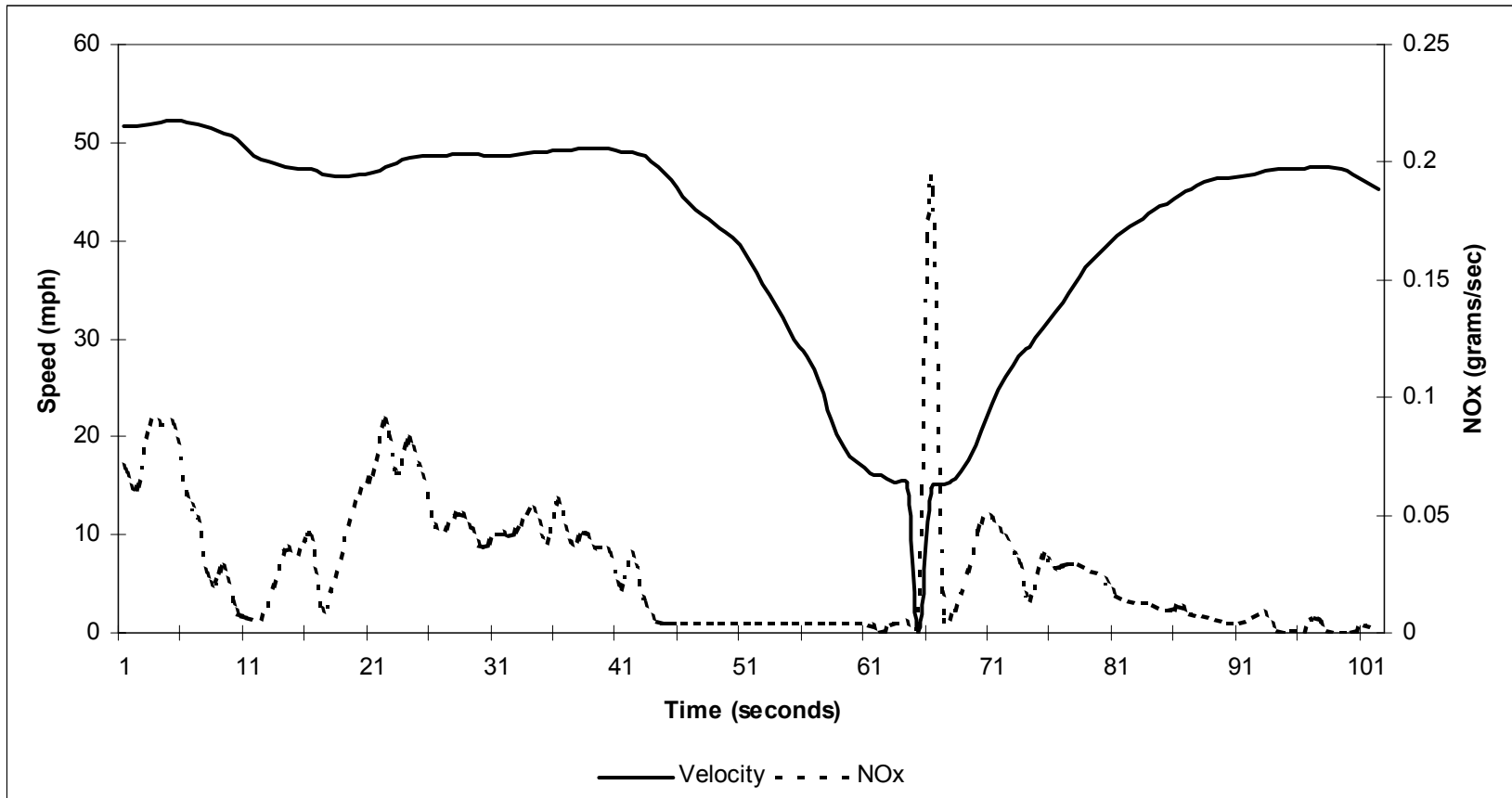


Figure 35. UT1 Speed-NOx Comparison (U-Turn).

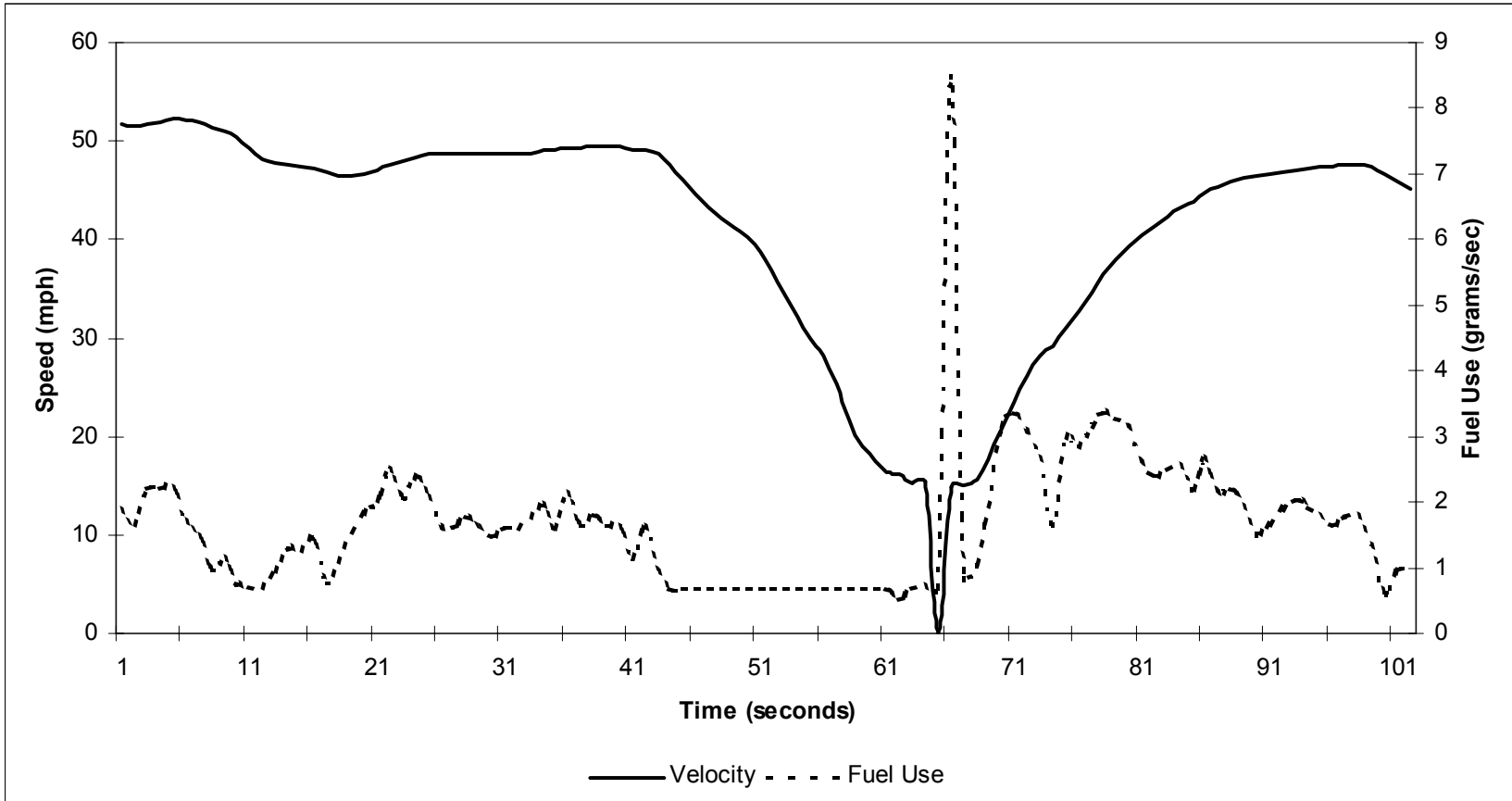


Figure 36. UT1 Speed-Fuel Use Comparison (U-Turn).

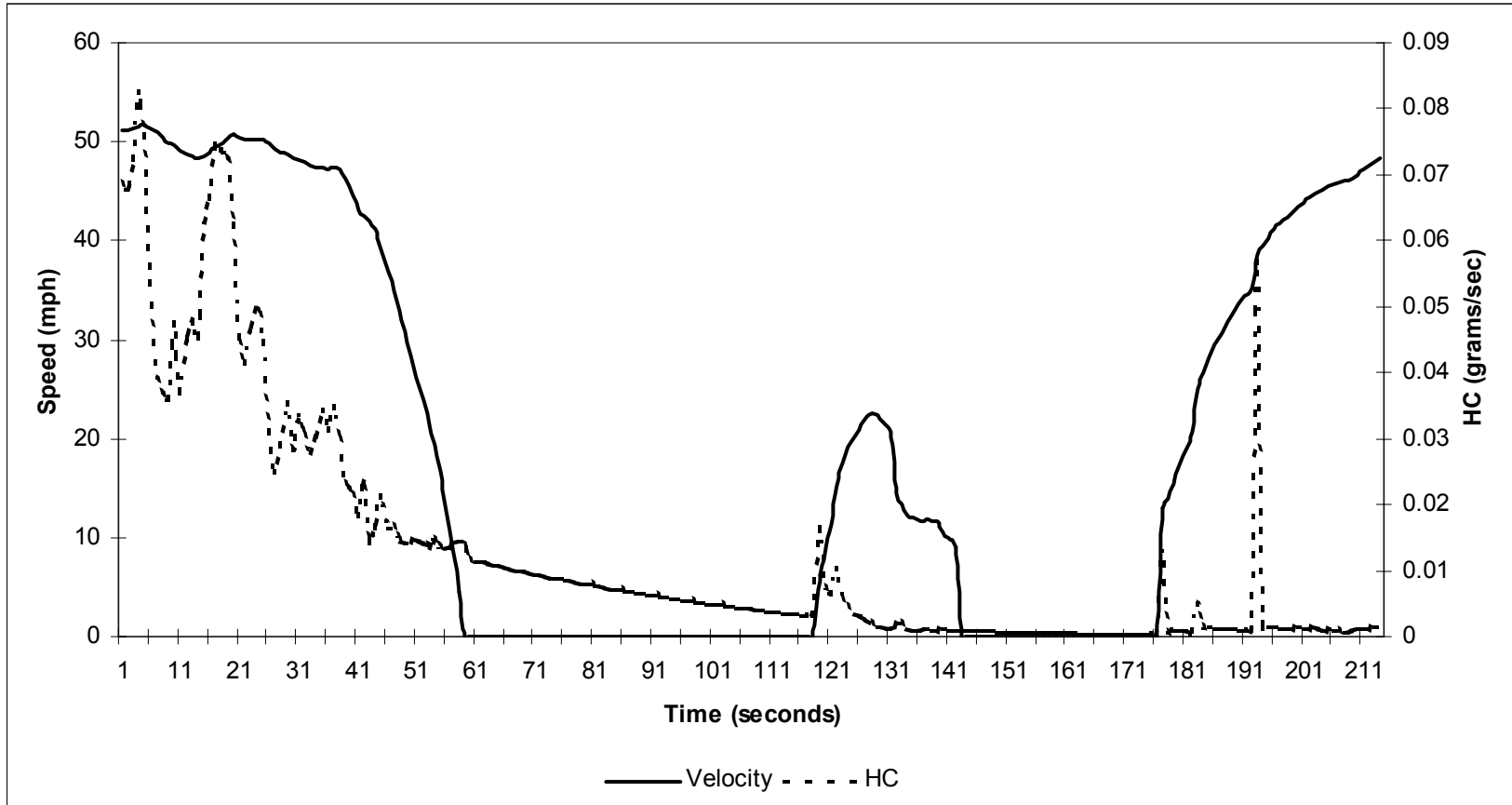


Figure 37. UT1 Speed-HC Comparison (Lights).

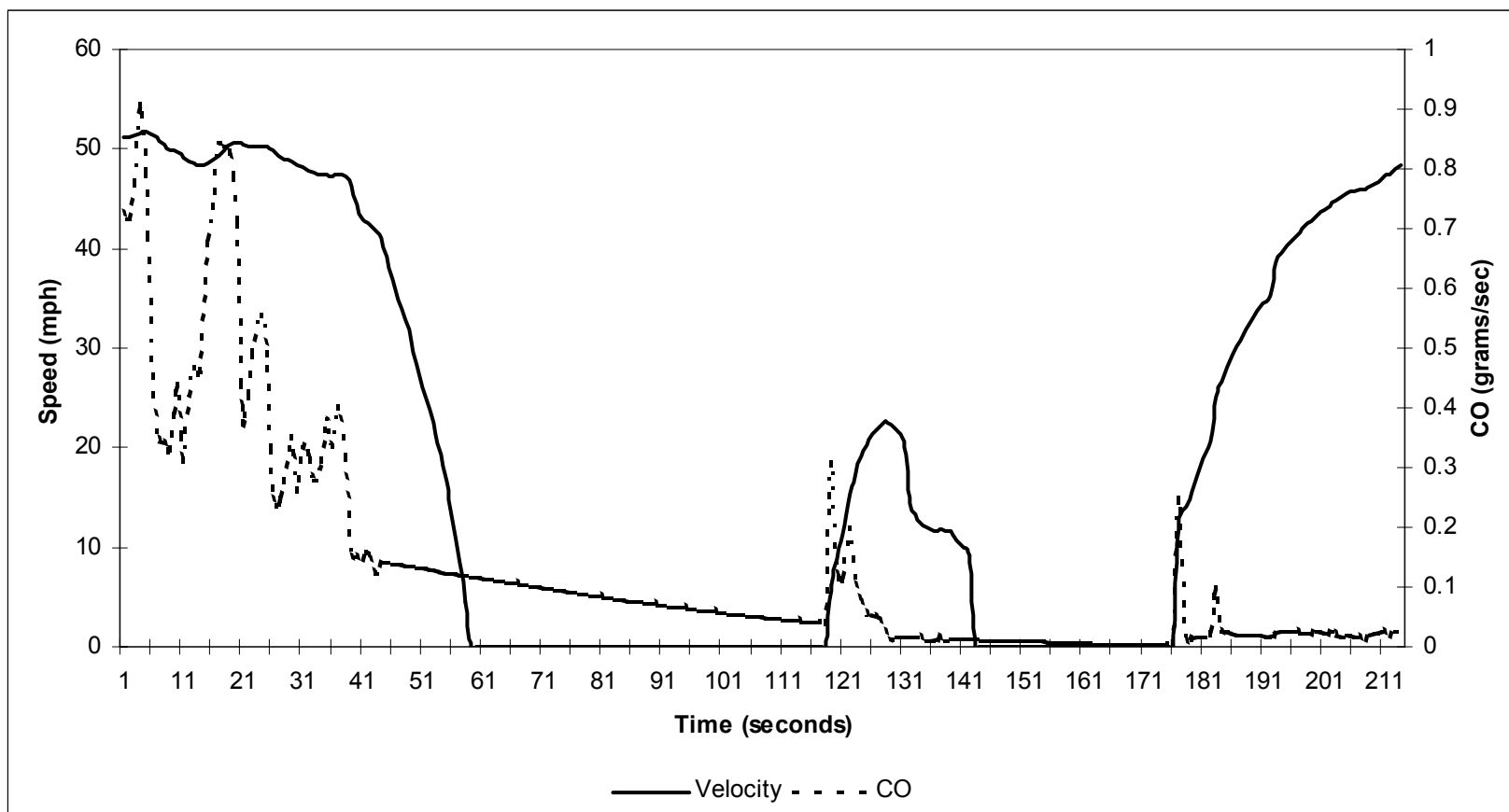


Figure 38. UT1 Speed-CO Comparison (Lights).

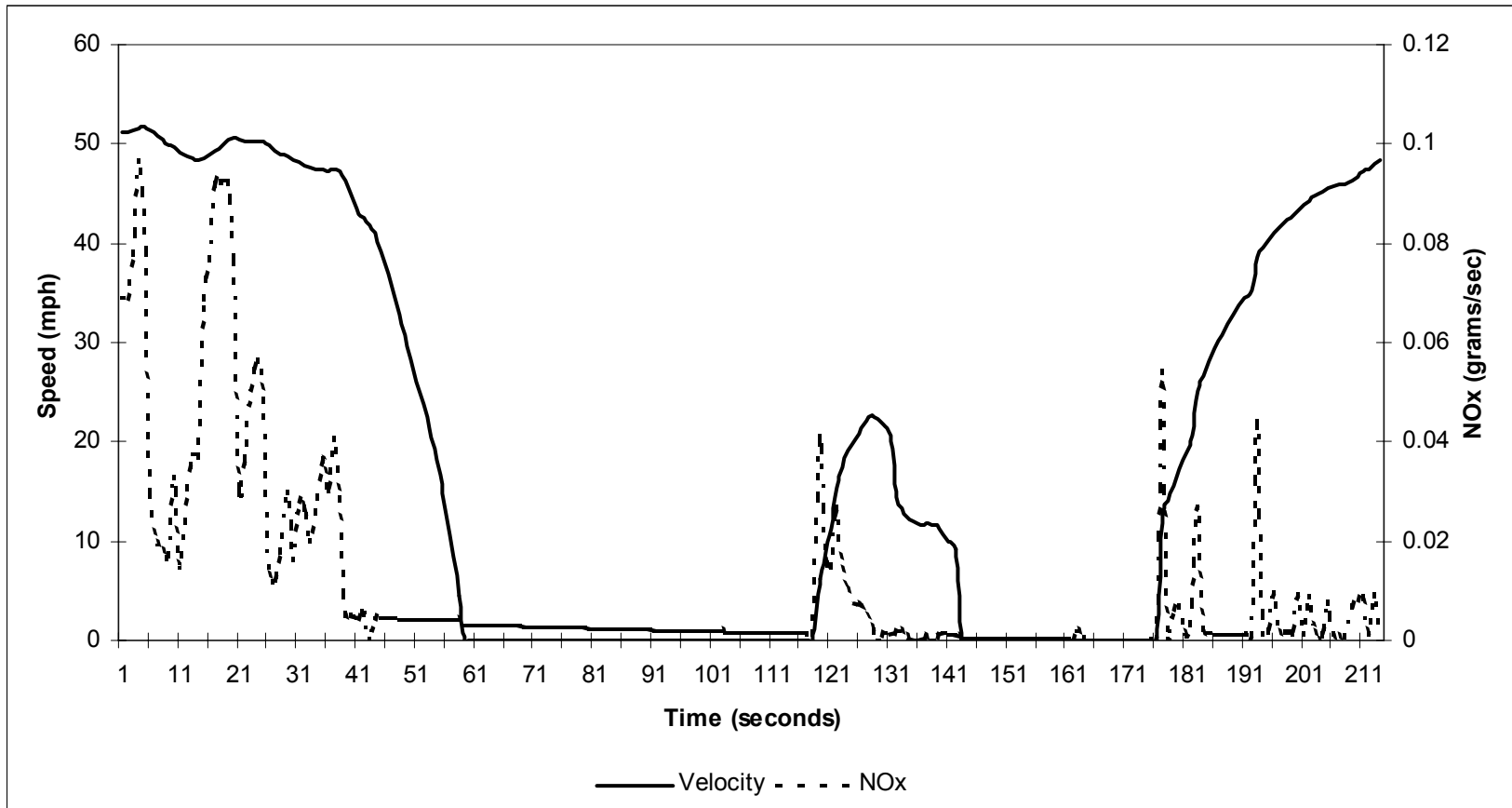


Figure 39. UT1 Speed-NOx Comparison (Lights).

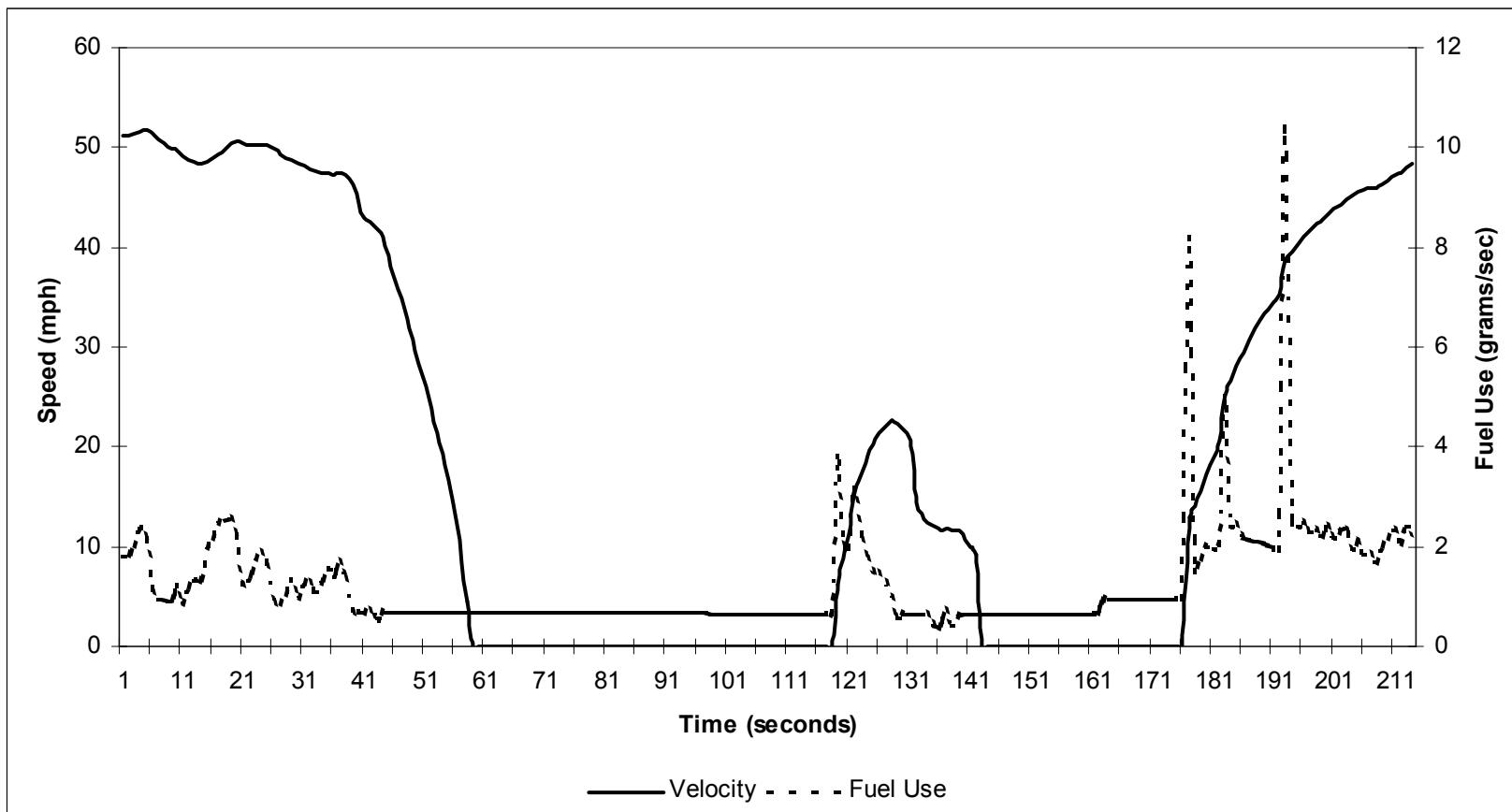


Figure 40. UT1 Speed-Fuel Use Comparison (Lights).

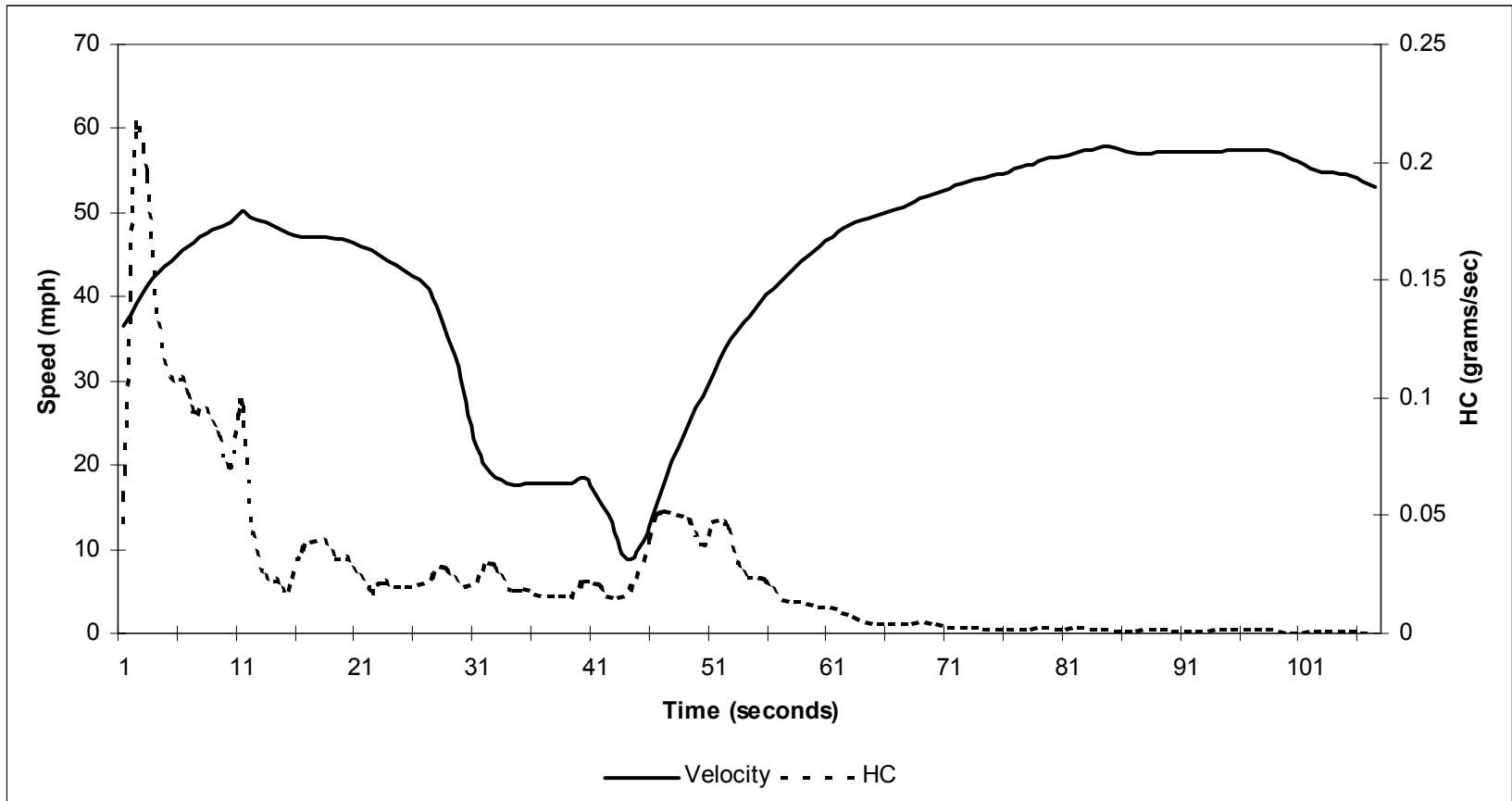


Figure 41. UT2 Speed-HC Comparison (U-Turn).



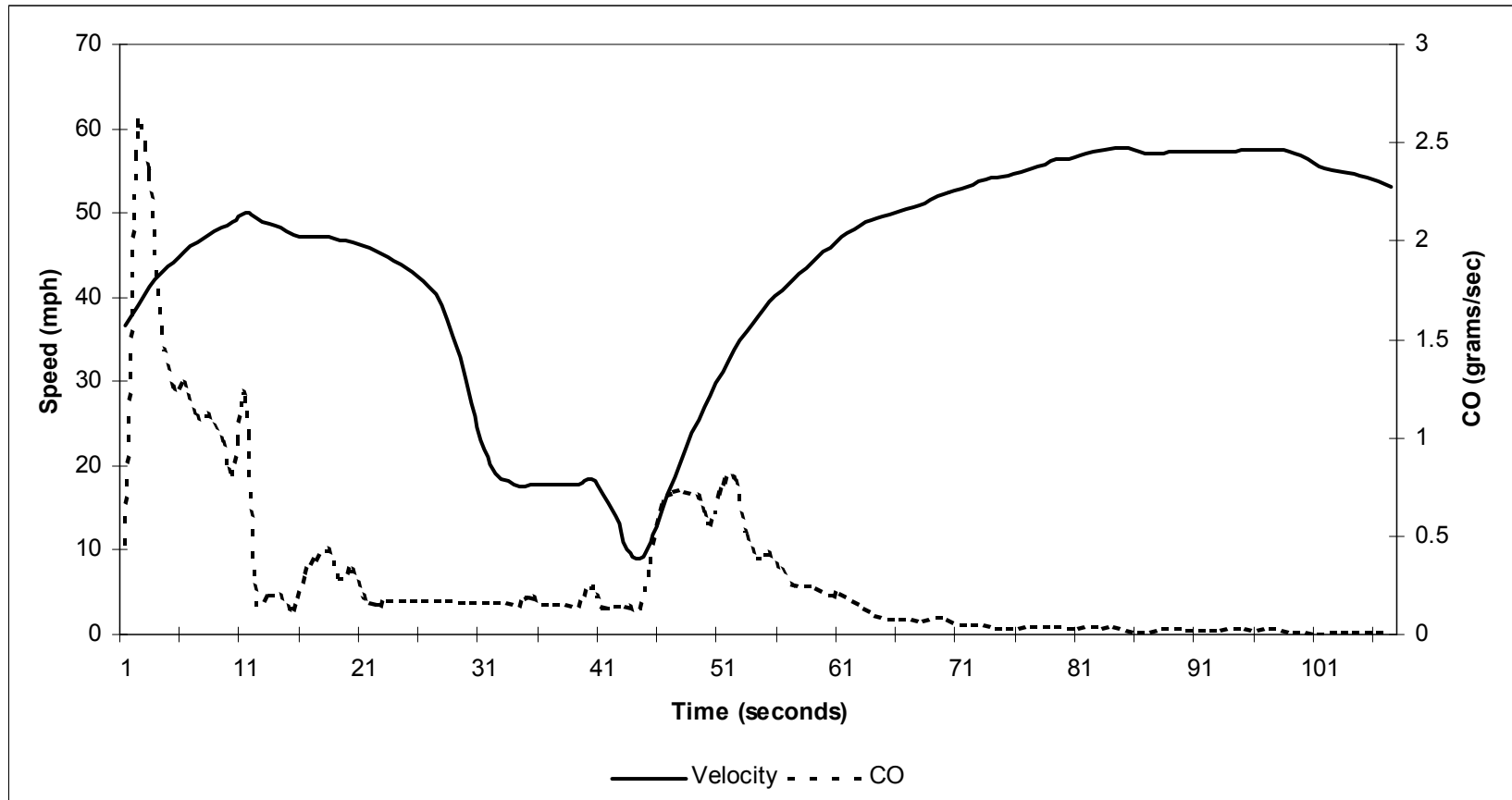


Figure 42. UT2 Speed-CO Comparison (U-Turn).

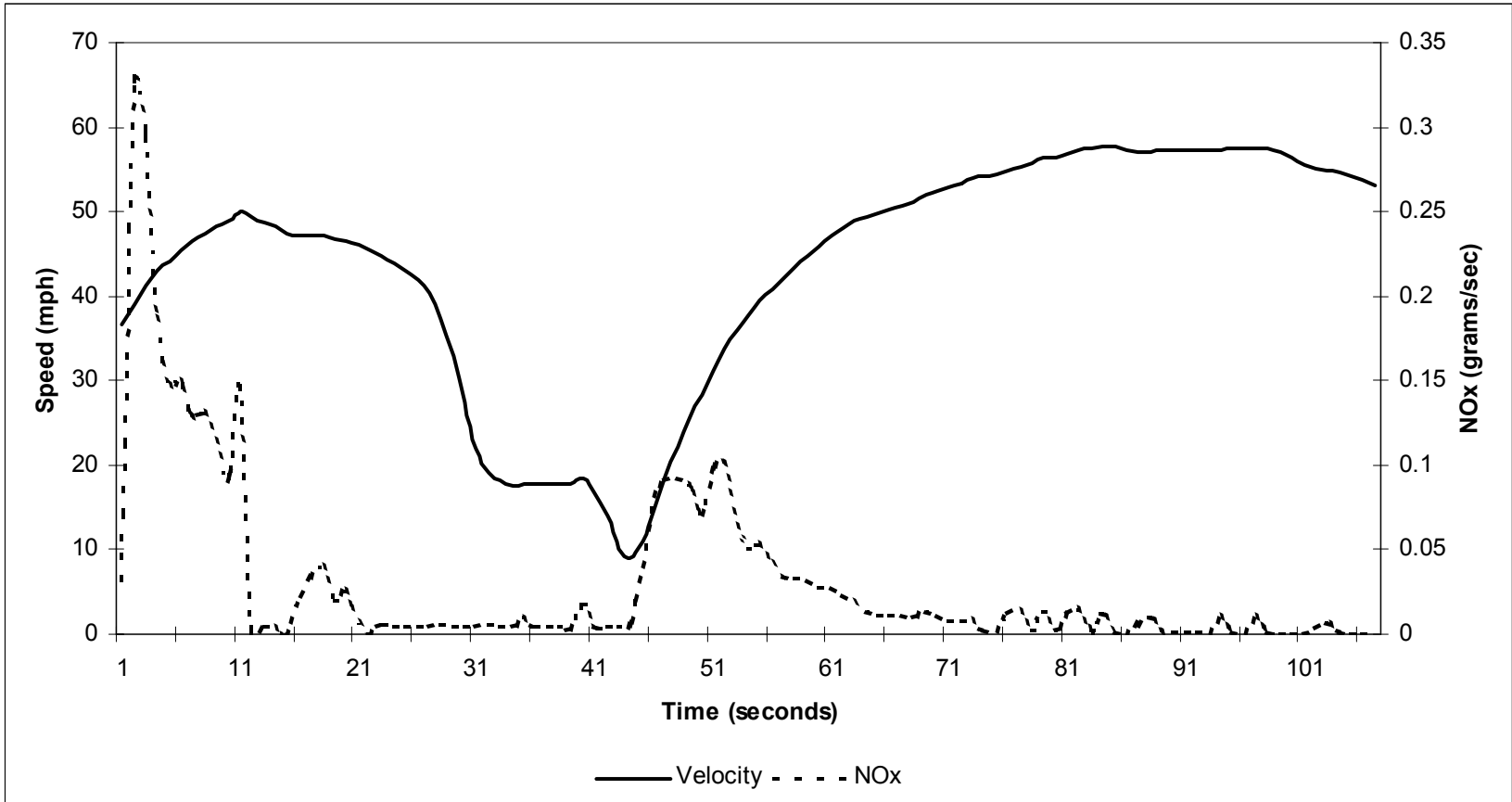


Figure 43. UT2 Speed-NOx Comparison (U-Turn).

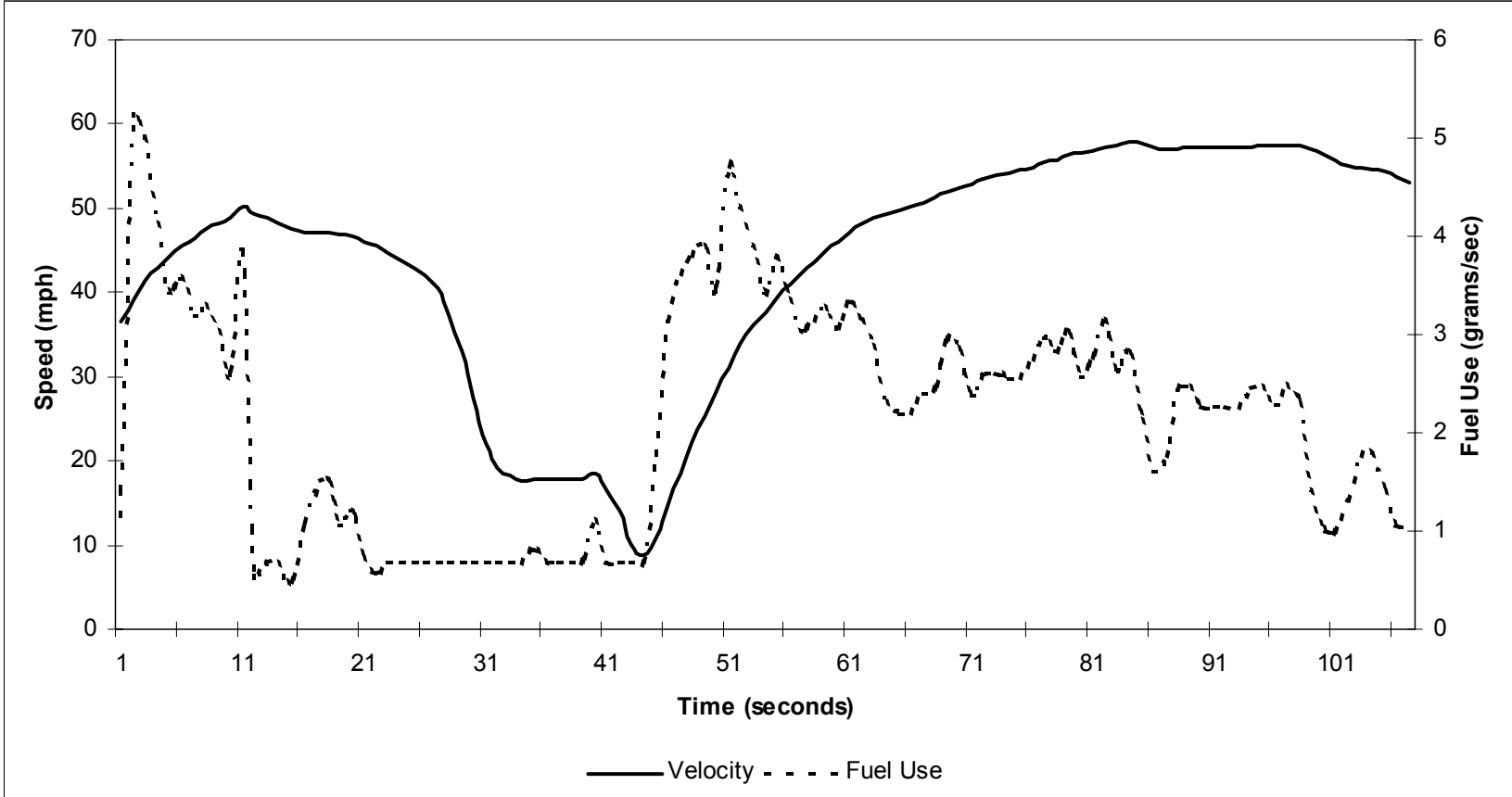


Figure 44. UT2 Speed-Fuel Use Comparison (U-Turn).

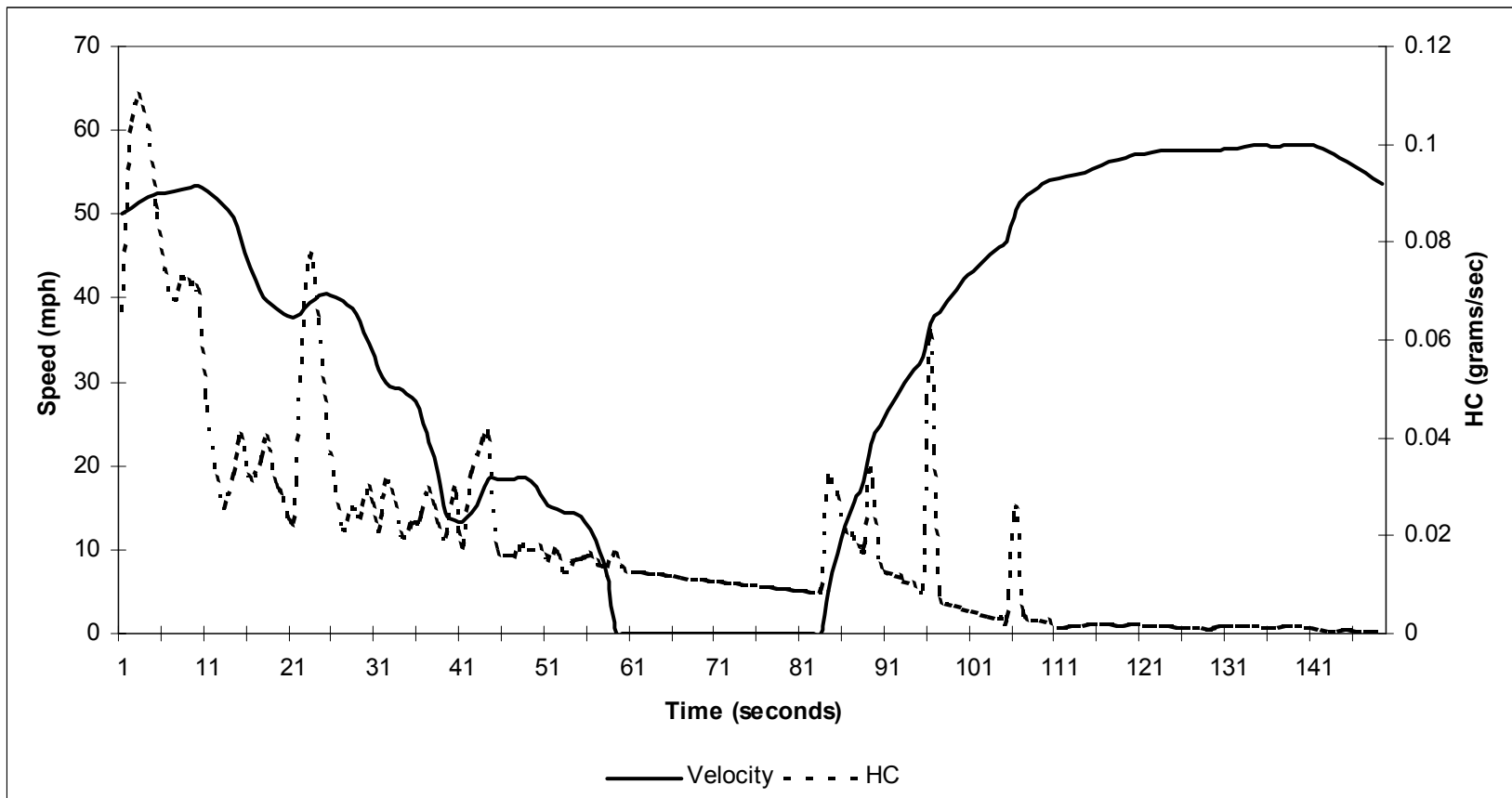


Figure 45. UT2 speed-HC Comparison (Lights).

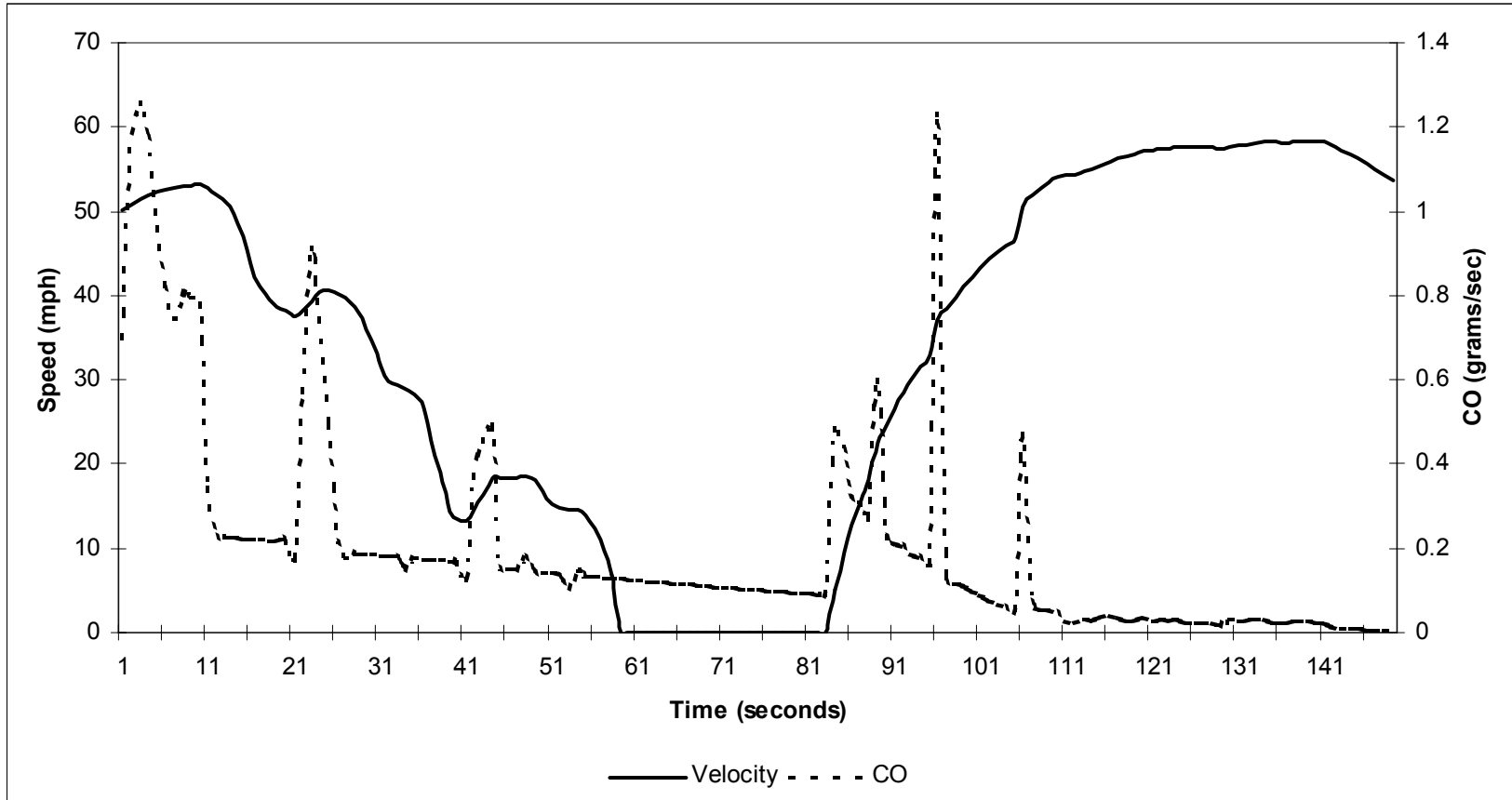


Figure 46. UT2 Speed-CO Comparison (Lights).

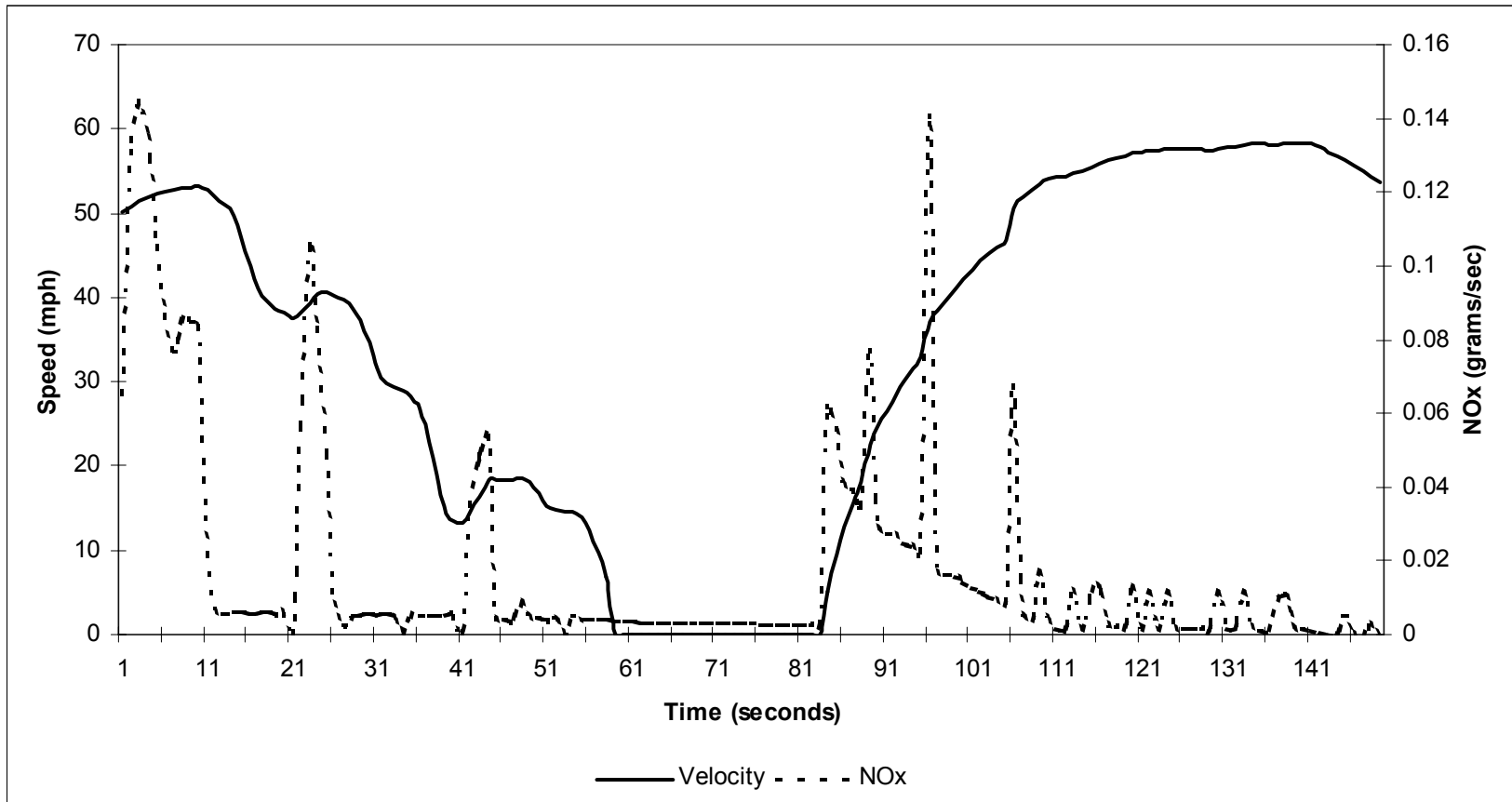


Figure 47. UT2 Speed-NOx Comparison (Lights).

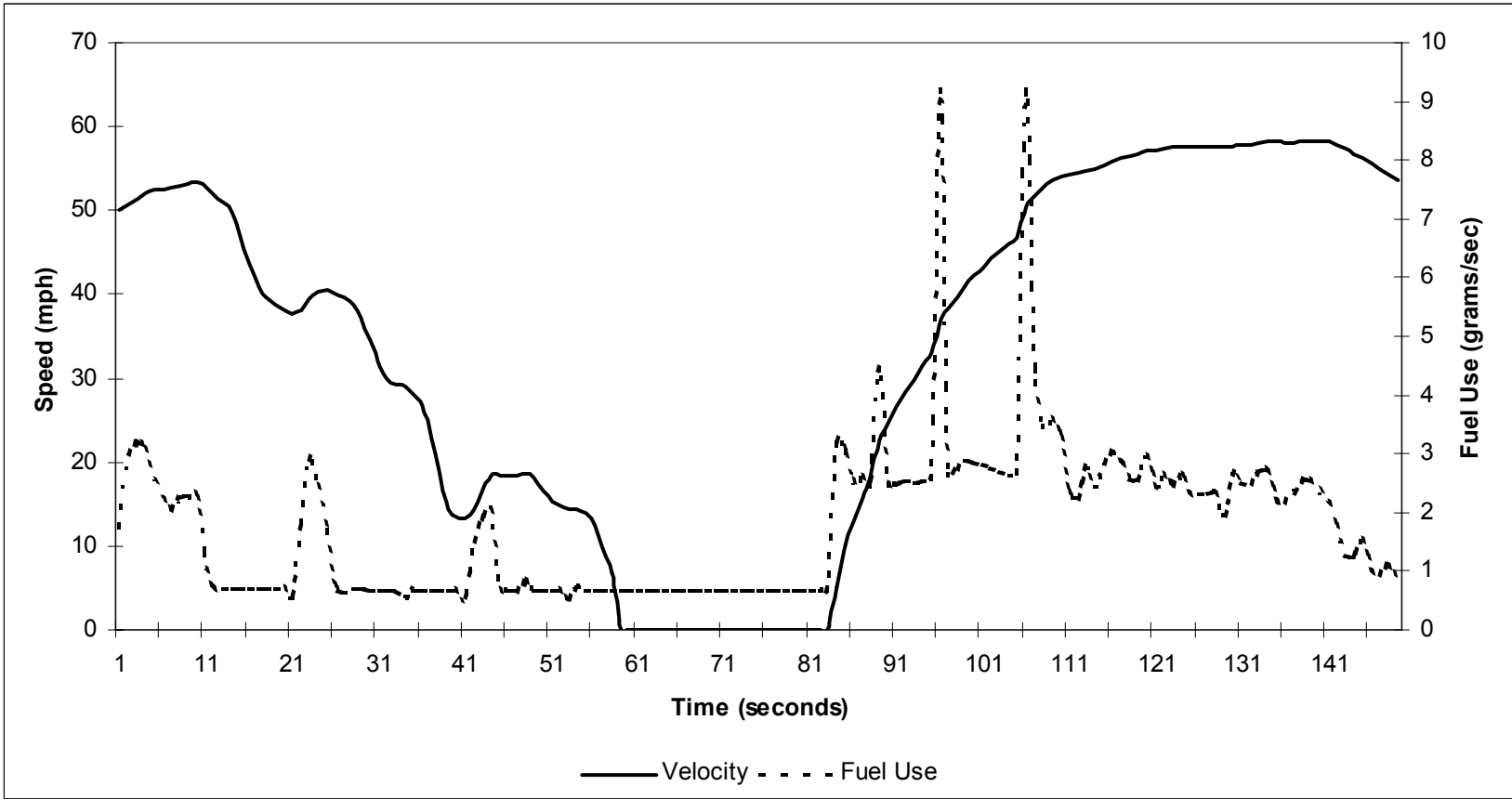


Figure 48. UT2 Speed-Fuel Use Comparison (Lights).