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DEVELOPMENT OF TRAFFIC MANAGEMENT STRATEGIES IN A FREEWAY CORRIDOR

by

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16. Abstract

The project is aimed at initiating a traffic management system on U.S. Highway 26 using video camersa, Mobilizer, and variable signs to guide traffic operations especially during peak hours. Mobilizer provides a third generation video image tracker to gather information about travel speed, volume and traffic density. It assists in data analysis in real time and thus makes it a powerful tool in directing traffic as well as incident management. Project is being undertaken jointly with the Oregon Department of Transportation, and the City of Portland. A phased plan for introduction of the new technologies for traffic data collection is used to strengthn training needs and lead to the development of traffic management strategies and techniques.

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Executive Summary

This report discusses the progress of a joint research project that is completed by Portland State University's Civil Engineering Department and The Oregon Department of Transportation (ODOT). The project entails the implementation of a new computerized traffic monitoring system called the Mobilizer. The operation method and implementation process of this system is discussed, along with the many key design considerations that have been recognized from the various challenges that were faced during the implementation phase of the project. Also, the results of some of the ongoing studies that are being conducted with the system are presented within this report.

The video monitoring system, namely the Mobilizer, takes "snapshots" from a video image then compares them to previous "snapshots" to locate and track vehicles. Also, the system performs location prediction operations to help pinpoint the propagation of vehicles and to identify false detections. This process reduces errors and helps increase the accuracy of the system. The system also identifies the type of vehicle for each track by determining the relative size of the vehicle. While locating and tracking the vehicles, the system calculates the speed, density, volume or flow rate, headway, and percent of trucks for each lane and for the entire freeway. The system also displays this information in real time and stores it in a retrievable database.

This particular system presently monitors the westbound lanes of US Highway 26 as the freeway leaves downtown Portland. This corridor is presently undergoing construction in various locations for road improvements and the addition of a light rail system. The freeway also has a long uphill grade which adds to the possibility of traffic incidents and congestion scenarios. The area being monitored is at the beginning of this corridor, immediately after the point where three ramps converge to create the beginning of the freeway. The study area is continuously monitored by a video camera located on a utility pole next to the freeway. From there, the signal is transmitted to the Portland State University Transportation Laboratory via the use of television lines owned by the area's private cable television company.

The execution of this research project required cooperation and efforts from various institutions and corporations. The alliance of these various enterprises was necessary not only for financial reasons, but also for technical assistance and specialized task labor by various individuals from the different institutions. The primary level of communication that was required was between the main contributors to the project, these being Portland State University, Oregon Department of Transportation, The City of Portland, and Condition Monitoring Systems.

During the implementation stages of the project many challenges were encountered. By recognizing these challenges and determining better design considerations, information is documented to help future implementation by any agency of such a system in an expeditious manner. Some problems in the design that are identified and discussed include: the optimum location for the camera, a description of all the equipment that may be required to be located at the monitoring site, considerations that need to be identified to determine the type of camera required at the site, and the method of installation for the camera.

Besides calculating information like speed, density, headway, and volumes, the system also counts the number of vehicles it tracks. Some short Microsoft Excel™ macros and Microsoft Access™ sorting queries to pick out desired data from the system's database have been written. These applications were also used to translate the data into Excel files so it could be summarized into traffic flow, densities, and speeds for analysis in short time periods, as well as hourly traffic counts.

An investigation is also performed to determine the accuracy of these traffic counts obtained by the Mobilizer. The first study compares traffic count data provided by ODOT to counts obtained by the Mobilizer. The counts provided by ODOT were obtained from loop detectors located near the monitoring site. The second analysis determines the ability of the Mobilizer to duplicate traffic counts by analyzing video tapes of the same periods. Also, a comparison is performed for manual counts and counts from the Mobilizer. These results, however, are not as admirable as results obtained during typical monitoring periods. This is due to high flows that were present during the video taping of the analysis periods. The results of these various analyses are discussed, with typical counts for ideal monitoring situations being 90% or better.

Graphs were created to display typical operating conditions of speed and density versus time, speed versus volume, and volume versus density. These graphs were then compared to typical graphs published in the Highway Capacity Manual and other publications of the Transportation Research Board. By studying these graphs and comparing them to typical graphs, certain reoccurring traffic characteristics could be identified for the study area. Using this information about reoccurring traffic characteristics, it is possible to make some preliminary conclusions about the typical operation of the freeway, as well as identify some situations that can be used for congestion prediction situations in congestion management. Since the Mobilizer displays this information in real time it is concluded that these recognizable characteristics can be used to make real time decisions in a congestion management monitoring system.

Development of Traffic Management Strategies in a Freeway Corridor

Introduction

During the summer of 1994, Portland State University's Civil Engineering Department, jointly with the Oregon Department of Transportation (ODOT), began the implementation of a new computerized traffic monitoring system called the Mobilizer™. This system borrows technology from developments in the defense industry for missile detection and tracking, and can be implemented to monitor traffic and determine its flow characteristics in real time. The system operates by tracking vehicles from a video image signal that is displayed for a standard television monitor. This system is being used as part of a research project to study the new system's accuracy and effectiveness as a real time traffic monitoring system. Also, study is aimed at determining its potential application to congestion and incident prediction on freeways and highways, in turn real-time traffic management.

Some initial challenges were faced in overcoming the implementation and communication problems. The current phase of implementation was essentially completed over a one year period. Additional data collection continues as we process and analyze the data already gathered. Many of the steps involved in the implementation of this traffic monitoring system were refined as we worked out the bugs and tested hypothesis.

The project's main participants include Portland State University (PSU), Oregon Department of Transportation, and The City of Portland Office of Transportation. The support of these organizations, along with some other local companies, like Paragon Cable, enabled the establishment of a communication system network that could not have been feasible without their support. With this cooperative effort, it has been possible to use the available capacity of the existing communication links. Other funding has come from the U.S. Department of Transportation via TransNow, a regional transportation research center based at the University of Washington, and the software's developers, Condition Monitoring Systems (CMS).

Mobilizer: The System's Background

The Tracking Process:

As mentioned, the software for this system was developed and written by a company located in Long Beach, California, called Condition Monitoring Systems. This system is a third generation data association video tracking system. Unlike older technology, like a tripwire video process, this tracking process is performed throughout the entire field of view of the camera (1). The system takes a "snapshot" of the view at designated time intervals. The tracking process is initiated by the computer recognizing a change in contrast in the video image when compared to the previous "snapshot". The software then performs a vehicle location prediction calculation with an algorithm that considers the existing speed and headway on the freeway, and the possible movements from a vehicle changing lanes. The computer then "looks" for the vehicle within this location in the next "snapshot". This process is repeated, usually tracking each vehicle four to five times as they pass through the field of view. The system also can determine the type of vehicle for each detection by the size and length of the detected object in the view.

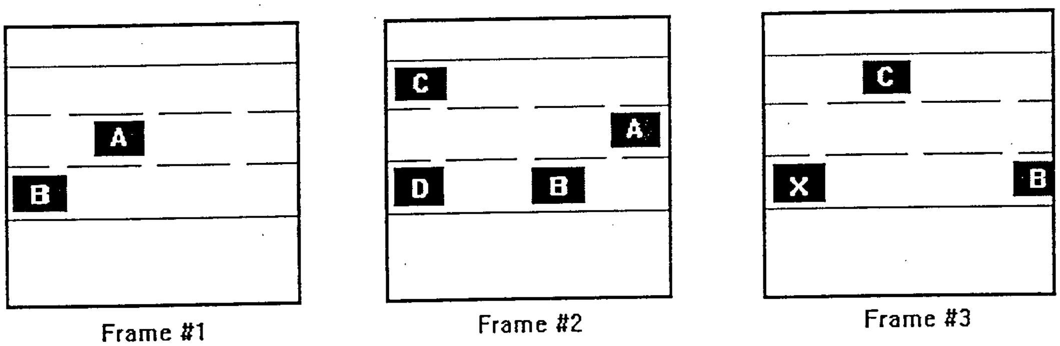

Figure 1. Example of the Mobilizer tracking process.

An example of this process is displayed above in Figure 1. In the first "snapshot", frame #1, the Mobilizer has recognized that two vehicles, vehicles A and B, have entered the field of view, and has begun its tracking process. Then in the next "snapshot", frame #2, the Mobilizer has "looked" for, and found, the same two vehicles, A and B, as well as detected two new vehicles, C and D. Finally, in frame #3, the Mobilizer has again "looked" for, and found, vehicles B and C, which were both still in the field of view. However, the system has recognized that vehicle D has not propagated down the roadway, and has remained at location X. Therefore, the Mobilizer will no longer continue to track vehicle D, and will not include it in its calculations. This process can occur anywhere in the camera's field of view, and will recognize and correct these errors. However, it will continue to "look" for vehicle D further down the roadway to confirm that it was indeed a false reading, and not that the vehicle was passing behind an obstacle or another vehicle, like a tall truck, during one of the "snapshots".

This process reduces many errors, and allows the system to operate with higher accuracy. As mentioned, the system can interpret obstructions and shadows by using this tracking process. This entire location prediction process is called "labeling", and is possible due to the fact that vehicles traveling on a freeway typically do not have any sudden changes in their present traveling path (2, pp. 67). This type of tracking process was adopted from mathematical studies performed by Wold in the 1930's, and by R. Kalman in the 1960's, and were later developed in the defense industry for missile tracking.

This third generation system requires minimal amounts of custom equipment, and is usually directly applicable to present wide area surveillance systems. The system operates on two standard IBM386, 33MHz personal computers, or better, and reads a standard video signal that would be transmitted to a typical television monitor. One computer does require a video digitizing card. The system can also implement existing loop detectors to increase data collection and accuracy, and help calibrate the system as it operates.

Data Collection and Display:

From the tracking process, the computer calculates and stores typical traffic characteristics like speed, flow, density, headway, and percent trucks. This information is calculated and displayed for each lane, see Figure 2, as well as an average for all lanes being monitored.

LANE #	1	2	3	Aggregate
SPEED (M/Hr)	54	59	61	58
DENSITY (V/M)	28	48	36	39
FLOW (V/Hr)	1860	3222	2136	2406
HEADWAY (ft)	187	111	146	14[illegible]
% TRUCKS	0	2	6	3

Figure 2. Typical computer screen display of traffic characteristics.

These traffic characteristics are recalculated in short time intervals, between 30 seconds and 15 minutes, and updated to the screen in semi-real time. This information is also stored in a database on the computer at the chosen time interval. This data can then be retrieved at a later point in time from the database, and can be reviewed and manipulated to study all of the traffic's characteristics.

The system also displays a real time dynamic icon screen, see Figure 3, which shows the vehicles that are being tracked, their type, and respective location with other vehicles on the freeway as they continue to travel down the freeway.

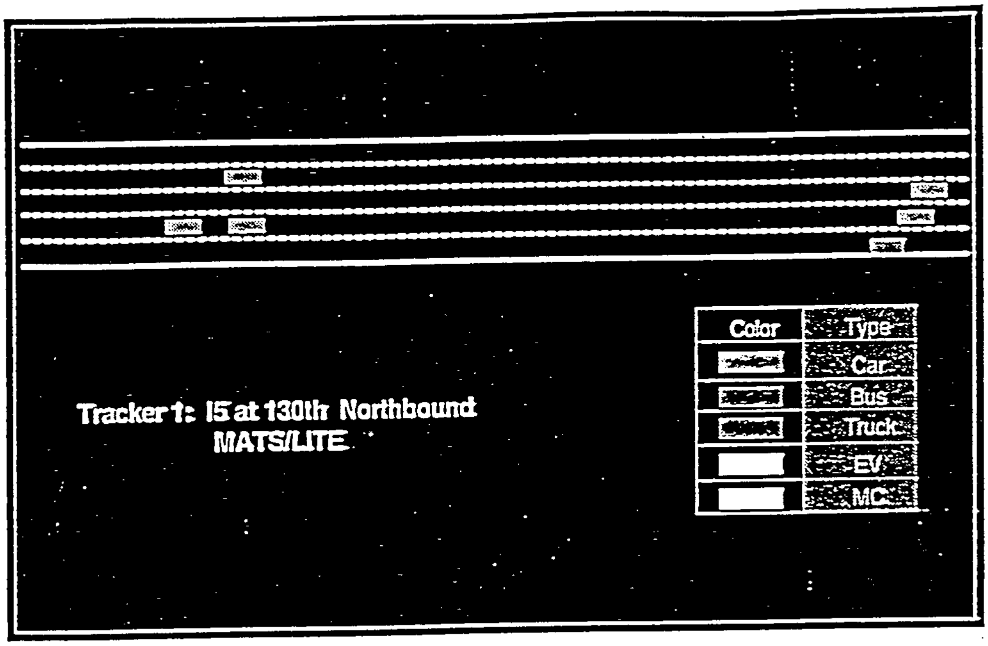

Figure 3. Typical dynamic real time icon display.

Portland's System

Presently, the system monitors the east end of U.S. Highway 26 as it leaves downtown Portland. This freeway corridor is undergoing construction in many areas for major improvements and widening, which causes the corridor to be very incident and congestion prone. Also, the beginning of this route near Portland's Central Business District consists of three separate on-ramps converging into the three lanes of the freeway. Two of these ramps come from the Central Business District (CBD) circumferential freeway that links Portland's west side to I-5 on the east side of the Willamette River, and the other ramp comes directly from the CBD. All of these ramps converge onto the freeway at the same point and have caused the area immediately downstream to become somewhat of a weaving area, before vehicles enter the tunnel that passes under Portland's West Hills.

In addition to the problems described above, this corridor frequently becomes congested after it passes through the tunnel and begins its 3 mile long climb up a 5.5 percent grade to the crest of the Tualatin Mountains at Sylvan Heights. Approximately 1 mile later, the freeway narrows to two lanes as it passes through a narrow section of right of way, then enters an area that has made room for the construction of Portland's new West Side Light Rail tunnel that passes under this steep terrain.

Because of all of these features within this freeway corridor, along with it being near Portland State's campus, it was determined that the beginning of this route, before it travels through the tunnel, would be an excellent site to study and test the new traffic monitoring system. Frequently occurring incidents along the corridor provide many opportunities to collect large quantities of data for different congestion scenarios, and also give the opportunity to determine how often the freeway is congested on a day to day basis.

Portland's system includes the use of existing cable television lines owned and operated by the local cable television carrier, Paragon Cable. The video image is transmitted from our camera on top of a pole next to the freeway, to a video modulator located in an equipment box mounted at the base of the pole. Then the signal is transmitted through existing Paragon Cable lines to their main transmission center; from there the signal is transmitted to Portland State's television services facility, as well as to The City of Portland Traffic Center. It is also feasible for the signal to be transmitted to other locations such as local television or radio stations, allowing them to monitor the freeway during their rush hour traffic reports.

Next, Portland State's television services facility demodulates and transmits the signal, via the campus coaxial cable system, across campus to the Civil Engineering Department's Transportation Laboratory. From there the signal is monitored and transmitted into the Mobilizer system. Here the Mobilizer system analyzes the traffic in real time and collects and stores data on the highway's traffic characteristics.

The camera monitoring the site can be controlled from the box located at the base of the mounting pole. Using its pan, tilt and zoom capability, the camera can be pointed in different directions to monitor on ramps or a section of the freeway

The System Implementation Process; Challenges and Successes

Institutional and Corporate Communications:

The execution of this research project required cooperation and efforts from various institutions and corporations. The alliance of these various enterprises was necessary not only for financial reasons, but also for technical assistance and specialized tasks performed by various individuals from different institutions. The primary level of communication existed between the main contributors to the project, these being Portland State University, Oregon Department of Transportation, The City of Portland, and Condition Monitoring Systems.

From each of these institutions a primary contact person had to be identified in order to prevent plans and work requests from being misplaced or forgotten in the shuffle. Plus, it was important that this contact person had some expertise in an area that would be beneficial to the project, or that they had an interest in the project to prevent requests from being considered unimportant. The contact persons for the project included Kent Lall from PSU, the leader of the research project, Som Sartunrak and Gary McNeel from ODOT, who both have contacts with many needed crews within the department like surveyors, electricians, and bucket truck operators, Rich Johnson from The City of Portland, who has a great deal of knowledge in the area of video imagery, digital and audio communications, and traffic engineering, and Kay Dermer of Condition Monitoring Systems. Many tasks had to be delegated and distributed between these various individuals, as well as further communications with other individuals.

Some of these extended communications consisted of contacts to other corporations that provided a service that we required. This included contacts to Portland General Electric, the local electric power utility company, Pacific Northwest Bell, the local phone company, and Paragon Cable, the television cable company. As mentioned, each of these companies provided some service that was needed for proper operation of the traffic monitoring system. ODOT installed a utility pole along the side of the freeway and The City of Portland assisted in the electric power connection to the equipment box mounted on the pole. The phone company ran a phone line to the equipment box so there would be communication to the site, and use this connection also to control the camera from the laboratory. Finally, the cable company installed a cable line to the pole and provided us a hook up near the Portland State University campus. The remaining link to the laboratory was actually completed with the aid of Portland State University. Paragon cable was linked directly to PSU TV Services, and from there to the laboratory. The latter connections were provided at the expense of the University.

Since each of the services would have been an expensive purchase, it was important to explain to these different institutions and corporations what the work entailed. In many cases the project had to be described in laymen terms so all of the institutions had some understanding of what the work entailed, as well as explaining that it was an investigative research project. This allowed the project to receive some of these services for free or at a reduced cost. Little would have been possible without this assistance as we simply could not afford to pay outright for these services.

There were some obstacles and problems while attempting to implement this proposed design of the system. This plan allowed us to implement the system at a fraction of the cost compared to installing a direct connection to the site. The system, as designed and implemented, provides a good example of public-private partnership. In addition, it shows the added value obtained from the use of the existing facilities. However, it has its shortcomings because of the fact that the signal is being handled and transmitted by different organizations. When the connection is interrupted, it can be time consuming to determine where the problem is located; however, once determined the responsibility for repair is clearly identified. The motivation to expedite repair still is lacking as the services are generally donated, but the level of cooperation is admirable. Over time the interruptions have reduced as the initial bugs were worked out.

Location of the Camera:

There were many different possibilities for locations to mount the camera at the site. All of these locations had benefits and drawbacks. Some of the different locations that were considered were: on the ceiling of one of the nearby tunnels that the highway passed through, on a power pole or light pole on the shoulder or in the median, above the entrance to the tunnel on a pole, or on a structure used for highway signs that passed over part of the highway.

Each of the different possible locations were then studied and the benefits for each site were considered. There were some key design issues that had to be considered for the different sites. These issues included accessibility to power, phone, and TV cable, the height of the camera, the angle of sight from the camera to the roadway, and the presence of and accessibility to an equipment storage box near the camera.

The camera location was primarily determined by cost of installing the required hardware and utilities, along with the ease of accessibility. In order to have the tasks completed in the most expeditious manner possible the selected site for the camera was chosen through a consensus approach. It was agreed to install a wooden utility pole at a location near the right shoulder of the west bound side of the freeway which was also less than 150 feet from existing power, phone, and cable lines.

This location allowed a bucket truck to get near the pole for easy installation of the camera on the pole, and also made the installation of the various needed utilities uncomplicated. This location also seemed to provide reasonably sufficient height of the camera to view all of the lanes on the west bound side of the freeway, and possibly be high enough to view the east bound lanes as well, which are located on the other side of a landscaped median that is approximately 50 feet wide. This location is also about 350 feet from the tunnel that the freeway passes through as it travels under Portland's West Hills. It was believed that this would be a sufficient amount of distance for the computer system to perform its tracking and calculations, and would be high enough to provide an adequate angle of sight to minimize false readings by the computer and have a good view of the entire site with the camera. However, after operating the system for about a year, it has been determined that the camera location is not the most ideal. The camera would probably provide better operating conditions and reduce many other minor problems if it was higher or in a position that would provide a view from the median or directly over the lanes. More discussion on these topics is provided later in this section and in the section discussing the accuracy of the system.

General criteria that should be considered when choosing the camera location include avoiding obstructions in the camera's view, maximizing the angle of view, and maximizing the height of the camera. Studies by Hoose (2, pp. 113) recommend that the camera should be positioned as high as possible and have an angle of 30° or less, when measured perpendicular to the road. The Mobilizer's technology will track vehicles that pass behind obstructions, by using an algorithm that predicts the location of where the vehicles should be after their initial tracking. As mentioned, the method of tracking vehicles uses a change in contrast to identify moving vehicles in the video image view. Because of this, night tracking can be accomplished by the Mobilizer locating and tracking headlights or taillights of vehicles. Problems arise, however, when the vehicle passes behind or near high intensity street lights. The sudden change in the level of contrast with the lights sometimes "confuses" the Mobilizer's tracking system. Therefore, it is recommended that the video camera's view of the tracking area be free of obstructions and light fixtures if at all possible.

The other problem that can reduce the accuracy of the Mobilizer tracking process and results is the obstruction created by trucks when the camera is not located over the center of the lanes. If the camera is located on the shoulder side of the road, trucks in the nearest lanes can obstruct the view of vehicles in the lanes to the left. Besides missing the vehicle behind the truck, the projection of the tall truck image can "trick" the Mobilizer into seeing two trucks, one in the near lane, and one in the lane next to it. Since the classification of vehicles is determined by vehicle length, a tall, long truck would appear to the Mobilizer as two long trucks, one in each lane.

To reduce this type of error, the camera should be located as close to the center of the lanes being analyzed as possible. By viewing from the direct rear or front of the vehicles path, the number of truck obstructions can be greatly reduced. A maximized height of the camera can also help reduce these false readings. By elevating the camera, and centering it over the traffic, the ability to view over and around trucks allows the Mobilizer to track vehicles on the sides of the obstructing trucks.

This configuration can be somewhat confusing when monitoring a section of freeway that is traveling through a curve. If a curve is being monitored, it is best to locate the camera on the outside of the curve, on the tangent line near the point of intersection (PI). This allows a clear view of vehicles near the end of the curve, making them appear to be moving straight away, or towards, the camera. Figure 4, below, shows the optimum location for the camera in a curved situation.

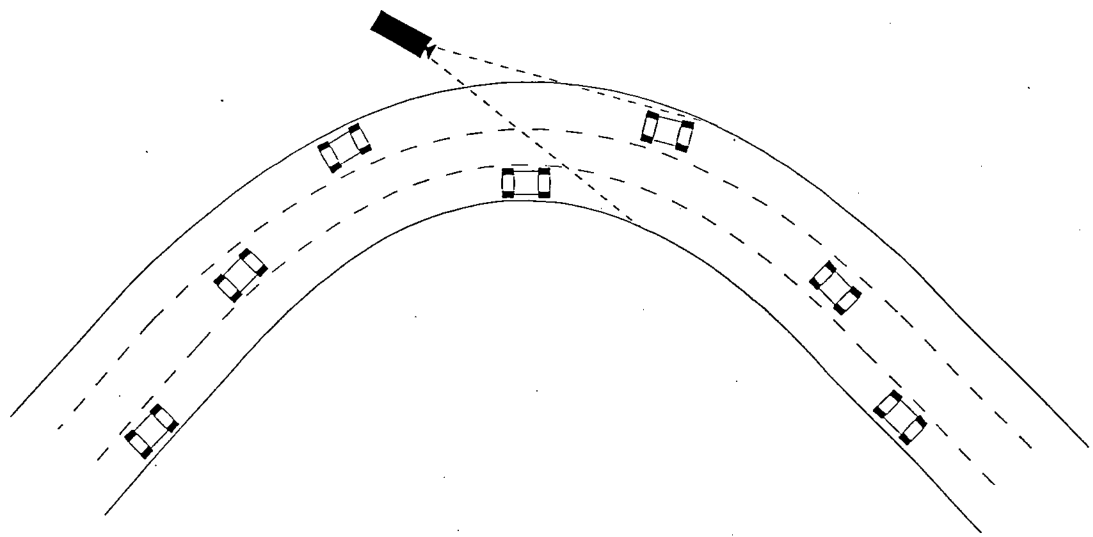

Figure 4. Optimum Camera Location on a Highway Curve (Top View).

This location of camera is recommended to minimize obstructions caused by larger vehicles to view other vehicles. It assists tracking of cars, as an example, that could otherwise be missed due to truck obstructions. However, this type of location, along with many others, can be difficult to gain access to. Some freeway configurations do not have adequate medians or left hand shoulders. This could create traffic hazards and hazards to maintenance personnel while working on the camera or other related equipment. Ease of access should always be considered, and implications of traffic hazards should be avoided if at all possible.

Careful consideration should also be given to the glare from the sun in selecting the camera location. Some of it may be unavoidable, however, if the roadway alignment is in east-west direction. The Mobilizer does have the ability to recognize most shadows from vehicles, and can extract them from its tracking process. However, when the camera is looking into the sun, glare or reflections on the camera lens or protective dome can greatly reduce the tracking accuracy. This effect could also occur from the reflection off windows of nearby buildings, causing the image to become a white out. If possible, the camera should be located on the south side of the monitoring zone, in order to have the sun behind the camera, and typical daily and yearly sun locations should be considered. A good location during summer months may not be the best location during the winter months when the sun is lower on the horizon, and rises and sets further south. Another alternative is to install a protective sun shield above or on one side of the camera. This could help glare situations for morning or evening sun locations, or glare from a building during part of the day.

Equipment at Camera Site:

Besides the camera mounting equipment, and the camera itself, one other piece of equipment that is needed at the site is an equipment storage facility. It should be weather-proof and secure to hold other electronic equipment at a site that is also near the camera location. The storage facility for this project is a traffic signal storage cabinet mounted onto the utility pole that is installed by ODOT. This cabinet is approximately 2.5 feet wide, 1.5 feet deep, and 3 feet tall. It is mounted at the bottom of the pole at about chest level so that the equipment inside is easily accessible to work with. All of the utilities that are run to the pole terminate within the cabinet, where a phone jack, 110 volt electric power plug box, and a BNC coaxial cable end are installed. The cabinet is weather-proof with a rubber seal on the door, and putty inserted into the wire access holes or conduit fittings installed. The cabinet is secured with a combination pad lock and to date no damage has occurred through inclement weather or vandalism.

Within the equipment cabinet is a small monitor for a review of traffic scene, the camera control box, and the modulator to translate the video signal to a form that Paragon Cable could transmit through their system. Also, there is a telephone to allow a person on site to communicate to the laboratory for troubleshooting scenarios or to help aim the camera to maximize the best possible view for the Mobilizer tracking system. It is proposed to have the camera control in the laboratory eventually and convey commands for pan, tilt or any adjustment over the telephone lines.

When determining the type and size of equipment cabinet, some important design elements need to be considered, in particular the system architecture that is going to be used. The Mobilizer application can be based on one of several system architecture types. Determining which architecture that is going to be used is usually highly dependent on the type of video transmission that is going to be used. This system in Portland has the live video transmitted directly to the transportation laboratory at Portland State where both computers that make up the Mobilizer system are located. However, it is possible to locate one of the two computers (SSI) at the camera site, and have the SSI computer send information to the other computer (MATS) using a low baud rate and utilizing a modem and standard phone line. This configuration, however, does not allow live imagery to be broadcast to the monitoring center.

If one of the computers is going to be located in an equipment cabinet at the site, additional considerations include excellent weather/water proof seals, temperature control, and overall size of the box. Computers usually can not tolerate the severe temperatures or possible wet conditions that could be present within an equipment box located at the site. Also, cramped corridors within the cabinet could decrease circulation and cause difficulties when trying to repair or maintain the computers or wiring of the system.

Camera Choice and Installation:

Many factors were considered when determining which camera to use at the site and how to install it into the system. The factors considered were: the clarity of the picture the camera produces, the field of view and movement the camera has and the feasibility of off-site remote controllability, the level of weatherization of the camera, and the method of mounting the camera.

The camera must be completely weather-proof, being capable of operating normally under severe weather conditions without decreasing the picture clarity a great deal. For the Pacific Northwest, these severe weather conditions may include heavy rain, sleet, snow, and freezing rain, with temperature ranges of 0° F to $+100^{\circ}$ F. If these conditions exist, a camera with waterproof seals and internal temperature control is highly recommended.

The clarity of the picture that the camera produces can greatly affect the performance of the Mobilizer's computer system. Even a slightly fuzzy or "snowy" video image can greatly decrease the computer's capabilities of tracking vehicles. Therefore it is very important that a clear picture is produced and that the signal is not reduced by its method of transmission to the laboratory or control center. A color image is not required for the system, and in most cases color is preferred only to satisfy operator preference. Most black and white cameras produce a much clearer picture at a much less expensive price.

A camera that has a sufficiently wide field of view should be used. All of the lanes that are going to be monitored need to fit within the camera's field of view. However, if different areas are going to be monitored at different times, for example inbound and outbound traffic, a camera that has remote control capabilities should be considered. Many cameras can be controlled from an off site location with the use of a control box linked into a phone line system. Many of these operations can also be performed if fiber-optics cable is being used for the method of video and data transmission.

One other feature that is not necessarily required, but could be of some use is the capability of displaying the date and time within the picture. This could be of assistance if certain scenes are recorded for later viewing or study. The date and time can be quite helpful in keeping track of video tape logs. Some cameras even have the capability of displaying some other short message, such as an ID#. This can also be helpful when numerous cameras are being used within one system. The location of the camera can then be displayed within the field of view.

Finally, one of the most important considerations when installing the camera is the mounting mechanism used. A stable, heavy duty mounting bracket needs to be designed for the installation of the camera. Our initial design of a camera bracket was insufficient, and caused the camera to sway extensively. Therefore, a more sturdy bracket was designed to be installed onto the pole, and then the camera was mounted to the bracket. This allowed easier removal and installation of the camera, without having to remove the bracket every time the camera needed repair or adjustment. When designing a bracket, use heavy enough material to support the camera without bending or swaying, and use a short moment arm (distance from mounting location to camera) to minimize torsional forces that could increase swaying and bending of the mounting bracket. About six months into the project, the design was further modified when a loose connecting wire to the camera needed repair. The camera and the bracket were assembled as one unit in the laboratory to take advantage of a skilled technician, so that the mounting crew had less handling to do with their limited skills. There have been little operational problems since then apart from an occasional power break down.

Other Design Considerations:

One other minor problem that was encountered during the implementation and operation of the system included an occasional power failure at the camera site during traffic monitoring sessions. However, power failures are usually few and far between, and a backup power source for the camera is planned to be installed in the future.

Other considerations that need to be studied during the implementation of the video monitoring system include the ability of video taping, method of storing and backing up data, mode of video transmission, and the location and installation of calibration marks.

The determination, if video taping capability is needed, is simply based on whether the agency desires it or not. However, due to invasion of privacy considerations, some agencies may not want, or are not allowed to video tape traffic scenes or incidents. At any rate, if video taping is desired, extended play capabilities may need to be considered to help conserve the use of video tapes.

Method of data backup and archiving is an important consideration in design. The Mobilizer creates an ongoing database, that is in an ASCII format, that can become quite large after a few days to a week of operation. For this system, a zipping program is used to minimize the size of the databases, and they are archived by using dates as filenames. The files can then be stored on floppies, tapes, or put in a backup sub-directory on the hard drive for later use.

Calibration marks are required to be placed on both sides of the road at the monitoring site. These marks can be simple paint marks or lane striping tape, but need to be large enough to be seen from 300 feet away or more. Therefore, calibration marks need to be at least 6 inches wide, and two feet or more in length. They need to be placed on both sides of the freeway, directly opposite to each other, at even distance increments, like 50 feet for example. Also, they can have a tendency to be covered by gravel or other road debris if placed off the edge of the roadway. Therefore, it may be best to actually have the marks overlap, or cross, the fog line a small amount to allow for a portion of the mark to be always visible.

One final design consideration would be the method of video transmission, if the live video image is going to be broadcast to the monitoring center. This area of technology has numerous options, and detailed descriptions of all the modes of transmission would be very lengthy. There is a large variety in costs associated with each technology, which is usually the deciding design factor. To name just a few of the most common methods, there is microwave, fiber optics, coaxial cable, T-1 wide band telephone lines, and hard wired twisted pair lines. The number of types of systems continues to increase and are improved as the technology improves. It is suggested that someone that is up to date on the present day technology be part of any team making design recommendations of a video transmission mode.

With a view to helping others considering implementation, our goal is to document problems that have occurred during the implementation process, like stabilizing the television signal from the camera and determining good camera locations for impeccable operation of the system. Also, determining how this implementation process could be expedited for future projects is being studied. This implementation process has taken some time, and for this system to be used as a city wide traffic management tool, there would need to be a much faster and smoother implementation process, along with a very reliable communication system.

Research Objectives

Include studying traffic characteristics on the freeway and examining any recurring events preceding congestion with a view to predicting the onset of congestion. Observation, record and resolution of any problems encountered during the implementation process of the project are, of course, essential areas of research. Some effort was given to determining level of accuracy of the Mobilizer tracking system. The process of collecting data before, during, and after congestion periods has been undertaken, and some typical recurring characteristics are identified. From these recurring characteristics, some real time congestion management decisions can be made to reduce the severity of the congestion period.

Accuracy:

Some preliminary studies by CMS have indicated that the Mobilizer's tracking process achieves a better than 97% accuracy, for benign lighting, shadow, and camera geometry, and with moderate traffic in good weather (1). However, it has been noted that this result may drop slightly in less than perfect operating conditions, but the system still operates with fairly high accuracy.

Traffic count accuracy studies performed in the course of this project show similar results. Besides calculating information like speed, density, headway, and volumes, the system also counts the number of vehicles it tracks for each data averaging period. Some short Microsoft Excel™ macros and Microsoft Access™ sorting queries to pick out desired data from the system's database were written. These applications were also used to translate them into Excel files so they could be summed into hourly traffic counts. This was done to get data for a standard period of time typical for traffic count data, similar to what one would get from data retrieved by magnetic field loop detectors.

Traffic count data from ODOT were obtained for loop detector stations located approximately 400 feet prior to the location of the camera. These stations are located on each of the three ramps that converge together to form the beginning of the freeway. There are no on- or off-ramps between the counting stations and the monitoring area, resulting in the same vehicles passing over the loop detectors and through the monitoring zone of the camera.

The ODOT traffic count data provided is in a format that shows counts for each station, one station for each of the three ramps. The Mobilizer also provides counts in a per lane format, but because there is over 400 feet of freeway between the ramps and the video monitoring area, and the fact that this area resembles a weaving area at times, it was determined that the counts would not accurately compare on a lane by lane basis. Therefore, the data for the three lanes were summed together for both sites, and an overall total count study was performed.

The data provided by ODOT is traffic count data for the entire month of August 1995, in an hour by hour format (see Appendix). Counts for various days for the month of August are then extracted from the database, and different time periods are summed into an hour by hour format. These time periods are selected somewhat at random, but considering that every hour of the day would be included, some days are chosen because those are the only days when traffic scene was videotaped for certain periods of the day and subsequently examined using the Mobilizer. These counts are then compared to the sum of the three lane counts taken from ODOT's counting stations, for the same particular hour. Different time periods of the day are categorized, based on similar volumes and lighting conditions. Then each data hour compared is placed into a time category. This is done to help identify the situations that may or may not cause problems with the Mobilizer's tracking system. Below, in

Table 1, the results of these counts are shown, along with the percent difference between the counts, the accuracy percentage of the Mobilizer data (assuming that the ODOT/loop detector count data is correct), and the time period of day category for each hour of data.

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak
8/14/95	11	3361	3444	2.41%	97.59%	Midday
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak
8/20/95	2	573	899	36.26%	63.74%	Late Night
8/20/95	3	362	603	39.97%	60.03%	Late Night
8/20/95	4	248	407	39.07%	60.93%	Late Night
8/22/95	13	3195	3745	14.69%	85.31%	Midday
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak
8/23/95	5	348	435	20.00%	80.00%	Early Morning
8/23/95	6	1407	1709	17.67%	82.33%	Early Morning
8/23/95	7	2922	3360	13.04%	86.96%	Early Morning
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak
8/24/95	20	2972	3320	10.48%	89.52%	Evening
8/24/95	21	2411	2732	11.75%	88.25%	Evening
8/24/95	22	2200	2742	19.77%	80.23%	Evening
8/24/95	23	1417	1936	26.81%	73.19%	Night
8/24/95	24	966	1335	27.64%	72.36%	Night
8/25/95	1	584	809	27.81%	72.19%	Night
8/30/95	11	3174	3317	4.31%	95.69%	Midday
8/30/95	12	3486	3633	4.05%	95.95%	Midday
8/30/95	13	3566	3667	2.75%	97.25%	Midday
Totals		84946	95131	10.71%	89.29%	
			Averages	14.43%	85.57%	

Table 1. Summary of Count Data.

Again, assuming that the ODOT/loop detector data was correct, the average accuracy for any hour period of data is about 85% accurate for the Mobilizer. An overall average of total counts is approximately 89% accurate, which is still a high accuracy rate when considering all times of the day with variable lighting, weather, and volume conditions. However, there does seem to be some noticeable patterns for change of count data accuracy for different times of the day, especially for different lighting conditions.

The accuracy of the Mobilizer counts appears to drop dramatically during the low light conditions at night time. In fact, when comparing the "Afternoon" and "Midday" periods to the "Night" and "Late Night" time periods, there is a 25% drop in the accuracy of the hourly counts (see Table 1 and appendix). This situation is be due to the fact that the present version of the Mobilizer does not have a night time tracking algorithm. The low accuracy during the night time is due to the decreased light. During these hours of operation, the scene appears very dark on the screen, with only the few street lights creating bright spots. The camera tries to over-compensate for the dark scene, causing the iris of the camera to open very wide, with the result that light sources become bright spots on the screen. These bright spots, in turn, cause reflections on the screen, as seen in Figure 5. The Mobilizer tracks vehicles during these night conditions by tracking the vehicle tail lights. Therefore, due to the obscure lighting, the system could have problems tracking each vehicle through the field of view. If a vehicle's tail lights are not functioning, or become blocked by a vehicle traveling behind or if the tail lights fall near a bright spot or refection, the Mobilizer could miss tracking it. If the vehicle has bright headlights and the headlights reflect off the roadway ahead or adjacent to the vehicle, the Mobilizer may try to track the reflection as another vehicle. Also, the Mobilizer has a setup process that requires the operator to identify the travel lanes and monitoring area. If the system is being set up during night time monitoring, difficulties can arise when trying to identify where the travel lanes actually are.

Figure 5. Typical night scene.

The next version of the software for the Mobilizer is due to be released during summer 1996, and will include algorithms to track vehicles better during night conditions. Sources from CMS state that the new version will be able to identify headlight reflections as well as shadows and glare created by other light sources. This new version is expected to use better edge detection technology. This technology will help pinpoint the vehicle's exterior limits to eliminate vehicles being tracked as multiple vehicles because of various contrasts within a single vehicle image. Also, this new version will have better shadow identification algorithms and will have a better ability to identify truck obstructions in adjacent lanes.

One problem worth noting in low volume situations (and night time traffic at the location belongs in this category) is that missing only a small number of vehicles still results in a large decrease in accuracy expressed as a percentage. For example, if a few hundred vehicles pass, and the system misses a couple dozen within an hour period, the percent accuracy will be much lower. However, if a few thousand vehicles pass and a couple dozen vehicles are missed, the accuracy will be much higher.

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description	Flow Rate	Accuracy	Cause
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon	high	ok	ok
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon	high	ok	ok
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak	high	ok	ok
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak	normal	ok	ok
8/14/95	11	3361	3444	2.41%	97.59%	Midday	normal	ok	ok
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon	high	low	headway
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon	normal	ok	ok
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak	high	ok	ok
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak	high	low	headway
8/22/95	13	3195	3745	14.69%	85.31%	Midday	high	low	headway
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon	high	low	headway
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon	high	ok	ok
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak	high	ok	ok
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak	high	low	headway
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak	high	low	headway
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak	high	low	headway
8/30/95	11	3174	3317	4.31%	95.69%	Midday	normal	ok	ok
8/30/95	12	3486	3633	4.05%	95.95%	Midday	normal	ok	ok
8/30/95	13	3566	3667	2.75%	97.25%	Midday	normal	ok	ok
Totals		68536	74844	8.43%	91.57%				
			Averages	8.27%	91.73%				

Table 2. Day Time Count Data.

By removing all night traffic counts, the overall accuracy of the counts improves. From Table 2, one can see that the average accuracy for any daytime hourly count rises to over 91%. Also notice that the Mobilizer's counts are always lower than the counts provided by ODOT. This probably means that the Mobilizer is indeed missing vehicles, and is not adding vehicles by mistakenly tracking shadows or extraneous items passing within the field of view. Besides the possibility of vehicles being missed during dark conditions, vehicles are also being missed during high volume, congested conditions. Table 2 indicates that hourly periods with counts over 3700 vehicles are the only periods where the accuracy may drop below 90%. This is because when high volumes are encountered, speed and headway may drop. When the vehicles slow down during congestion, the headway between vehicles become small enough that many vehicles could appear to be one, especially as the vehicles progress away from the camera, reducing the angle of the line of sight to the roadway. This situation is demonstrated in Figures 6 and 7, where as the bunched vehicles move farther from the camera, the camera view combines them to appear as one to the tracking system. Figure 7 is an actual scene from the camera, and notice how the two cars in the white box could appear to be one. Some of these problems, however, can be reduced by having an optimum camera location.

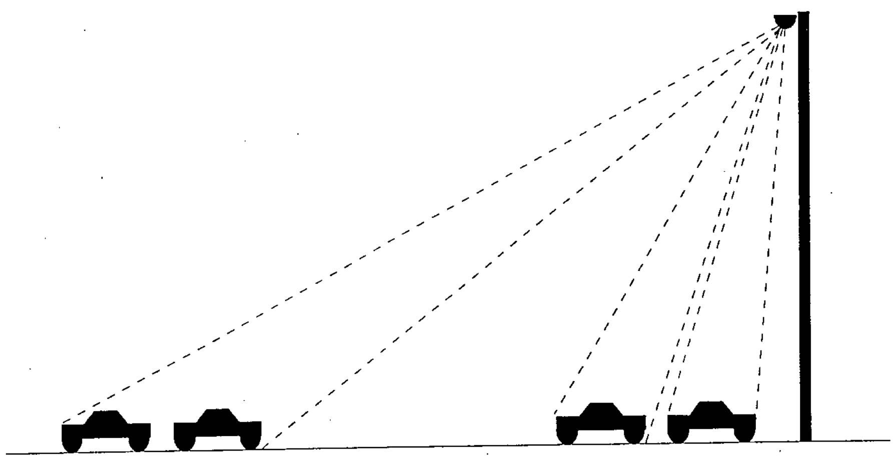

Figure 6. Camera's line of sight as vehicles move away.

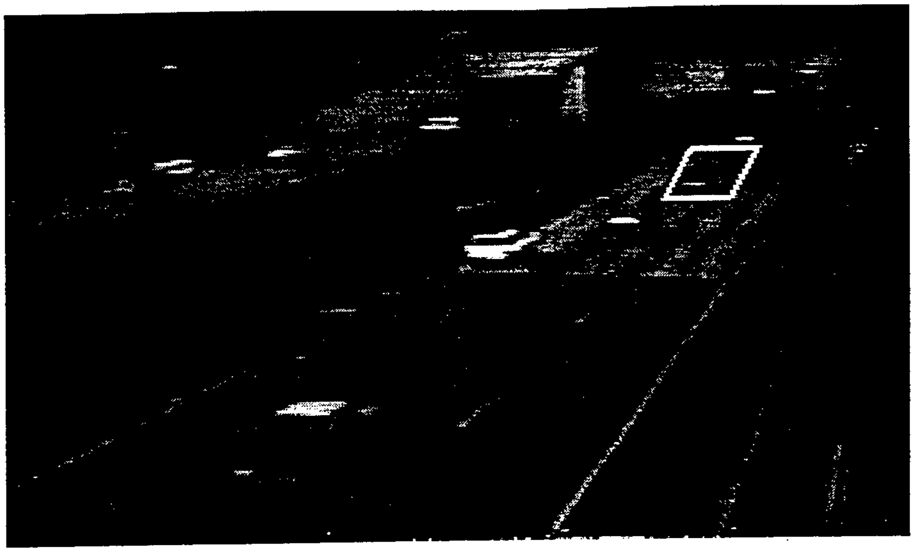

Figure 7. Two vehicles appearing as one with small headway.

These results, however, may not be as accurate as possible. The Mobilizer may be capable of operating at higher accuracy if extra care is taken in the setup procedure and lane geometry configuration process. The data displayed here is accumulated by an operator that had only minimal training. The operator for most of the month of August had only a couple hours of training on how to set up the system for a specific scene geometry and the process required to store, retrieve, and backup daily data. It is possible that the operator did not have the optimum lane geometry configuration, and therefore the computer was missing vehicles. Experience allows the operator to gain knowledge with the system's capabilities and problem areas, and therefore they can identify when extra care may be required in the setup process. This discussion emphasizes the fact that an operator with minimal training obtained very accurate results, which could be improved with better operator skills over time. The software is easy to work with and requires minimal to moderate training.

This entire discussion on accuracy is assuming that the traffic counts provided by ODOT are indeed 100% correct. This, however, may not be the case. It is possible that the counts from the loop detectors are high. The magnetic loop detectors could be counting any vehicle/trailer combination as two vehicles, for example. Other possible errors could be that the time stamp on the loop detectors is not the same as the time clock within the Mobilizer computer, or that the loops are counting axles and using a conversion factor to transfer the counts to vehicles, but the conversion factor is inaccurate. Therefore, it is important to keep in mind that by stating an accuracy of the Mobilizer's tracking ability, it is related to the accuracy of ODOT's traffic counts. If the counts by the magnetic loops are not 100% accurate, it is quite possible that the Mobilizer has higher accuracy than indicated here. At any rate, the two methods of vehicle counting are probably within 10% error when compared to each other for day time hourly counts.

Date	Time Period of Counts	Manual Count	Mobilizer Count #1	% difference w/man. count	Mobilizer Count #2	% diff. from 1st Mobilizer count
12/11/95	2:30-3:00pm	2345	2529	7.85%	2619	3.56%
12/11/95	3:00-4:00pm	5035	5492	9.08%	5605	2.06%
12/14/95	2:30-3:00pm	2176	2565	17.88%	2593	1.09%
12/14/95	3:00-3:30pm	2400	2699	12.46%	2731	1.19%
12/14/95	3:30-4:00pm	2546	2885	13.32%	2815	2.43%
12/15/95	12:30-1:00pm	2033	2389	17.51%	2456	2.80%
12/15/95	1:00-1:30pm	2022	2527	24.98%	2547	0.79%
12/15/95	1:30-2:00pm	2182	2686	23.10%	2701	0.56%
			Ave. % diff. =	15.77%	Ave. % diff. =	1.81%
			accuracy =	84.23%	accuracy =	98.19%

Table 3. Summary of Manual Counts and Mobilizer Counts.

A comparison of the Mobilizer counts to manual counts was also attempted by analyzing video taped traffic periods, but varying results were produced. Table 3 displays the results of the Mobilizer counts with manual counts. Also, the Mobilizer counts were repeated to determine its capability to reproduce the counts. The results of the Mobilizer count comparison only produced an overall average accuracy of 84% when compared to the manual counts. However, notice that all of these periods are over the previously stated 3700 vehicles per hour cutoff for the counts to be better than 90% accurate. The lowest hourly total volume for the periods analyzed is 4044 vph. The Mobilizer's ability to reproduce counts for a particular period is much better. From Table 3, one can see that the Mobilizer has an overall average accuracy of over 98% for reproducing the same counts for any period of time. This means that the errors that the Mobilizer is producing are not random, but are produced in every tracking scenario. Again, many of these errors may be related to operator setup error. The analysis period with the poorest reproduced count had two entirely different setup configurations that were produced on different days. However, the period that has the lowest percent difference, or the closest reproduced count, used the same setup configuration and was run one analysis right after the other. In other words, the period that used two different setup configurations may have one setup slightly better than the other. The period that used the same setup configuration produced close to the same results, but produced data that was less accurate then other analysis periods when compared to manual counts. This means that the errors attributable to the Mobilizer were reproduced in both analyses. Therefore, it appears that if the operator takes great care in outlining the travel lanes and monitoring area during the setup process, some of these errors may be reduced. The fact remains that operator experience plays a role in the accuracy obtained from machine counts.

Traffic Characteristics:

The system stores all of its data into a database, which is in a standard ASCII file format. By using short Microsoft Excel macros and Microsoft Access sorting queries, the desired data is selected and translated into Excel files. From there it is fairly effortless to graph typical traffic characteristics like speed over time, volume versus density, speed versus volume, and speed versus density.

Figure 8, below, shows a typical graph displaying speed over a specific period of time. As one can see, on this particular day, the speed drops rapidly once the afternoon peak hour begins, and congestion sets in within approximately 10 minutes. At this point speeds become very unstable, and begins to fluctuate between 20 and 30 mph. This condition continues for about one half hour, then the freeway begins a recovery period where the speeds slowly begin to increase until they stabilize at approximately 53 to 55 mph. This operation scenario is very typical for this freeway corridor during the peak hour period. From the speeds, it appears that the freeway operated at all levels of service ranging from A through F, as it went from a free flowing 55+ mph, to a congested 20 mph, then slowly back to a fairly stable 55 mph. The variation of speed, density, volume and headways over this range appear to provide a good example for a study of traffic characteristics.

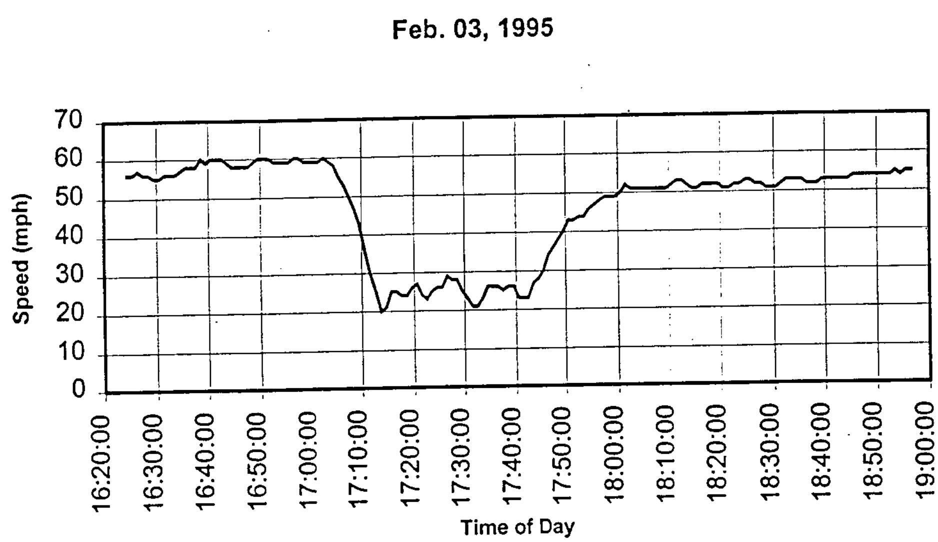

Figure 8. Freeway traffic speed over time.

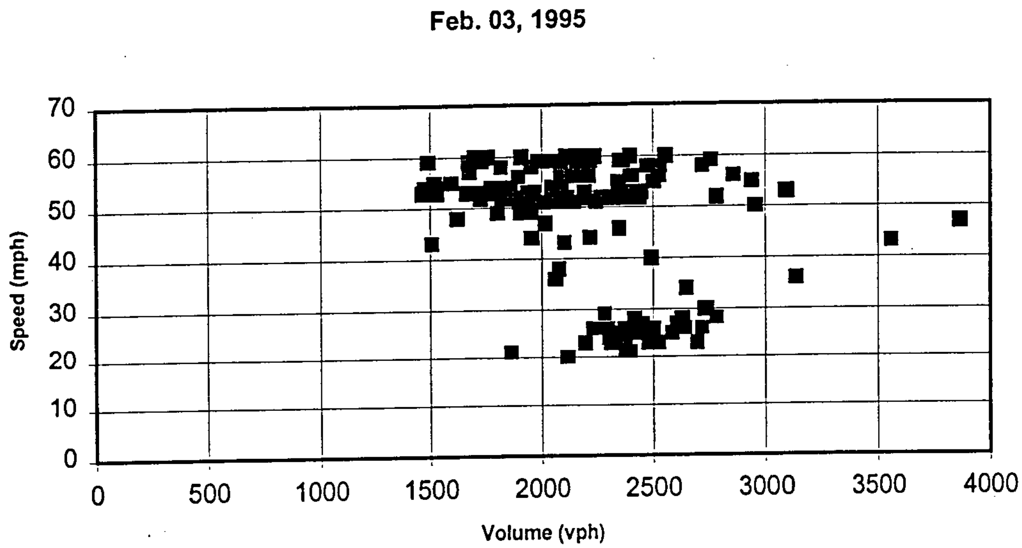

Figure 9. Speed versus volume: 4:25-6:55 PM analysis period.

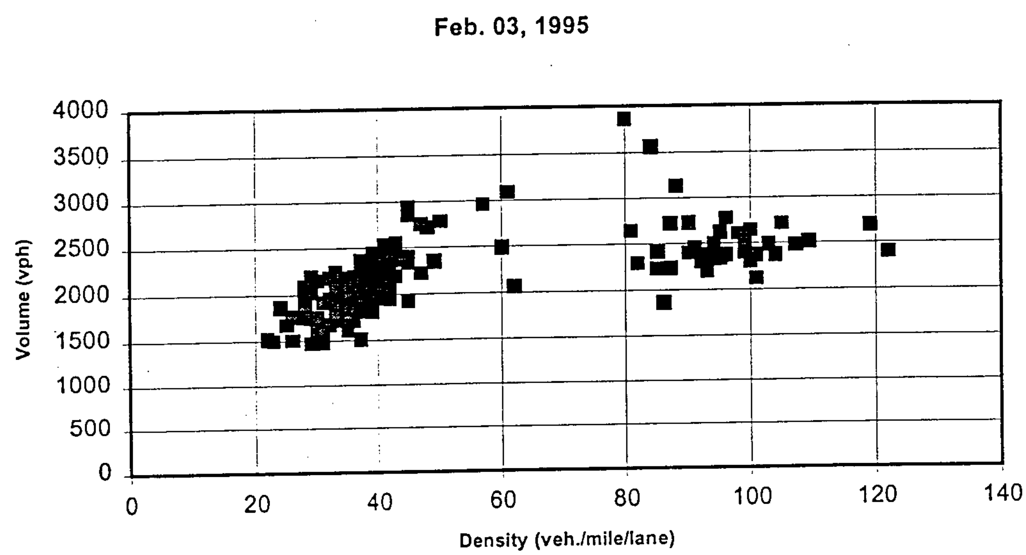

Figure 10. Volume versus density: 4:25-6:55 PM analysis period.

Typical graphs of the traffic characteristics were produced for the time period from 4:25-6:55 P.M. based on the data stored in the computer's database. In Figures 9, 10, and 11, traffic characteristics for this time period are shown as speed vs. flow, flow vs. density and speed vs. density respectively. Each point on these respective graphs represents the average measurement for a 30 second time interval. The results show a great similarity to "general density-speed-flow relationship" graphs presented in the Highway Capacity Manual, 1985 and 1994 (3,4). The basic form of the results show similar shapes as those recognized standard graphs, with the speed verses flow and the flow versus density graphs taking a parabolic shaped curve appearance. As with the idealized graphs (3,4), the speed decreases as flow increases or headway decreases, until the freeway reaches a maximum capacity. The speed versus density graph is somewhat similar to the recognized inversely related linear graph. However, the numbers in this study appear to be somewhat higher in the areas of speed, flow, and density, especially at the point of maximum flow or capacity.

From Figures 9 and 10 the maximum flow for this freeway appears to be approximately 3100 vphpl at an operating speed of about 42 mph. There are many possible reasons for the apparent high flow rate, one being that most of the peak hour traffic for this corridor consists of daily commuters. They have become so comfortable traveling along this corridor, that they have started to increase their densities while maintaining higher speeds, perhaps, unknowingly over time. Presently, the Highway Capacity Manual uses 2200 pcphpl for the maximum flow rate (3). This freeway appears to operate above a 2200 vphpl before adjusting for any heavy vehicles in traffic. Other analyses periods with congestion show similar results for traffic characteristics.

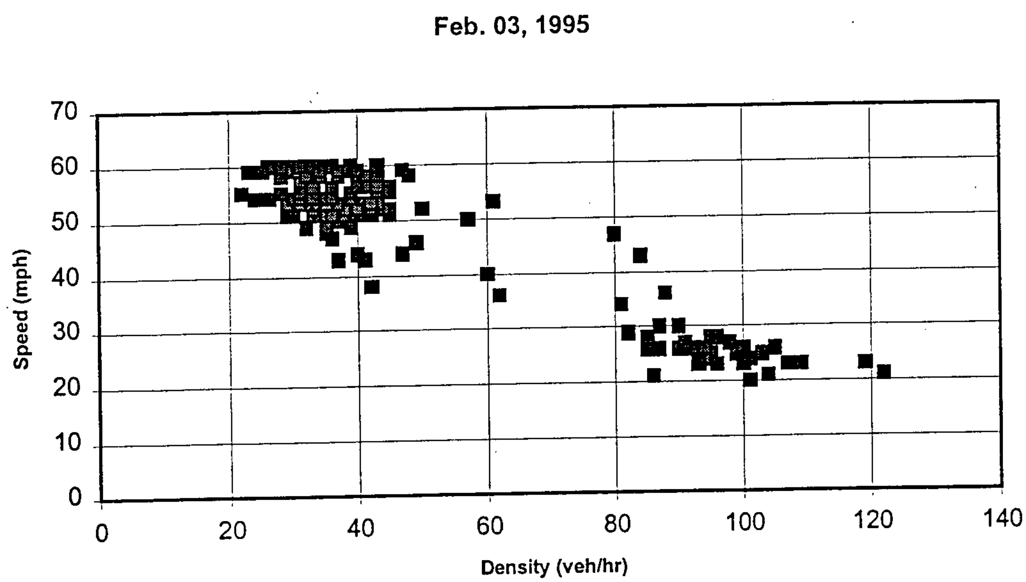

Figure 11. Speed versus density: 4:25-6:55 PM analysis period.

There is additional explanation for the high flow rates. For example, a cursory view of Figure 9 may indicate that the freeway's maximum flow is above 3500 vphpl. However, it is important to recall that these data points represent the average measurement over a 30 second time interval. It is quite possible for the freeway to be operating at this very high, 3500+ vphpl, flow rate for a brief period, but it is probably not feasible for this freeway to be operating at this flow for any extended period of time. Figure 12 shows that the freeway does not operate continuously at these high flow rates, but that it periodically operates at these flow rates for short periods of time. In fact, the two data points that are at a +3500 vphpl value were probably during the time that a higher density platoon was arriving at this point on the freeway, perhaps indicating the onset of a shock wave. It appears that the freeway does not operate at the various levels of service (LOS) with various speeds as the 1985 Highway Capacity Manual (1985 HCM) describes, but rather it operates in a high speed, high density, high volume "zone", then rapidly transitions to a low speed, high density, high volume operating zone, as shown in Hall's findings (5). This typical day begins with a speed equal to its free flow speed of about 57 mph which would be in the LOS B range, but at densities around 35-40 vpmpl, which represents LOS D conditions(4). The freeway continues to operate in this state until densities begin to increase to about 55 vpmpl. At that point volume/flow rates rapidly climb to over 3500 vphpl, to a point where a shock wave is created. At this point the onset of congestion is very rapid, and speeds drop to 25 mph and a LOS F in a few minutes. This scenario is better represented in the 1994 Highway Capacity Manual (1994 HCM), where operating speeds are sustained above 55 mph until a density of approximately 32 pcpmpl is obtained, then speeds tail off to about 48 mph, until the densities reach 48 pcpmpl. At that point a LOS F prevails, and speeds, densities, and volumes theoretically become very unstable and unpredictable(3).

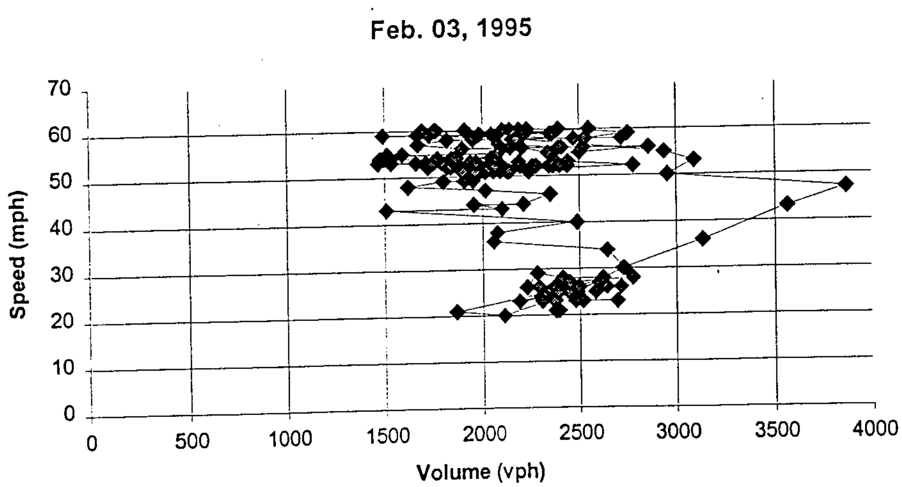

Figure 12. Time trace of traffic volume and speed during congestion period.

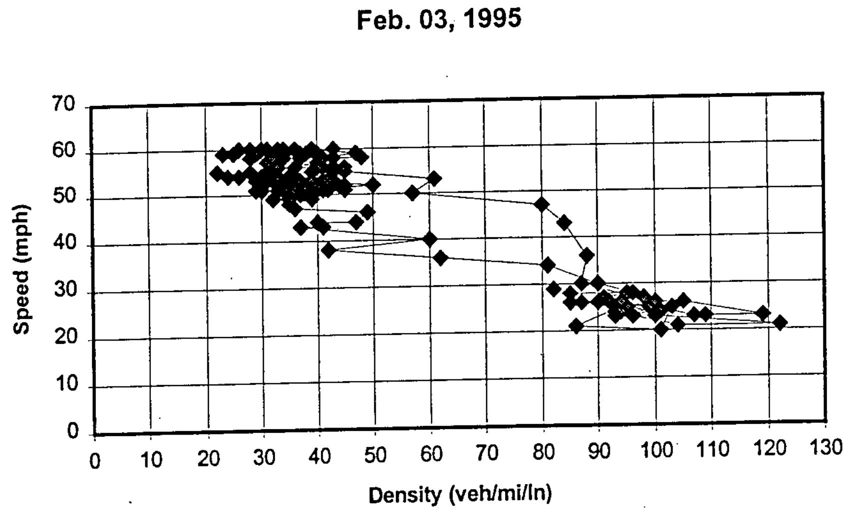

Figure 13. Time trace of traffic density and speed during congestion period.

There are some additional characteristics that can be identified as well. First, the freeway does operate at a fairly stable, high volume/flow rates during congestion periods. The 1994 HCM defines LOS F as where there is a breakdown in vehicular flow(3). However, congestion does not necessarily translate into low flow for this location on the freeway. From Figures 12 and 13, one can see that the speeds and densities are well within the range of a LOS F classification. However, volume/flow is sustained at a very stable flow of over 2000 vphpl for the entire congestion period. Thus the flow is not a total break down, and volume flows of over 2000 vphpl are maintained even with speeds below 30 mph and densities above 80 vpmpl. These results are again very similar to Hall's findings (5), where the volume versus density graphs have a "hanging flag" appearance, and the volumes stay sustained at all levels of density. Typically, density is calculated from speeds and flows, but the density is measured directly in the Mobilizer system. This allows us to show the densities and speeds do have a strong link of dependency, as indicated by the typical speed/density graphs showing the linear relationship. However, a high volume can still be maintained at many different speed/density scenarios. This is confirmed by McShane and Roess (6), when they state that volume/flow rate cannot be used as a measure to describe the operational quality of the traffic stream.

This leads to the second noteworthy characteristic. It has been assumed by transportation researchers that the operation of the traffic stream follows the typical relationship shown in the HCM graphs for both the occurrence of congestion, and the recovery of congestion and speed situations. However, Figure 12 shows a different type of recovery. It appears that the speed recovery period occurs at lower flow rates than the typical operation and congestion periods, even though the speeds have begun to increase. Figure 12 indicates that the recovery period does not seem to follow the path of the typical HCM speed versus flow curve. Instead, it recovers by passing through the middle of the typical speed versus flow graph. This is because the recovering traffic is held at a saturation flow rate until the queue which has formed on the freeway has dissipated and the densities have recovered. The 1994 HCM defines the *saturation flow rate* as the discharge flow rate from a continuous queue with an ideal flow rate being 1900 pcphpl (3). As the recovery period begins, there is a continues queue of vehicles on the freeway, moving at a very low speed. Then the densities at the front of the queue begin to decrease, as headway increase, and the cars at the front of the queue are able to speed up. These cars leaving the queue and speeding up are traveling at the saturation flow rate. As more cars leave the queue, a shock wave begins to travel down the queue as the densities increase. This is the operation of the recovery period which has a flow rate equal to the saturation flow. Notice that this particular freeway has a saturation flow rate around 1900-2100 vphpl as the speeds of the vehicles increase while they exit the queue. In other words, density must decrease while the queue dissipates at the saturation flow rate before speeds can recover and stabilize to 55 mph.

Congestion Prediction and Real Time Decision Making:

While studying these typical traffic stream characteristics, plots of speed and density versus time were prepared to establish the dependence of speed and density. In the process of making plots of the daily peak hours, it was observed that there were some reoccurring characteristics when congestion occurred. Below, in Figure 14, is a graph of speed and density during the peak hour. The two most noticeable characteristics are that once the density reaches 50 to 55 vpmpl, there is an onset of congestion. Also, as long as the high density is maintained, the speeds can only be sustained at a low value of 20 to 30 mph.

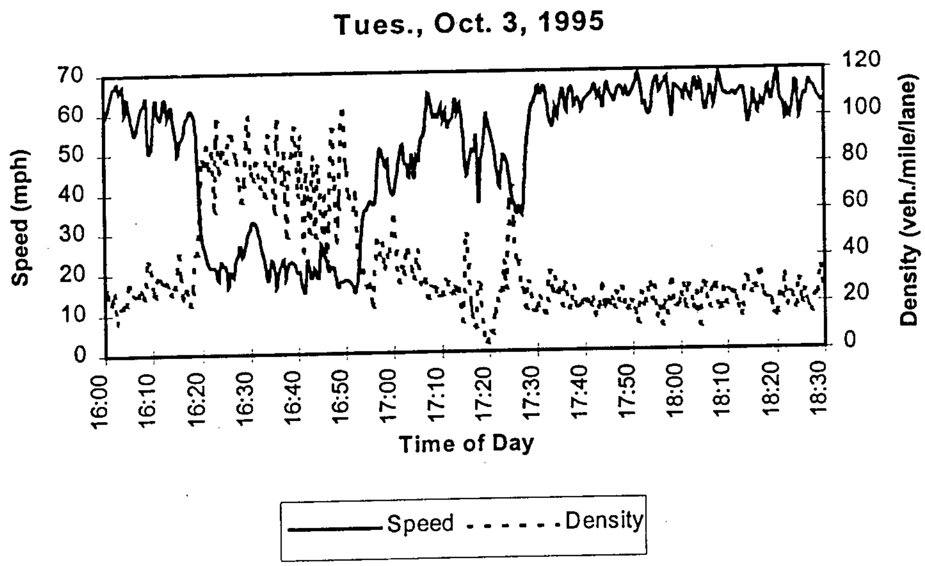

Figure 14. Speed and density versus time for peak hour of typical day.

A very noticeable characteristic that is seen in this graph is that once the density gets above 55 vphpl, there is a significant decrease in speed of the traffic stream, and the density becomes very unstable. Notice how the density jumps radically while the speeds remain below 30 mph. However, once the densities drop back below 55 vpmpl, and the speeds begin to recover back to the 55 mph range, the densities stabilize somewhat. The unstable behavior displayed by vehicle densities during a congestion period appears to be affected by two factors. The first is that shock waves are being created from the stop and go oscillations that the traffic stream experiences during these congestion periods. During the congestion period, while vehicles are really in a stop and go scenario, the travel speeds as calculated by the Mobilizer are average vehicle speeds, which appear to be somewhat stable. However, the stop and go scenario changes the densities radically from one short period to the next. That leads to the next factor why the densities are so unstable.

Since the Mobilizer is using short periods of time to average the data, 30 seconds in this case, the change in density shows an exaggerated variation as vehicles close gaps and separate during peak-hour flows. Longer averaging periods do smooth out the graphs somewhat, see Figures 15 and 16, however, these short term flow rates and densities are crucial to identifying and predicting the traffic conditions that develop over time, and allow a real-time decision making process to occur in a congestion management application. Thus a short time averaging period format is very valuable to real-time congestion management decisions.

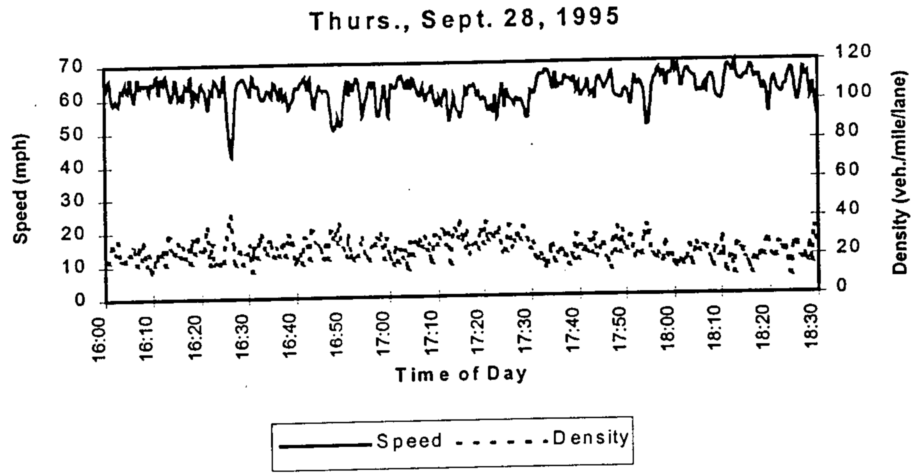

Figure 15. Typical graph for 30 second averaged data.

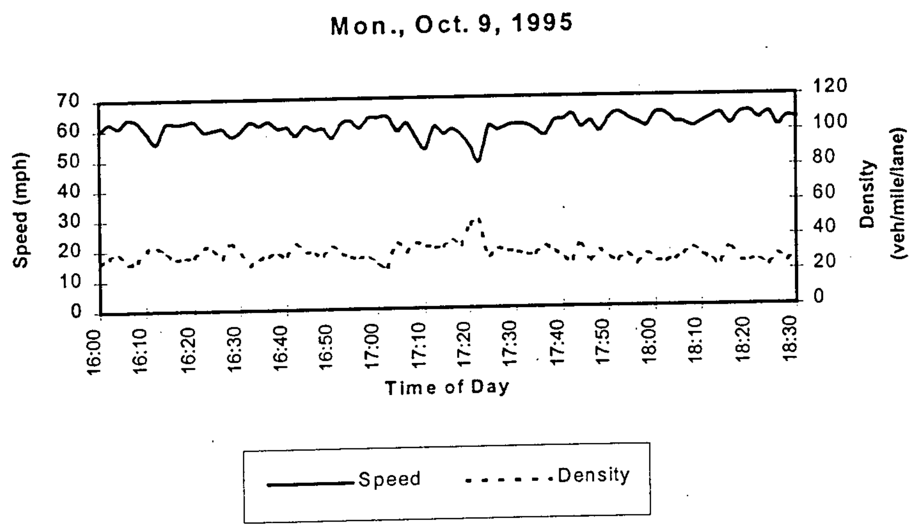

Figure 16. Typical graph for 1 minute averaged data.

Typically, data from a 15-minute period is used for highway capacity studies. However, this time frame of data averaging is too long for a congestion management system. An example of this can be seen back in Figures 8 and 14, where congestion was inflicted in less than 10 minutes. It may be a worthwhile suggestion to consider accumulation of data over short periods of time for any new highway capacity studies. This will enable freeway LOS analysis to be done in real time, and the actual transition from one LOS to the next can be better tracked and identified.

The use of these types of characteristics and relationships in a traffic congestion management system could allow the system to do some congestion/incident predictions. By pinpointing these precursor occurrences and monitoring the ongoing appearance of the traffic stream over time, one could make some preliminary estimations of the onset of congestion before it is fully encountered. For example, even by using the results of the preliminary investigations that indicate a density above 55 vpmpl will result in congestion, a congestion management system could trigger a warning system to have motorists slow down before shock waves are created, or to maintain a constant speed to produce maximum flow. According to the 1994 HCM, maximum flow occurs at 48 mph. For this freeway it appears to be around 45 mph. Theoretically, if the increase in density and decrease in speed is noticed, as in this case, before the onset of congestion, maximum flow could be maintained longer if the motorists are advised to maintain speed for maximum flow of say 45 mph. It could avoid the shock waves and delay or even relieve congestion. Therefore, a frame work for real-time decisions can be created within a congestion management system, whereby message signs could be implemented to advise motorists to maintain a 45 mph speed for maximum flow, for example. While the value of advisory speed signs can be debated, it is certain that when implemented during the peak-hour flows they are likely to have a desired impact. Drivers generally have little freedom to maneuver or change lanes during rush hours, and even if half of the motorists followed the advisory speed signs, it will have an overall impact on the entire traffic.

From a study of daily peak-hour graphs of speed and density (see appendix), it is apparent that a value of density that indicates the onset of congestion, is not reached at the same time every day. On some days it may not be reached at all. Thus traffic congestion is not a time dependent operation; that is, it does not occur at the same time every day. Some days have congestion, some do not. Also, there is no reoccurring length of time that congestion will last. Therefore, it is important to attempt to find ways other than time to pinpoint and predict the onset of congestion. Also, the recoverability of the freeway can be important for a congestion management system. An area wide congestion management system could even notify motorists about different operating characteristics on different freeways via a variety of media including variable message signs, highway advisory radio, and electronic bulletin boards like the Internet. In turn, motorists could use this information for planning their minimum trip-time routes. These types of motorist information systems, along with many other possibilities, makes the system a complete congestion management system, as discussed by Bautch (7). This could save fuel consumption, improve air quality, as well as reduce the time lost to motorists in congestion. However, for this system to work on an area wide basis, the determination of congestion onset and recoverability needs to be pinpointed, in order to maximize the capacity of all the freeway segments, without having one operating under capacity and another well over capacity.

Mobilizer's Future

Video Traffic Monitoring and Congestion Management:

From some of the preliminary studies it seems feasible that an implementation plan for the Mobilizer (or similar systems) into a region wide advanced traffic management system may be determined. It appears that this system, implemented along with a series of surveillance cameras along freeway corridors and major arterials, could be transformed into a city wide traffic management system. Existing loop detectors can be interfaced into the system at other points to obtain better traffic condition information. The system could then be used to control arterial and ramp signals by using a roadside equipment interface (REIF) to adjust the signal timings to maximize the capacity of the roadways. Information from the Mobilizer could be used for other uses like congestion and incident prediction, as discussed earlier, and implementing the system with a series of roadside variable message signs, or roadway radio information stations that could be automated to notify motorists of slower speeds ahead or problem areas and alternate routes. Also, information, graphs, and semi-real time pictures could be taken from the Mobilizer and loaded onto the Internet at recurring time intervals, like every 2 minutes, to allow workers at their office to plan their commute trip home on a minimum travel-time route. Additional research is underway in the area of travel time prediction between specific points along a major commuter freeway. This would also help people plan their travel routes and even forecast their arrival times better. Generally, the Mobilizer appears to have many possible future uses. The capability of implementing existing surveillance cameras and loop detectors, along with the minimal need for specialized equipment, allows for the system to be implemented at a minimal cost. All of these possible traffic management situations can be done in real time, resulting in superior travel conditions, no matter what the traffic situation.

Better Freeway Data for LOS Traffic Analysis:

Basically, this system could be implemented in almost any location, and could collect up to the minute data in any desired averaging time period. This data can be stored in a database and used at a later time for freeway studies. However, by having the ability to collect this data in any time frame, the ability to create analysis scenarios for shorter time periods is possible. The 15 minute time averaging time frame does not allow for any real time decision making, which will probably soon be a necessity. By implementing these systems now on various freeway corridors throughout the country, data collection can now begin for future analysis tools.

Conclusions

The versatility of video detection make systems like the Mobilizer a truly viable replacement to loop detectors. With video detection, roads do not need to be torn up for the installation or repair of the detection system, and video allows for detection on any road surface, like gravel or thick snow. Also, installation and maintenance to loop detectors can only be done in warm, non-freezing weather, making breakdowns non-repairable in the winter months for many northern states. Plus, just the simple fact that video detection only requires one camera, while loops require at least one loop per lane makes video technology a very attractive alternative. Because of these hardware problems associated with loop detectors, video detection is becoming a serious contender in the field of traffic monitoring technology (8). However, there are more reasons than just hardware maintenance that make systems like the Mobilizer a better alternative for traffic monitoring. One main reason is the possible congestion management opportunities the system possesses.

There have been many findings within this study. Research continues as more systems are implemented, and other uses are determined. First, the implementation process and system architecture design can be a long process. Identifying some of the problems which were encountered during the study will help agencies implement the system in a much faster, efficient manner in any future applications. Investigation continues in various areas to create a better design of the overall system, including better camera locations, architecture designs, tracking algorithms, and other equipment needed.

Other findings make the idea of region wide traffic monitoring and congestion management systems a feasible reality. With systems like the Mobilizer, real time information can be brought to a congestion management center where real time decision can be made to better manage the area freeways. Up to the minute information can assist in the analysis of a traffic problem, determination of a solution and its implementation, all in real time, on a freeway system. Also, with continued improvements in communication technology, getting information from the monitoring site, and back to the motorist is becoming easier and less expensive every day.

As this study at Portland State University continues, there is optimism that the findings will result into reliable methods of improving level of service analysis and vehicle travel on the nation's already congested freeways and major arterials. It is felt that the Mobilizer could be an ATMS of the future. With traffic management system moneys being available, but remaining at minimum levels, the Mobilizer could be the superior solution. This system can be implemented at costs much lower than other ATMS, with many options to make the system as advanced or simple as desired.

References

1. Dermer, Kay D., and Lall, B. Kent, *Wide Area Surveillance of Freeways Using Video Image Processing Techniques,* Transportation Congress, Proceedings of the 1995 National Conference, American Society of Civil Engineers, Volume 1, pp. 245-256, October 1995.

2. Hoose, Neil, Computer Image Processing in Traffic Engineering, John Wiley & Sons Inc., New York, 1991.

3. *Special Report 209: Highway Capacity Manual, Third Edition.* Transportation Research Board, National Research Council, Washington, D.C., 1994.

4. *Special Report 209: Highway Capacity Manual.* Transportation Research Board, National Research Council, Washington, D.C., 1985.

5. Hall, Fred L., et al., *Synthesis of Recent Work on the Nature of Speed-Flow and Flow-Occupancy (or Density) Relationships on Freeways,* Transportation Research Record, No 1365, pp. 12-18.

6. McShane, William R., and Roess, Roger P., Traffic Engineering, Prentice Hall, Englewood Cliffs, New Jersey, 1990, pp. 55.

7. Bautch, Russell C., *Congestion Management on a Budget?* ITE Journal, January 1995, pp. 21-28.

8. Barbaresso, James C., *Solving Real World Problems on the Fast Track,* Intelligent Highway Systems, Supplement to ENR, November 28, 1994. pp. 16-20.

Appendix

- Oregon Department of Transportation Monthly Traffic Counts, August 1995.
- Summary of Traffic Counts, from ODOT and the Mobilizer.
- Speed and Density versus Time plots for various days that data was taken.

STATION NUMBER: 2611000 (Combined) STATION NAME: NB STADIUM-WB SUNSET COUNTY NAME : MULTNOMAH
HIGHWAY NUMBER: 47 MILE POINT : DATA DATE : AUGUST, 1995

Average Daily: 23,553 Average Weekday: 25,001 (Monday thru Thursday)
Maximum Hour : 2,009 Day: WED Date: 02 Hour: 17
Maximum Day : 27,054 Day: FRI Date: 04

SUNDAY DATE	SUNDAY VOLUME	MONDAY DATE	MONDAY VOLUME	TUESDAY DATE	TUESDAY VOLUME	WEDNESDAY DATE	WEDNESDAY VOLUME	THURSDAY DATE	THURSDAY VOLUME	FRIDAY DATE	FRIDAY VOLUME	SATURDAY DATE	SATURDAY VOLUME
06	17,539	07	24,963	01	26,182	02	26,339	03	25,770	04	27,054	05	21,114
13	17,912	14	24,750	08	25,082	09	25,726	10	25,840	11	26,490	12	20,914
20	18,347	21	24,885	15	26,184	16	25,002	17	24,048	18	27,052	19	21,048
27	15,584	28	22,534	22	25,710	23	25,939	24	25,823	25	25,959	26	
				29	22,197	30	24,042	31	24,004				
Avg.	17,346	Avg.	24,283	Avg.	25,071	Avg.	25,410	Avg.	25,097	Avg.	26,639	Avg.	21,025

DD	DAY	HR-01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL	DD
01	TUE	320	176	145	133	227	710	1328	1701	1592	1309	1354	1406	1414	1413	1595	1846	1915	1807	1651	1138	891	950	717	444	26182	01
02	WED	302	206	145	106	213	717	1339	1794	1583	1148	1099	1480	1338	1413	1610	1901	2009	1869	1639	1140	1026	1001	775	486	26339	02
03	THU	317	183	148	139	210	710	1323	1771	1571	1351	1307	1428	1494	1479	1605	1768	1300	1620	1688	1196	923	966	754	519	25770	03
04	FRI	355	203	151	135	221	703	1303	1720	1526	1371	1453	1535	1541	1592	1699	1849	1758	1535	1471	1199	969	1039	933	793	27054 ◄	04
05	SAT	596	295	198	138	151	273	441	631	764	976	1229	1465	1536	1336	1468	1469	1347	1357	1225	1028	869	909	780	633	21114	05
06	SUN	472	267	189	103	111	128	204	298	433	723	719	1014	1225	1301	1273	1263	1379	1419	1288	1048	939	793	586	364	17539	06
07	MON	224	107	87	92	192	677	1250	1734	1508	1260	1274	1401	1334	1265	1598	1915	1939	1952	1558	1019	792	758	594	433	24963	07
08	TUE	275	183	140	102	218	675	1277	1793	1607	1280	1213	1478	1404	1466	1682	1359	1718	1780	1532	1095	904	846	630	425	25082	08
09	WED	290	200	128	123	192	678	1285	1728	1087	1334	1341	1463	1394	1464	1672	1895	1885	1696	1556	1183	968	934	711	519	25726	09
10	THU	320	193	149	124	195	672	1263	1755	1666	1290	1310	1365	1411	1416	1576	1947	1739	1738	1636	1160	899	862	696	458	25840	10
11	FRI	282	175	127	150	213	653	1289	1632	1593	1385	1351	1506	1549	1444	1224	1848	1980	1823	1612	1265	999	934	800	656	26490	11
12	SAT	463	271	177	140	166	266	482	579	803	949	1184	1361	1467	1494	1435	1398	1534	1436	1222	959	847	884	795	602	20914	12
13	SUN	372	213	170	102	85	121	244	310	416	710	876	1082	1199	1298	1312	1339	1416	1420	1246	1062	1002	867	669	381	17912	13
14	MON	242	139	114	105	177	625	1245	1696	1546	1273	1285	1350	1225	1470	1627	1870	1995	1751	1481	968	792	776	610	388	24750	14
15	TUE	284	179	105	113	214	642	1272	1728	1605	1333	1357	1380	1431	1431	1628	1872	1992	1868	1638	1111	905	855	766	475	26184	15
16	WED	308	181	110	121	186	665	1298	1657	1585	1306	1278	1375	1403	1410	1634	1925	1618	1433	1664	1097	909	844	568	427	25002	16
17	THU	278	172	130	133	196	660	1331	1737	1554	1310	1295	1408	1454	1458	1639	1904	1695	1644	1028	478	639	839	644	422	24048	17
18	FRI	330	196	159	139	197	633	1277	1699	1512	1345	1384	1537	1497	1603	1775	1792	1789	1700	1593	1256	1049	980	891	719	27052	18
19	SAT	472	286	228	151	149	274	437	601	847	995	1367	1549	1610	1458	1447	1024	1373	1396	1291	964	827	924	752	626	21048	19
20	SUN	422	235	160	114	118	118	207	311	465	730	1001	1153	1259	1340	1273	1409	1413	1485	1225	1008	1054	852	611	384	18347	20
21	MON	258	116	84	102	164	654	1212	1740	1589	1215	1306	1431	1430	1446	1557	1820	1938	1626	1534	1030	873	768	585	407	24885	21
22	TUE	282	158	117	127	192	663	1254	1720	1641	1347	1273	1508	1406	1468	1597	1813	1939	1689	1524	1106	992	853	620	421	25710	22
23	WED	320	174	140	111	185	682	1319	1726	1543	1379	1286	1403	1405	1427	1632	1884	1955	1674	1592	1150	992	898	634	428	25939	23
24	THU	281	188	144	120	202	641	1316	1728	1581	1140	1414	1451	1445	1415	1612	1817	1941	1585	1685	1141	969	903	659	445	25823	24
25	FRI	318	169	146	123	201	644	1277	1644	828	1316	1390	1425	1540	1591	1726	1801	1790	1689	1596	1328	1003	925	861	628	25959	25
26	SAT																										26
27	SUN	360	217	151	102	65	142	209	252	390	663	804	1014	1086	1185	1166	1167	1204	1230	1049	921	902	636	416	253	15584	27
28	MON	204	87	58	79	164	598	1233	1637	1322	1144	1115	1238	1209	1249	1347	1858	1861	1709	1439	956	672	600	424	331	22534	28
29	TUE	221	147	109	105	167	618	1192	1598	1521	1175	1111	1253	1181	1254	1521	1490	1486	1222	1415	983	795	728	534	371	22197	29
30	WED	283	191	123	111	173	613	1310	1689	1405	1195	1158	1242	1269	1247	1493	1804	1842	1721	1491	1072	842	790	586	392	24042	30
31	THU	281	168	122	122	174	667	1209	1609	1515	1133	1183	1323	1289	1319	1506	1795	1729	1654	1506	1065	859	772	602	402	24004	31

TRANSPORTATION DEVELOPMENT BRANCH - RESEARCH SECTION

MONTHLY TRAFFIC DATA
AUGUST, 1995

STATION NUMBER: 2611200 (Combined)
HIGHWAY NUMBER: 47

STATION NAME: NB STADIUM-WB SUNSET
MILE POINT :

COUNTY NAME : MULTNOMAH
DATA DATE : AUGUST, 1995

Average Daily: 28,352
Maximum Hour : 2,287
Maximum Day : 31,054

Average Weekday: 29,145 (Monday thru Thursday)
Day: WED Date: 30 Hour: 8
Day: THU Date: 31

SUNDAY		MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY	
DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME	DATE	VOLUME
06	24,342	07	27,882	01	29,218	02	29,421	03	30,239	04	30,442	05	27,546
13	24,409	14	28,291	08	28,235	09	28,884	10	28,856	11	29,433	12	26,212
20	25,083	21	28,678	15	28,969	16	28,596	17	29,815	18	31,041	19	26,435
27	25,909	28	29,594	22	28,885	23	29,210	24	29,681	25	30,366	26	
				29	27,592	30	30,652	31	31,054				
Avg.	24,936	Avg.	28,611	Avg.	28,580	Avg.	29,353	Avg.	29,929	Avg.	30,321	Avg.	26,731

DD	DAY	HR-01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL	DD
01	TUE	279	161	92	75	207	929	1782	2029	1855	1533	1442	1471	1510	1544	1728	1828	1994	1806	1748	1364	1185	1168	905	583	29218	01
02	WED	286	169	114	74	202	939	1723	2108	1806	1329	1233	1520	1501	1561	1745	1940	2041	1898	1927	1436	1155	1177	934	603	29421	02
03	THU	310	189	110	99	201	955	1767	2101	1796	1556	1516	1632	1535	1585	1740	1742	1879	1920	2009	1534	1200	1247	955	661	30239	03
04	FRI	343	212	132	93	185	928	1624	1989	1775	1511	1569	1612	1665	1592	1920	1800	2014	1581	1789	1533	1208	1268	1163	936	30442	04
05	SAT	652	344	242	133	148	346	616	795	1107	1449	1655	1772	1856	1808	1808	1806	1771	1753	1622	1428	1205	1094	1106	1030	27546	05
06	SUN	573	354	251	133	89	202	359	409	620	993	1180	1492	1715	1818	1747	1684	1863	2030	1703	1427	1247	1074	819	560	24342	06
07	MON	265	151	104	84	179	886	1662	1985	1701	1452	1417	1522	1516	1516	1642	1854	1790	1752	1776	1272	1030	1015	847	464	27882	07
08	TUE	284	149	110	76	199	887	1785	2021	1781	1507	1479	1549	1474	1531	1810	1426	1699	1818	1631	1321	1160	1095	868	575	28235	08
09	WED	323	155	119	80	195	913	1702	2052	1001	1491	1401	1541	1689	1622	1737	1950	1977	1785	1793	1398	1221	1114	957	668	28884	09
10	THU	392	208	121	102	207	892	1730	1691	1787	1469	1392	1513	1541	1642	1809	1952	1705	1661	1864	1431	1136	1133	919	559	28856	10
11	FRI	389	176	136	73	187	842	1653	2025	1694	1518	1592	1615	1645	1420	1259	1913	1838	1733	1908	1583	1326	1204	928	776	29433	11
12	SAT	530	329	262	137	179	361	678	783	1026	1271	1571	1742	1895	1678	1800	1701	1429	1831	1633	1223	1143	1147	1038	825	26212	12
13	SUN	501	337	246	170	115	195	315	453	594	1060	1274	1456	1638	1916	1787	1735	1841	1867	1619	1376	1349	1169	900	496	24409	13
14	MON	281	171	82	75	187	902	1765	1725	1799	1412	1436	1544	1563	1704	1750	1963	1829	1706	1695	1271	1119	1047	806	459	28291	14
15	TUE	278	171	109	92	196	858	1698	2112	1801	1451	1435	1498	1550	1555	1748	1900	1954	1846	1754	1318	1116	1129	891	509	28969	15
16	WED	322	184	111	94	178	892	1737	2053	1845	1455	1388	1499	1612	1651	1609	2048	1615	1509	1856	1377	1117	1079	836	529	28596	16
17	THU	290	182	98	112	203	892	1708	2031	1715	1462	1449	1618	1586	1567	1704	1952	1689	1577	1994	1878	1450	1208	886	564	29815	17
18	FRI	318	209	141	106	191	838	1698	2004	1796	1544	1565	1697	1660	1861	1907	1823	1873	1868	1875	1524	1336	1230	1147	830	31041	18
19	SAT	541	291	299	102	5	379	585	796	1081	1410	1782	2022	1874	1827	1758	809	1526	1873	1697	1306	1114	1319	1153	886	26435	19
20	SUN	557	363	215	146	118	199	331	470	682	1100	1273	1524	1758	1820	1672	1778	1832	1870	1742	1560	1435	1243	900	495	25083	20
21	MON	251	155	83	78	208	891	1754	1982	1839	1558	1523	1558	1579	1529	1796	1965	1923	1618	1731	1344	1078	990	764	481	28678	21
22	TUE	279	156	104	94	186	925	1734	2080	1639	1535	1564	1563	1469	1600	1753	1863	1893	1671	1793	1328	1176	1222	768	490	28885	22
23	WED	248	156	125	83	203	927	1781	2094	1788	1490	1398	1617	1518	1553	1773	1973	1925	1692	1861	1423	1175	1095	756	556	29210	23
24	THU	298	179	102	94	202	885	1787	2068	1734	1470	1417	1599	1569	1607	1781	1949	1923	1687	1890	1526	1199	1250	878	587	29681	24
25	FRI	298	188	142	93	216	885	1764	1936	848	1584	1558	1749	1766	1746	1944	2082	1901	1815	1770	1564	1379	1277	1077	784	30366	25
26	SAT																										26
27	SUN	441	326	239	154	122	216	351	448	692	1124	1342	1611	1760	1913	1739	1882	2017	1924	1832	1577	1550	1272	831	546	25909	27
28	MON	283	153	98	62	215	988	1811	2207	1770	1512	1549	1607	1577	1691	1829	2052	1974	1884	1809	1250	1067	966	737	503	29594	28
29	TUE	260	153	109	95	205	995	1748	1937	1856	1462	1388	1549	1541	1535	1802	1641	1445	1260	1712	1306	1213	1079	811	490	27592	29
30	WED	290	178	132	83	215	981	1821	2287	1851	1534	1497	1595	1564	1673	1772	2034	2073	1843	1826	1452	1294	1186	878	593	30652	30
31	THU	322	202	107	91	212	980	1855	2171	1890	1552	1516	1662	1618	1743	1807	2079	1992	1777	1808	1518	1333	1241	964	614	31054 ◄	31

STATION NUMBER: 2611100 (Combined)
HIGHWAY NUMBER: 47

STATION NAME: SE CLAY -WB SUNSET
MILE POINT :

COUNTY NAME : MULTNOMAH
DATA DATE : AUGUST, 1995

Average Daily: 12,667
Maximum Hour : 1,476
Maximum Day : 14,644

Average Weekday: 13,678 (Monday thru Thursday)
Day: WED Date: 02 Hour: 18
Day: THU Date: 03

SUNDAY DATE	SUNDAY VOLUME	MONDAY DATE	MONDAY VOLUME	TUESDAY DATE	TUESDAY VOLUME	WEDNESDAY DATE	WEDNESDAY VOLUME	THURSDAY DATE	THURSDAY VOLUME	FRIDAY DATE	FRIDAY VOLUME	SATURDAY DATE	SATURDAY VOLUME
06	8,612	07	13,196	01	14,067	02	14,292	03	14,644	04	14,520	05	10,766
13	9,649	14	13,339	08	13,794	09	13,968	10	13,997	11	14,136	12	11,750
20	8,304	21	12,889	15	13,602	16	13,619	17	13,847	18	14,072	19	10,997
27	8,334	28	12,878	22	13,721	23	13,583	24	13,692	25	13,987	26	
				29	13,384	30	13,843	31	13,529				
Avg.	8,725	Avg.	13,076	Avg.	13,714	Avg.	13,861	Avg.	13,942	Avg.	14,179	Avg.	11,171

DD	DAY	HR-01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL	DD
01	TUE	149	98	66	36	32	100	235	626	628	566	612	786	854	916	975	1119	1281	1407	964	628	500	578	394	517	14067	01
02	WED	205	104	61	29	37	121	241	605	586	547	642	796	855	889	904	1127	1305	1476	1005	683	548	628	449	449	14292	02
03	THU	325	128	73	38	34	115	255	583	581	584	676	863	817	914	970	1089	1275	1417	966	675	589	635	479	563	14644 ◄	03
04	FRI	231	142	110	58	52	94	256	590	551	591	726	843	871	1006	1047	1101	1172	1233	846	609	491	616	606	678	14520	04
05	SAT	583	350	216	123	62	45	80	125	217	348	455	621	636	696	771	759	715	747	600	529	462	528	490	608	10766	05
06	SUN	452	333	260	138	69	43	56	88	139	218	301	474	576	575	646	598	672	749	515	439	288	349	394	240	8612	06
07	MON	144	86	63	33	42	73	245	594	556	559	643	776	830	824	838	1013	1316	1357	988	659	460	531	323	243	13196	07
08	TUE	170	95	52	35	39	87	246	621	576	563	667	840	819	874	884	1066	1283	1392	970	696	522	637	400	260	13794	08
09	WED	159	100	63	45	32	91	247	619	507	601	687	869	858	879	937	1054	1262	1400	921	710	578	629	361	359	13968	09
10	THU	228	115	75	51	42	89	225	615	680	560	660	765	829	853	922	1136	1265	1346	983	708	533	583	407	327	13997	10
11	FRI	209	134	92	43	39	104	240	569	589	557	715	844	954	877	937	1009	1149	1270	868	589	510	671	621	546	14136	11
12	SAT	429	298	254	107	69	50	92	130	232	309	460	568	745	728	762	827	872	811	668	566	576	651	774	772	11750	12
13	SUN	394	384	270	141	60	55	54	69	150	253	335	457	574	622	685	720	958	735	636	509	461	471	423	233	9649	13
14	MON	150	94	53	38	35	80	256	720	624	541	723	789	830	848	915	1018	1242	1361	892	543	502	537	326	222	13339	14
15	TUE	144	83	69	36	32	86	238	604	579	556	646	824	824	877	980	1092	1324	1350	928	650	534	480	397	269	13602	15
16	WED	171	100	61	35	36	95	260	611	581	556	682	792	790	885	977	1093	1239	1244	1050	567	528	544	402	320	13619	16
17	THU	181	105	70	50	43	93	237	574	594	573	637	801	863	905	889	1031	1234	1288	1001	716	581	615	409	357	13847	17
18	FRI	183	128	123	42	35	94	245	597	599	538	698	875	906	971	1013	1120	1154	1223	829	654	519	549	492	485	14072	18
19	SAT	412	323	259	122	204	50	76	159	261	372	505	636	862	752	803	660	855	737	586	474	396	518	461	514	10997	19
20	SUN	391	301	228	147	49	40	47	85	138	219	320	417	626	593	655	678	666	628	452	409	366	378	231	240	8304	20
21	MON	132	89	58	38	42	71	241	620	539	536	631	786	809	802	839	1047	1217	1343	900	573	509	447	365	255	12889	21
22	TUE	146	82	60	29	34	85	249	620	604	592	646	820	870	883	939	1079	1237	1366	904	570	557	704	367	278	13721	22
23	WED	144	97	61	40	47	100	260	617	592	559	651	805	783	889	943	1073	1259	1367	944	628	536	558	355	275	13583	23
24	THU	160	100	76	32	41	100	228	623	623	591	604	772	869	850	921	1176	1229	1275	914	653	564	589	399	303	13692	24
25	FRI	193	150	88	47	43	102	231	584	454	537	730	872	883	929	958	1145	1131	1192	892	720	499	599	546	462	13987	25
26	SAT																										26
27	SUN	397	289	218	142	65	48	60	88	128	248	343	488	620	581	603	643	684	611	506	407	353	353	260	199	8334	27
28	MON	130	103	48	40	31	86	249	613	563	534	662	804	782	866	850	1021	1159	1369	953	550	477	446	308	234	12878	28
29	TUE	127	78	57	32	29	106	242	667	665	555	672	816	783	901	945	1076	1229	1214	914	598	515	547	365	251	13384	29
30	WED	149	86	42	30	38	98	256	630	576	581	662	796	834	948	926	1072	1304	1306	942	637	609	632	409	280	13843	30
31	THU	172	96	78	40	31	102	264	640	610	558	664	760	778	871	982	1086	1263	1267	886	581	531	550	423	296	13529	31

counts

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak
8/14/95	11	3361	3444	2.41%	97.59%	Midday
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak
8/20/95	2	573	899	36.26%	63.74%	Late Night
8/20/95	3	362	603	39.97%	60.03%	Late Night
8/20/95	4	248	407	39.07%	60.93%	Late Night
8/22/95	13	3195	3745	14.69%	85.31%	Midday
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak
8/23/95	5	348	435	20.00%	80.00%	Early Morning
8/23/95	6	1407	1709	17.67%	82.33%	Early Morning
8/23/95	7	2922	3360	13.04%	86.96%	Early Morning
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak
8/24/95	20	2972	3320	10.48%	89.52%	Evening
8/24/95	21	2411	2732	11.75%	88.25%	Evening
8/24/95	22	2200	2742	19.77%	80.23%	Evening
8/24/95	23	1417	1936	26.81%	73.19%	Night
8/24/95	24	966	1335	27.64%	72.36%	Night
8/25/95	1	584	809	27.81%	72.19%	Night
8/30/95	11	3174	3317	4.31%	95.69%	Midday
8/30/95	12	3486	3633	4.05%	95.95%	Midday
8/30/95	13	3566	3667	2.75%	97.25%	Midday
Totals		84946	95131	10.71%	89.29%	
			Averages	14.43%	85.57%	

No Night #'s	80796	89142	9.36%	90.64%

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description	
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak	
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak	
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak	
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak	
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak	91.42%
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon	
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon	
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon	
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon	
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon	
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon	90.66%
8/23/95	7	2922	3360	13.04%	86.96%	Early Morning	
8/23/95	6	1407	1709	17.67%	82.33%	Early Morning	
8/23/95	5	348	435	20.00%	80.00%	Early Morning	83.10%
8/24/95	20	2972	3320	10.48%	89.52%	Evening	
8/24/95	21	2411	2732	11.75%	88.25%	Evening	
8/24/95	22	2200	2742	19.77%	80.23%	Evening	86.00%
8/20/95	2	573	899	36.26%	63.74%	Late Night	
8/20/95	4	248	407	39.07%	60.93%	Late Night	
8/20/95	3	362	603	39.97%	60.03%	Late Night	61.57%
8/14/95	11	3361	3444	2.41%	97.59%	Midday	
8/30/95	13	3566	3667	2.75%	97.25%	Midday	
8/30/95	12	3486	3633	4.05%	95.95%	Midday	
8/30/95	11	3174	3317	4.31%	95.69%	Midday	
8/22/95	13	3195	3745	14.69%	85.31%	Midday	94.36%
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak	
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak	
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak	90.00%
8/24/95	23	1417	1936	26.81%	73.19%	Night	
8/24/95	24	966	1335	27.64%	72.36%	Night	
8/25/95	1	584	809	27.81%	72.19%	Night	72.58%

Late Night and Night =	67.07%
Afternoons and Miday =	- 92.15%
	25.07%

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak
8/14/95	11	3361	3444	2.41%	97.59%	Midday
8/30/95	13	3566	3667	2.75%	97.25%	Midday
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak
8/30/95	12	3486	3633	4.05%	95.95%	Midday
8/30/95	11	3174	3317	4.31%	95.69%	Midday
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon
8/24/95	20	2972	3320	10.48%	89.52%	Evening
8/24/95	21	2411	2732	11.75%	88.25%	Evening
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon
8/23/95	7	2922	3360	13.04%	86.96%	Early Morning
8/22/95	13	3195	3745	14.69%	85.31%	Midday
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak
8/23/95	6	1407	1709	17.67%	82.33%	Early Morning
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon
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8/25/95	1	584	809	27.81%	72.19%	Night
8/20/95	2	573	899	36.26%	63.74%	Late Night
8/20/95	4	248	407	39.07%	60.93%	Late Night
8/20/95	3	362	603	39.97%	60.03%	Late Night

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8/30/95	13	3566	3667	2.75%	97.25%	Midday
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon
8/30/95	12	3486	3633	4.05%	95.95%	Midday
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon
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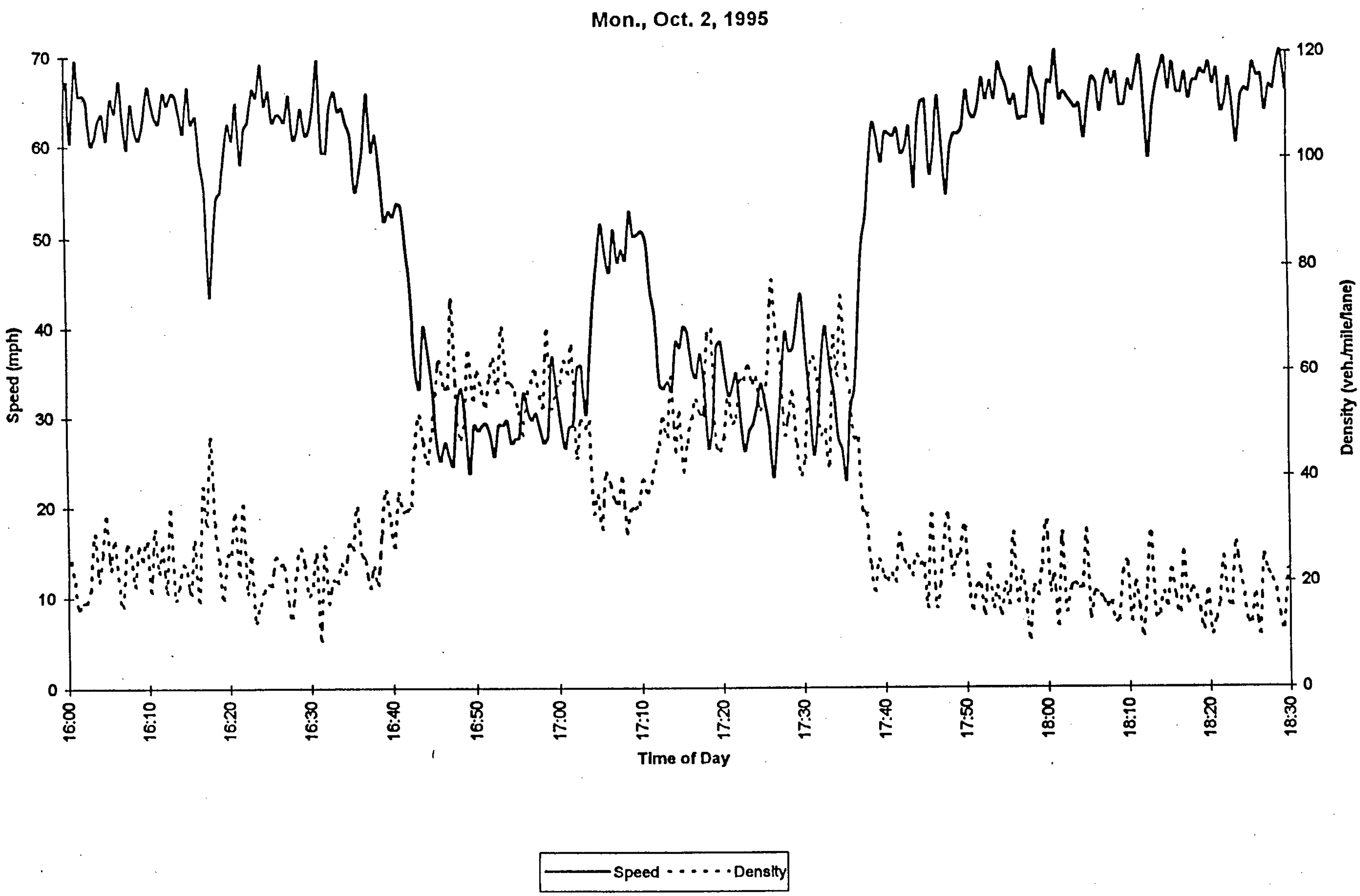
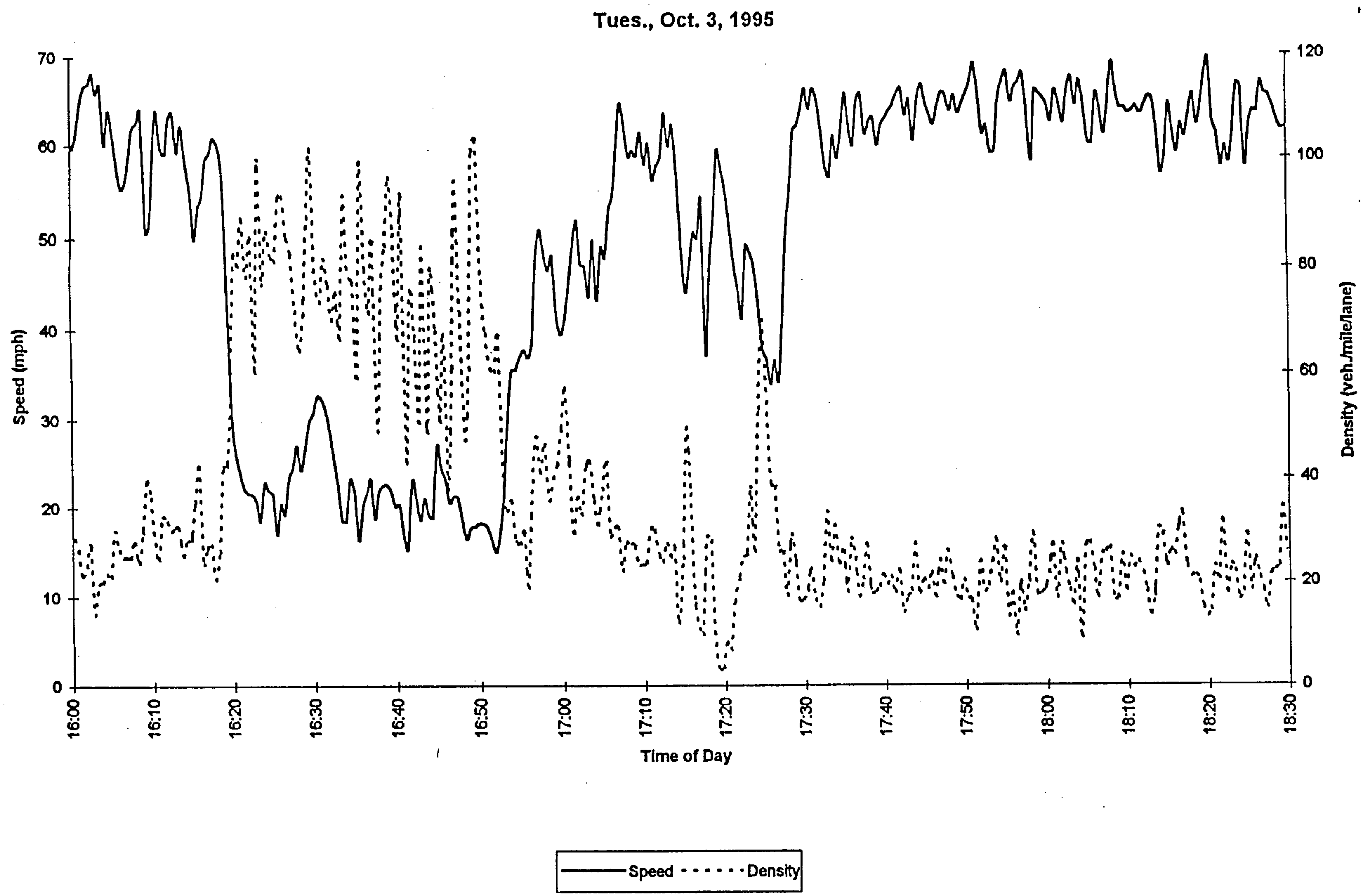
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak
8/22/95	13	3195	3745	14.69%	85.31%	Midday
8/30/95	13	3566	3667	2.75%	97.25%	Midday
8/30/95	12	3486	3633	4.05%	95.95%	Midday
8/14/95	11	3361	3444	2.41%	97.59%	Midday
8/23/95	7	2922	3360	13.04%	86.96%	Early Morning
8/24/95	20	2972	3320	10.48%	89.52%	Evening
8/30/95	11	3174	3317	4.31%	95.69%	Midday
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak
8/24/95	22	2200	2742	19.77%	80.23%	Evening
8/24/95	21	2411	2732	11.75%	88.25%	Evening
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon
8/24/95	23	1417	1936	26.81%	73.19%	Night
8/23/95	6	1407	1709	17.67%	82.33%	Early Morning
8/24/95	24	966	1335	27.64%	72.36%	Night
8/20/95	2	573	899	36.26%	63.74%	Late Night
8/25/95	1	584	809	27.81%	72.19%	Night
8/20/95	3	362	603	39.97%	60.03%	Late Night
8/23/95	5	348	435	20.00%	80.00%	Early Morning
8/20/95	4	248	407	39.07%	60.93%	Late Night

Date	Hour	Mobilizer	ODOT count	% diff	% accurate	Description	Flow Rate	Accuracy	Cause
8/8/95	15	4312	4376	1.46%	98.54%	Early Afternoon	high	ok	ok
8/8/95	16	3515	3851	8.73%	91.27%	Early Afternoon	high	ok	ok
8/8/95	17	4557	4700	3.04%	96.96%	Afternoon Peak	high	ok	ok
8/14/95	10	3068	3226	4.90%	95.10%	Morning Peak	normal	ok	ok
8/14/95	11	3361	3444	2.41%	97.59%	Midday	normal	ok	ok
8/19/95	15	3236	4008	19.26%	80.74%	Early Afternoon	high	low	headway
8/19/95	16	2340	2493	6.14%	93.86%	Early Afternoon	normal	ok	ok
8/19/95	17	3668	3754	2.29%	97.71%	Afternoon Peak	high	ok	ok
8/19/95	18	3404	4006	15.03%	84.97%	Afternoon Peak	high	low	headway
8/22/95	13	3195	3745	14.69%	85.31%	Midday	high	low	headway
8/22/95	14	3439	3951	12.96%	87.04%	Early Afternoon	high	low	headway
8/22/95	16	4399	4755	7.49%	92.51%	Early Afternoon	high	ok	ok
8/22/95	17	4697	5069	7.34%	92.66%	Afternoon Peak	high	ok	ok
8/23/95	8	3897	4437	12.17%	87.83%	Morning Peak	high	low	headway
8/23/95	9	3416	3923	12.92%	87.08%	Morning Peak	high	low	headway
8/24/95	19	3806	4489	15.21%	84.79%	Afternoon Peak	high	low	headway
8/30/95	11	3174	3317	4.31%	95.69%	Midday	normal	ok	ok
8/30/95	12	3486	3633	4.05%	95.95%	Midday	normal	ok	ok
8/30/95	13	3566	3667	2.75%	97.25%	Midday	normal	ok	ok
Totals		68536	74844	8.43%	91.57%				
			Averages	8.27%	91.73%				

100295 Chart 1



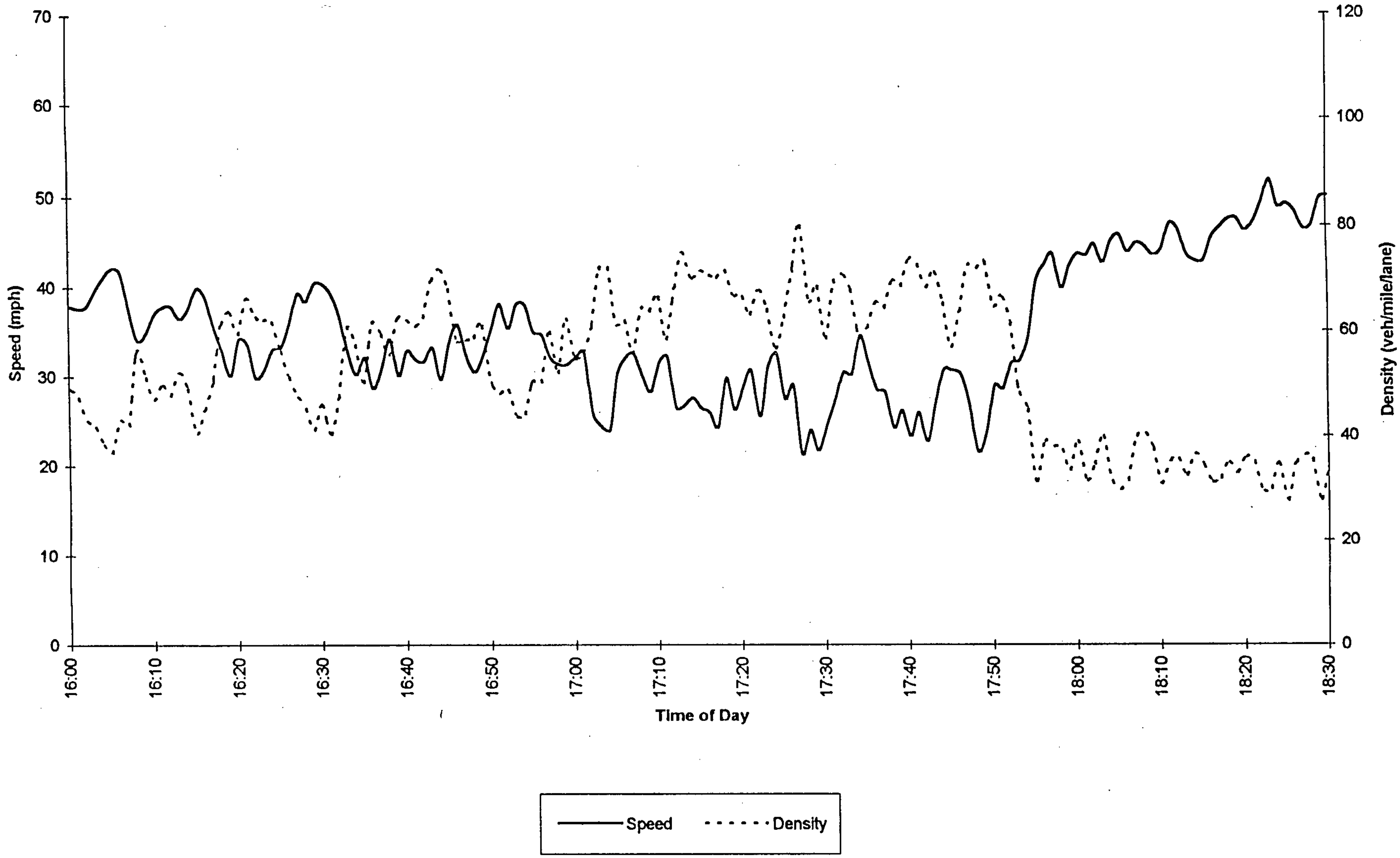
100395 Chart 1



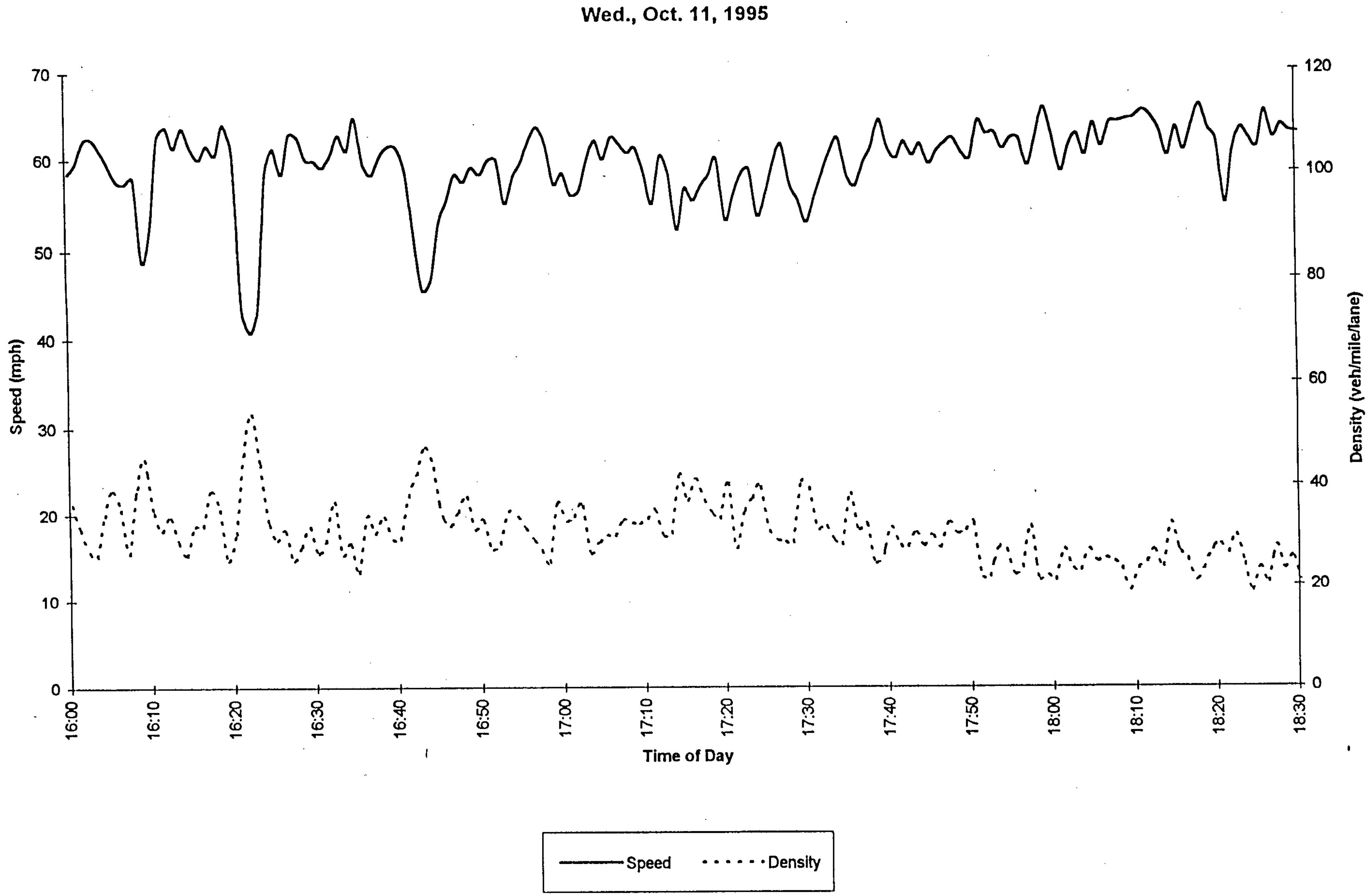
100995 Chart 1

101095 Chart 1

Tue., Oct. 10, 1995

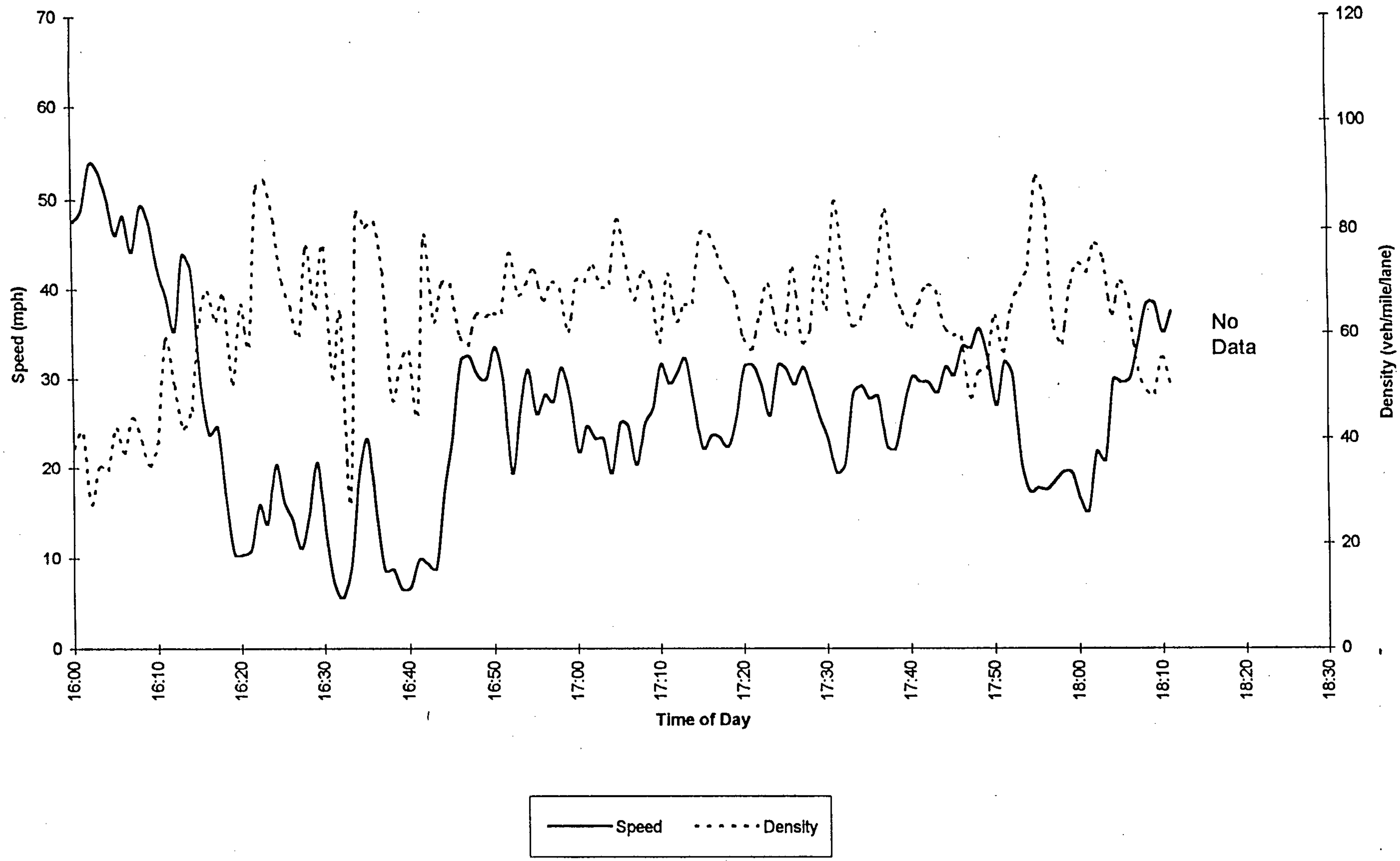


101195 Chart 1

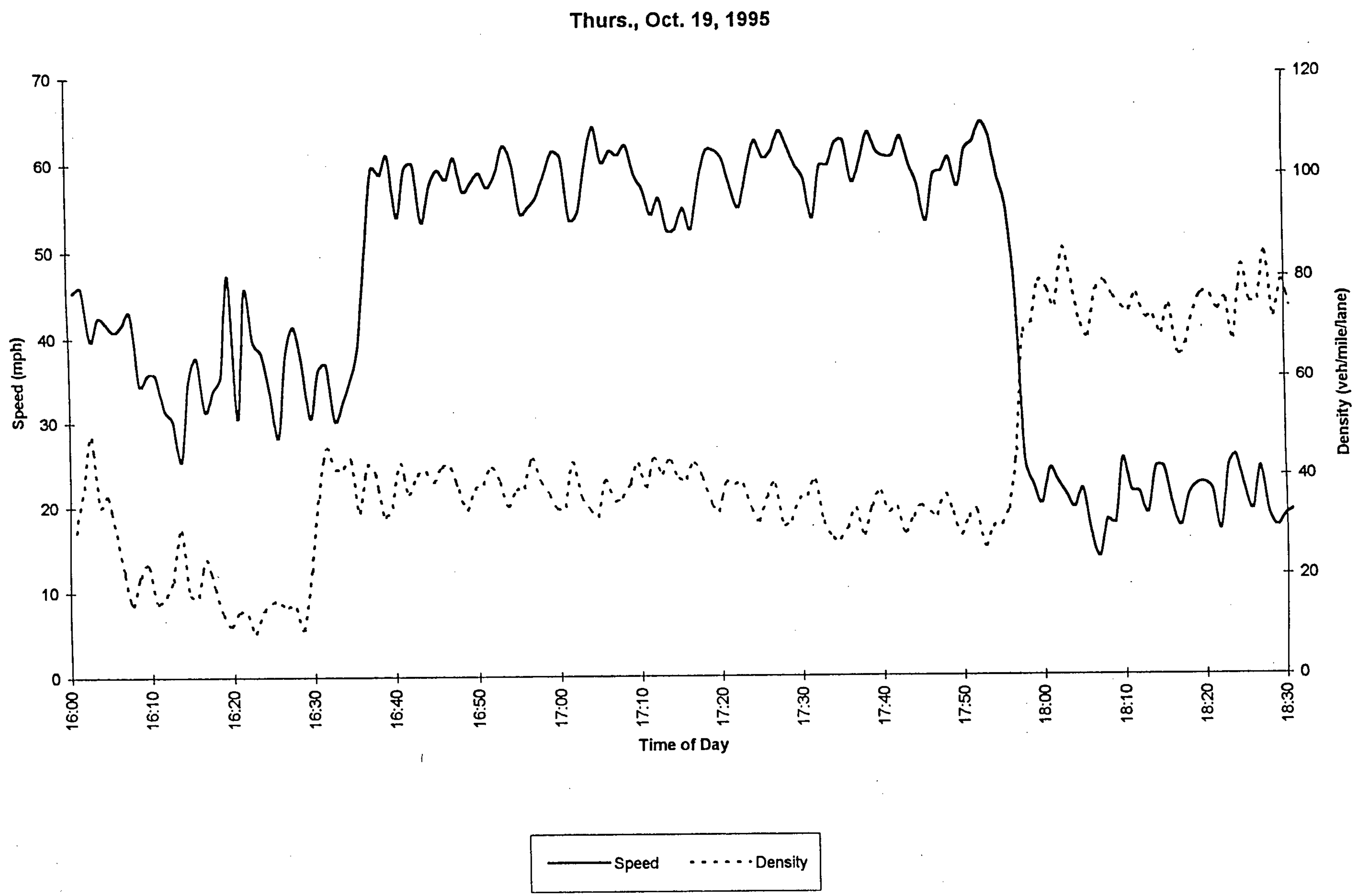


101795 Chart 1

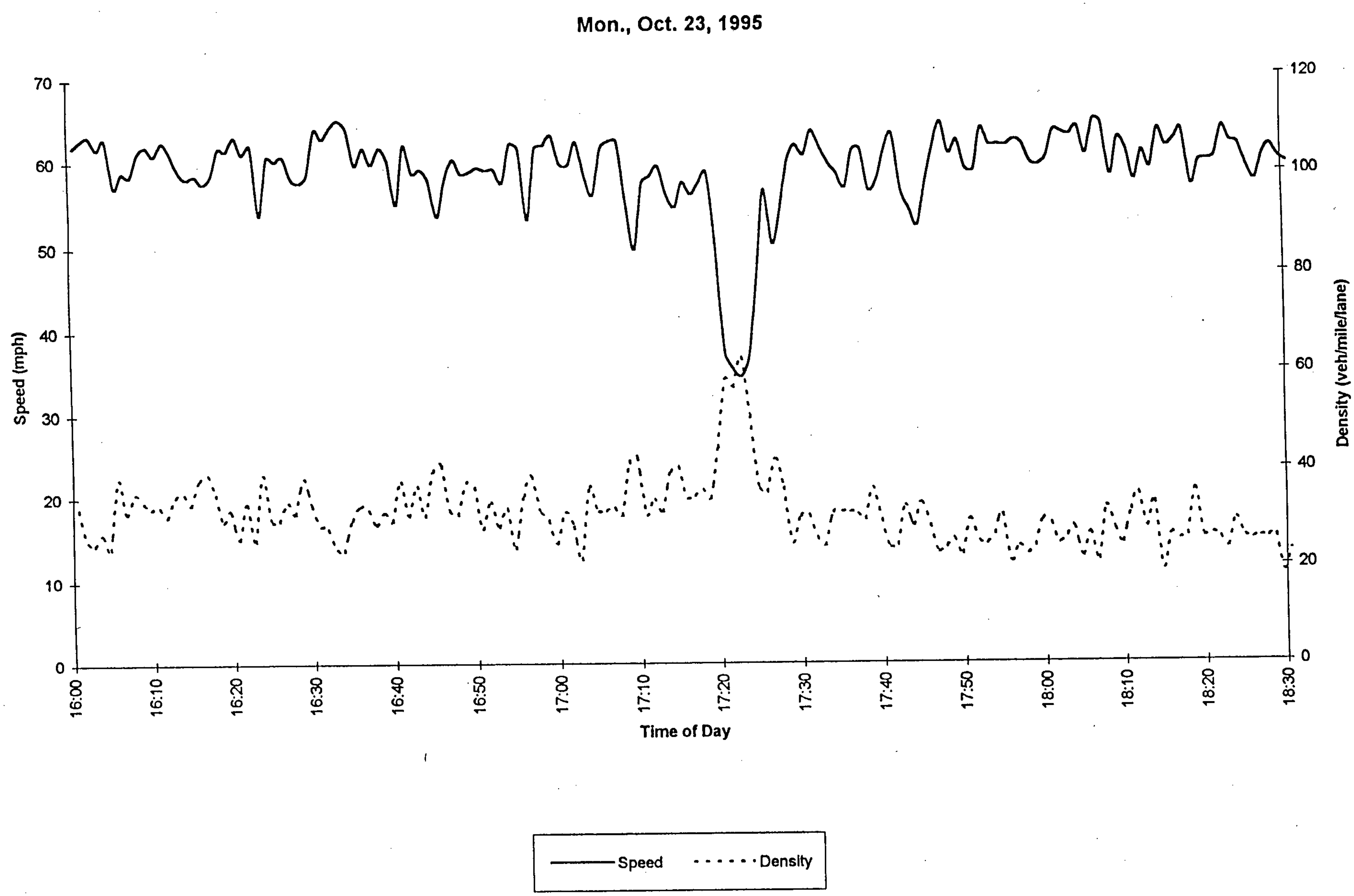
Tue., Oct. 17, 1995



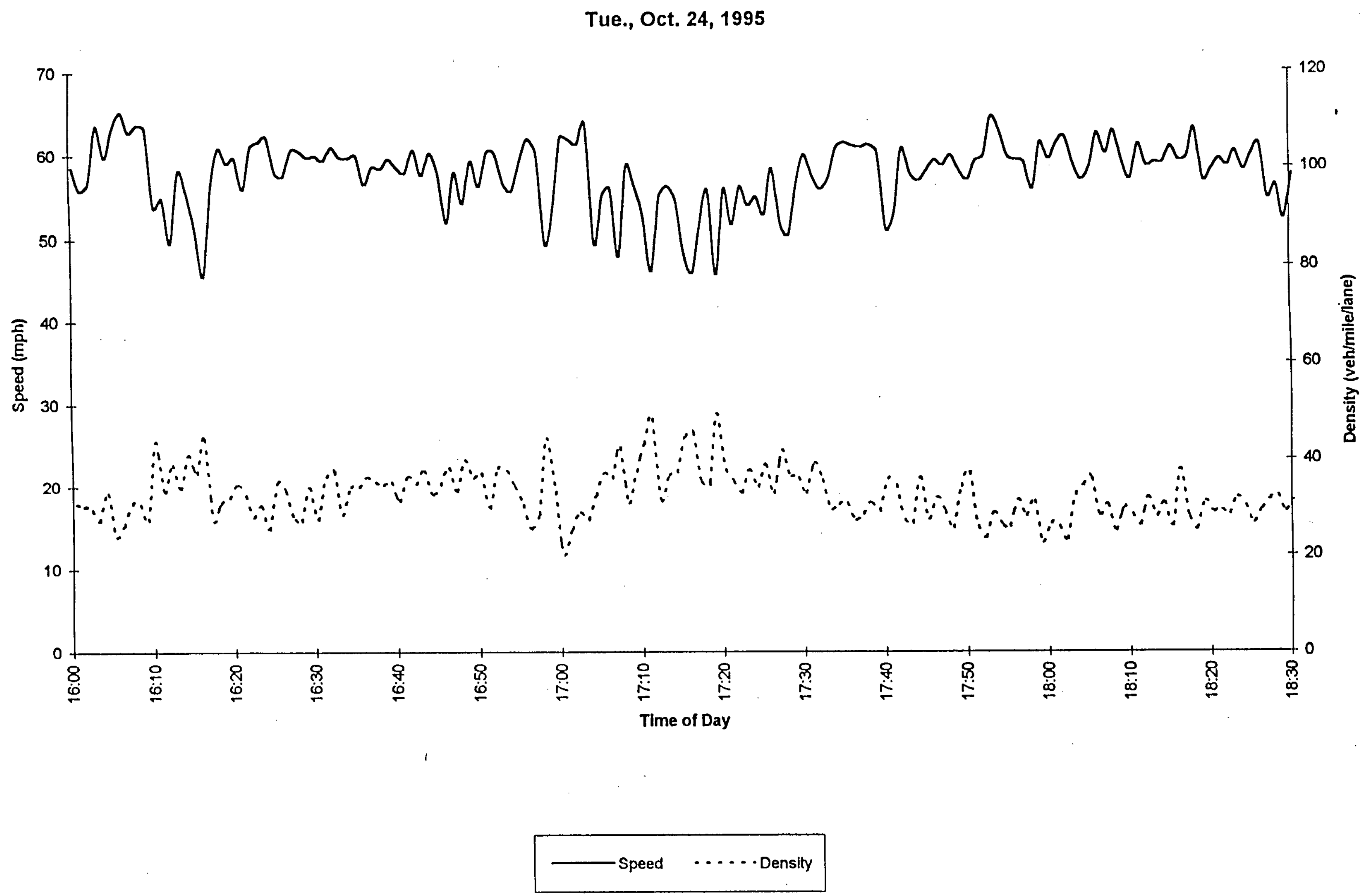
101995 Chart 1



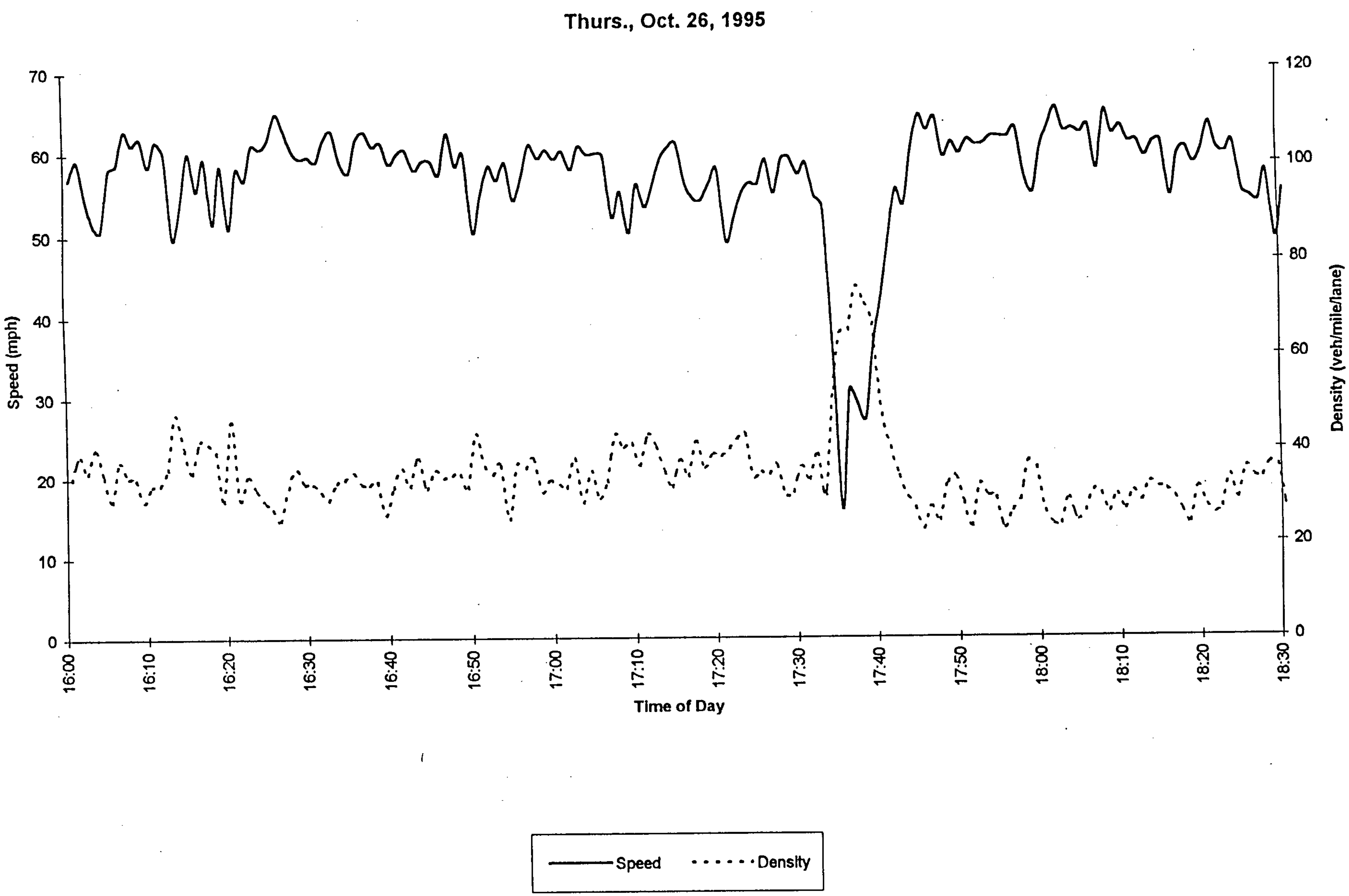
102395 Chart 1



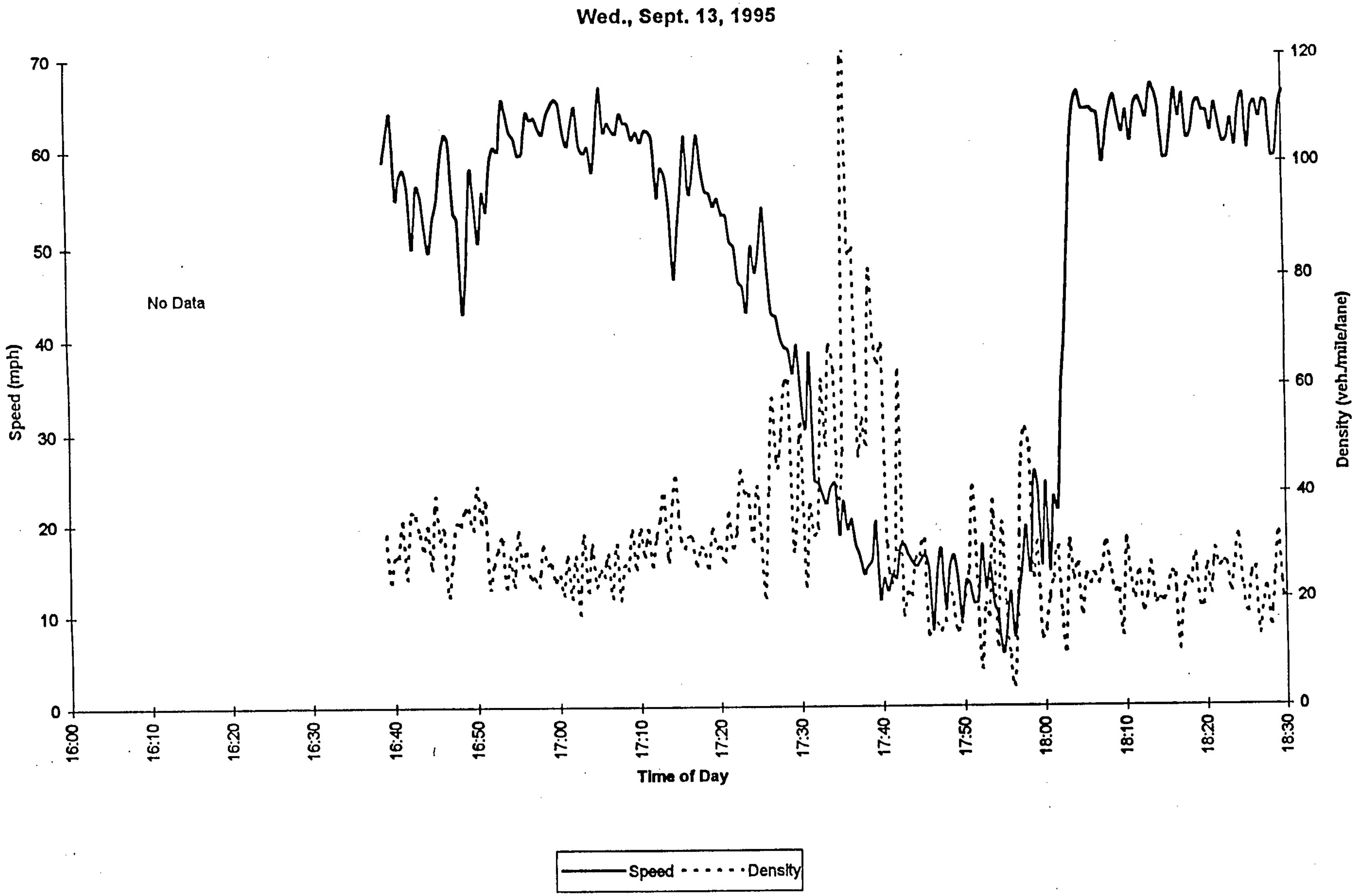
102495 Chart 1



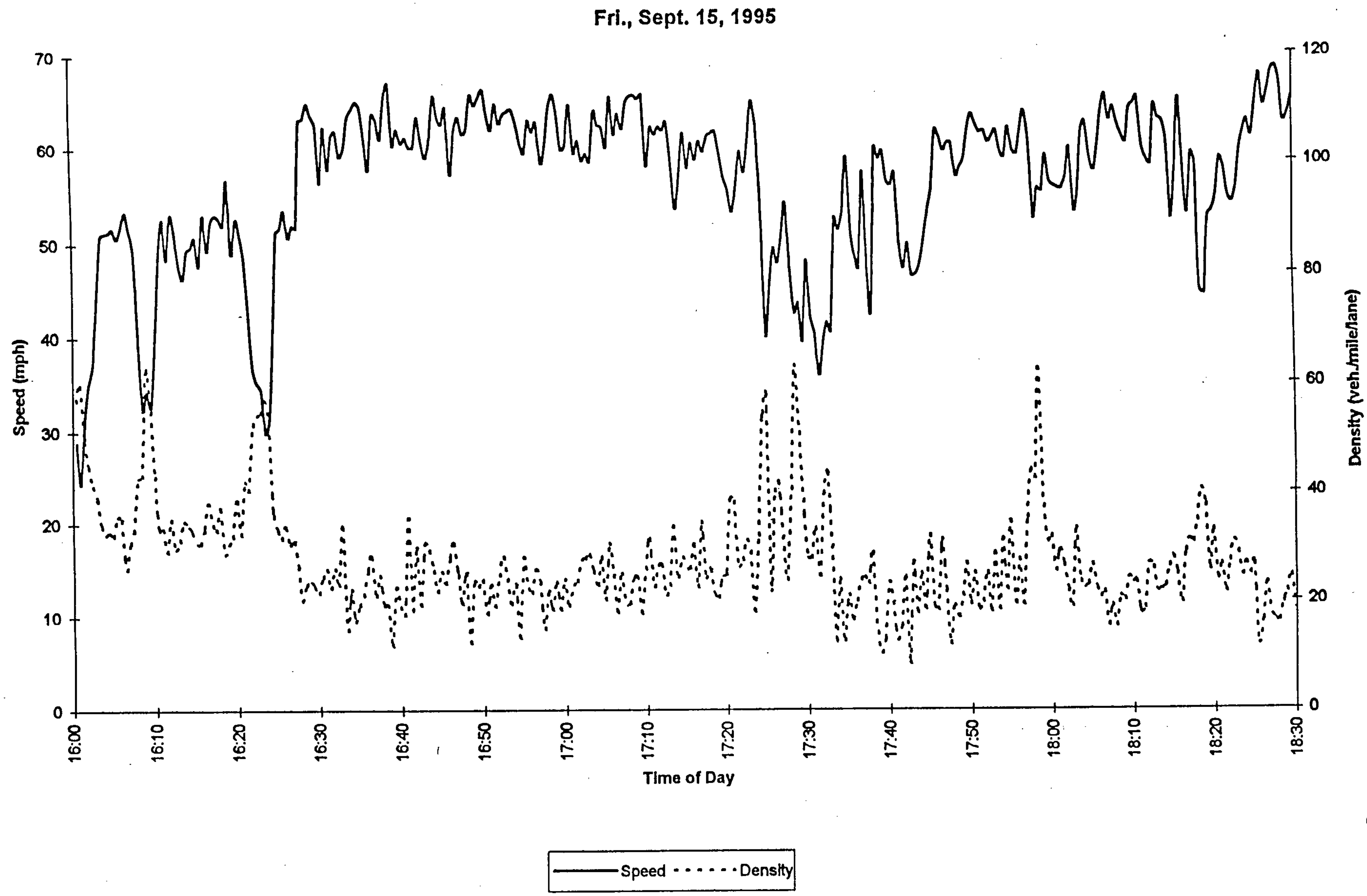
102695 Chart 1



091395 Chart 2

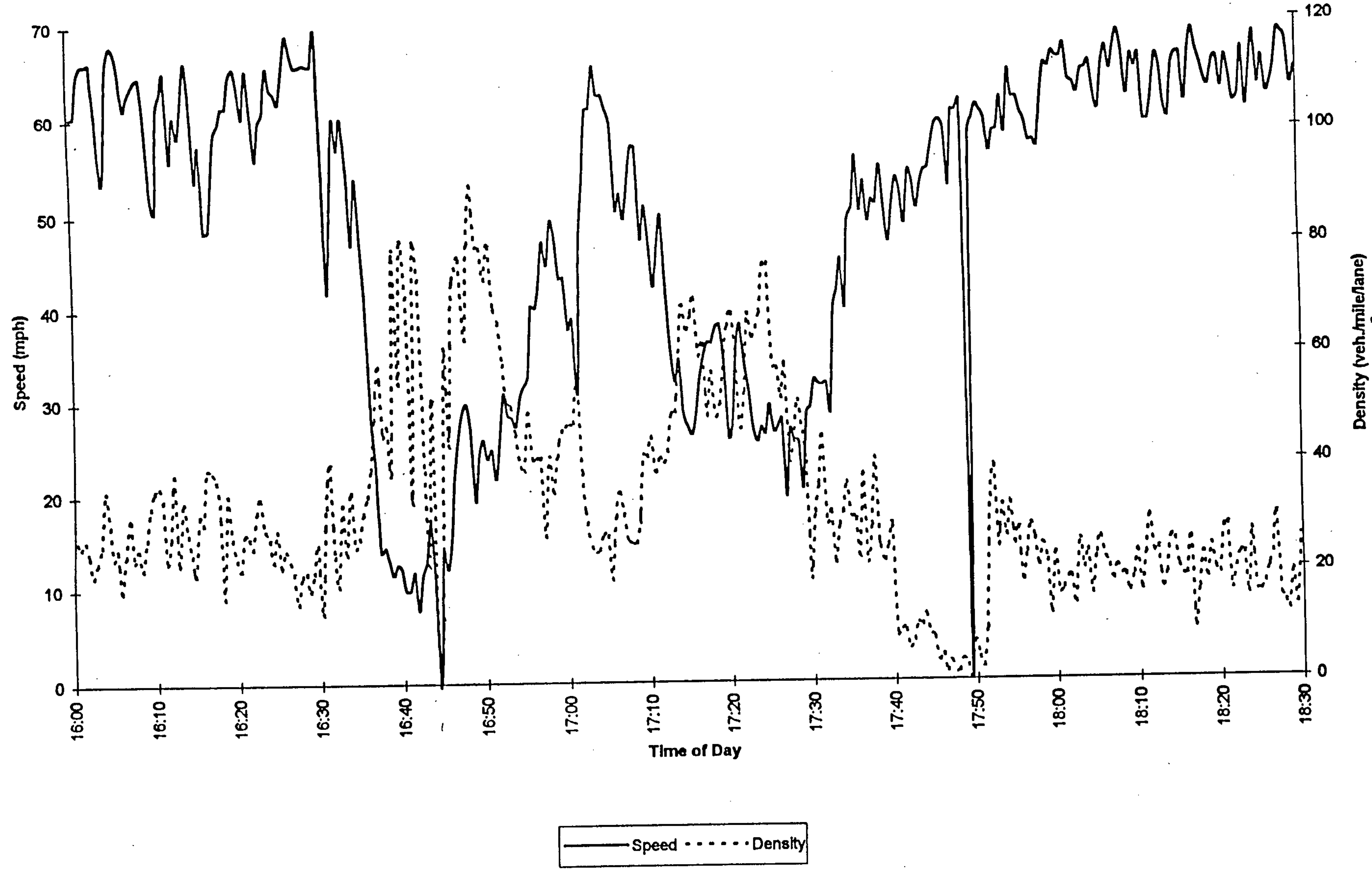


091595 Chart 1

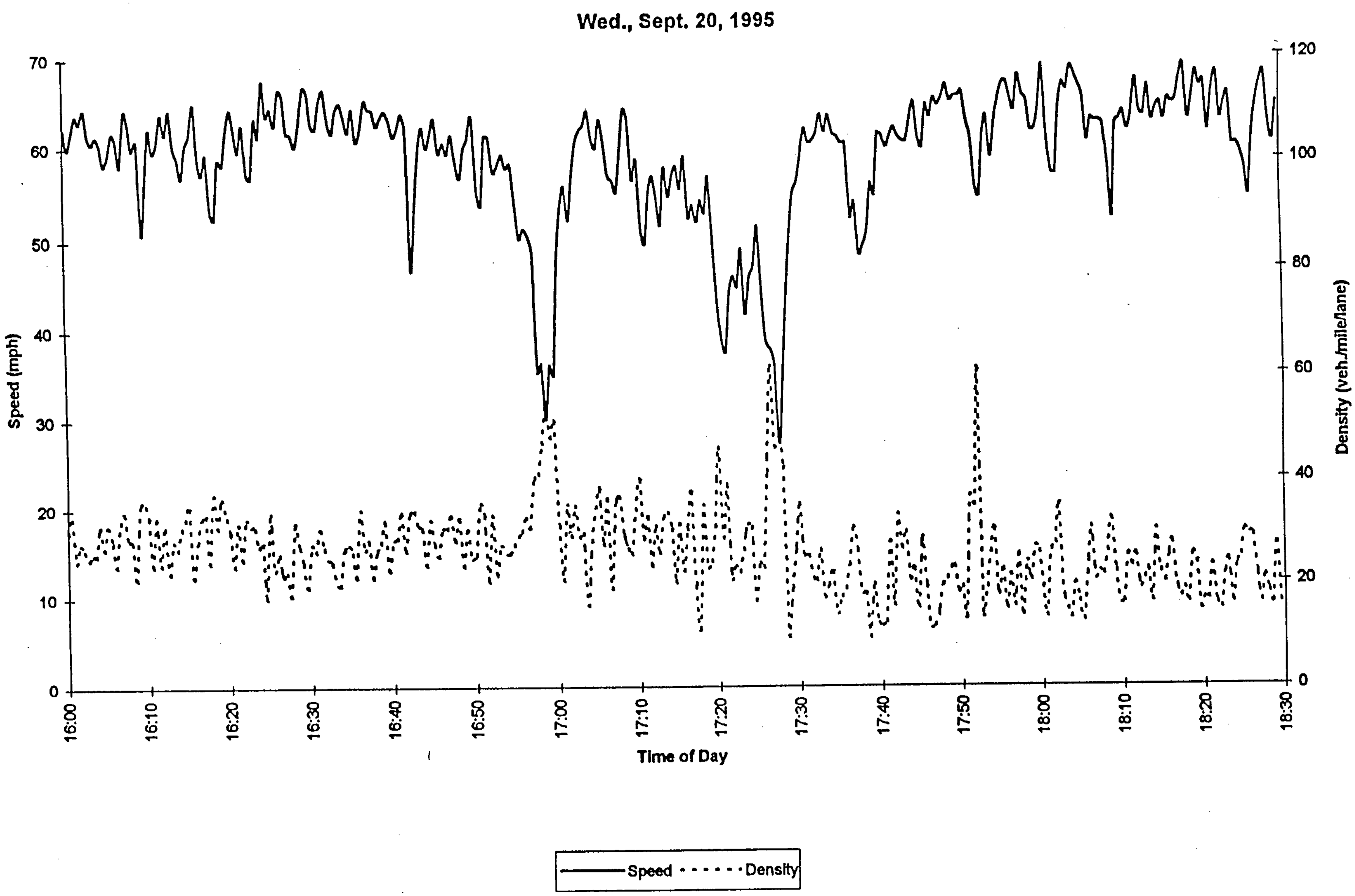


091895 Chart 1

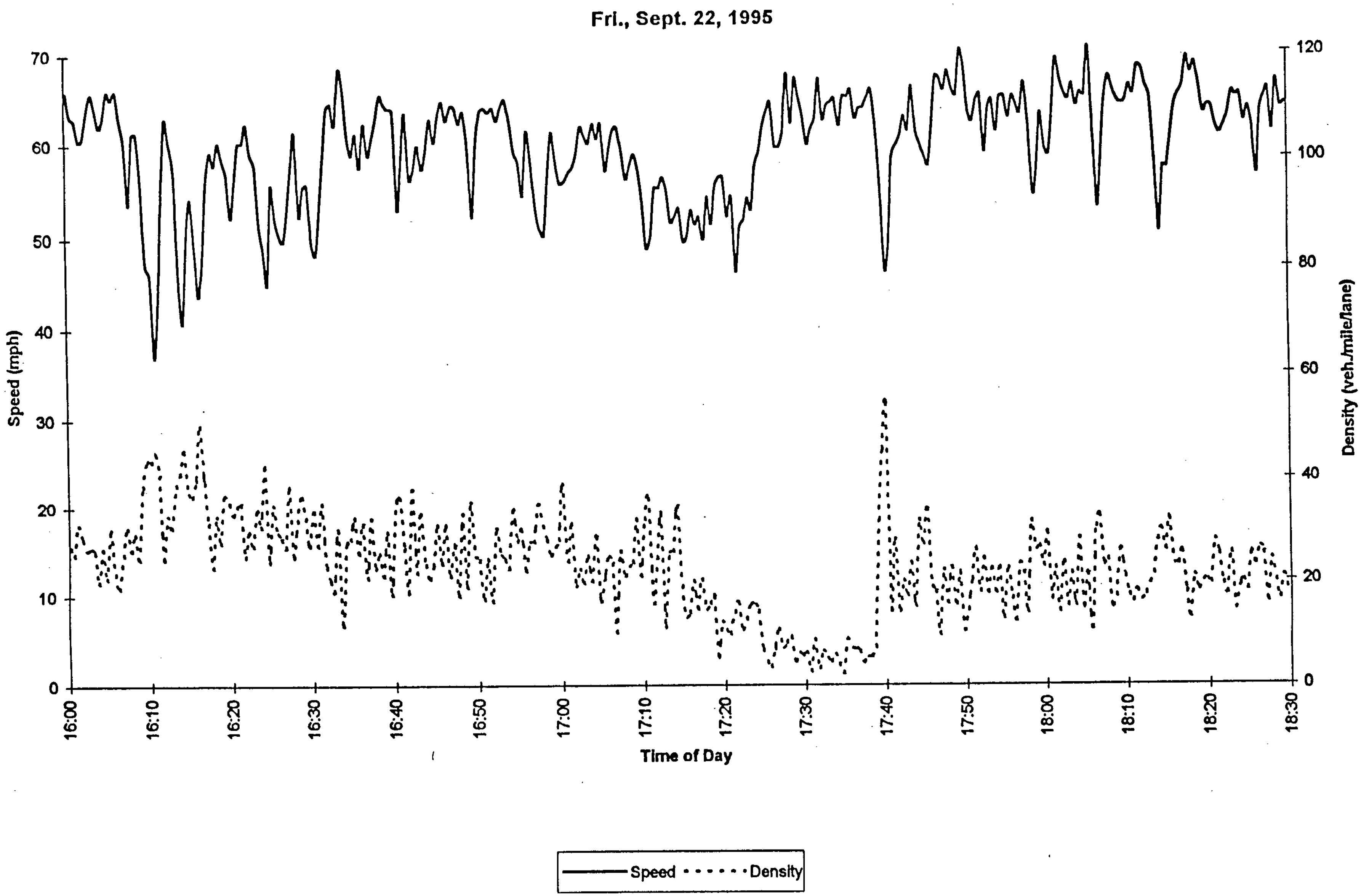
Mon., Sept. 18, 1995



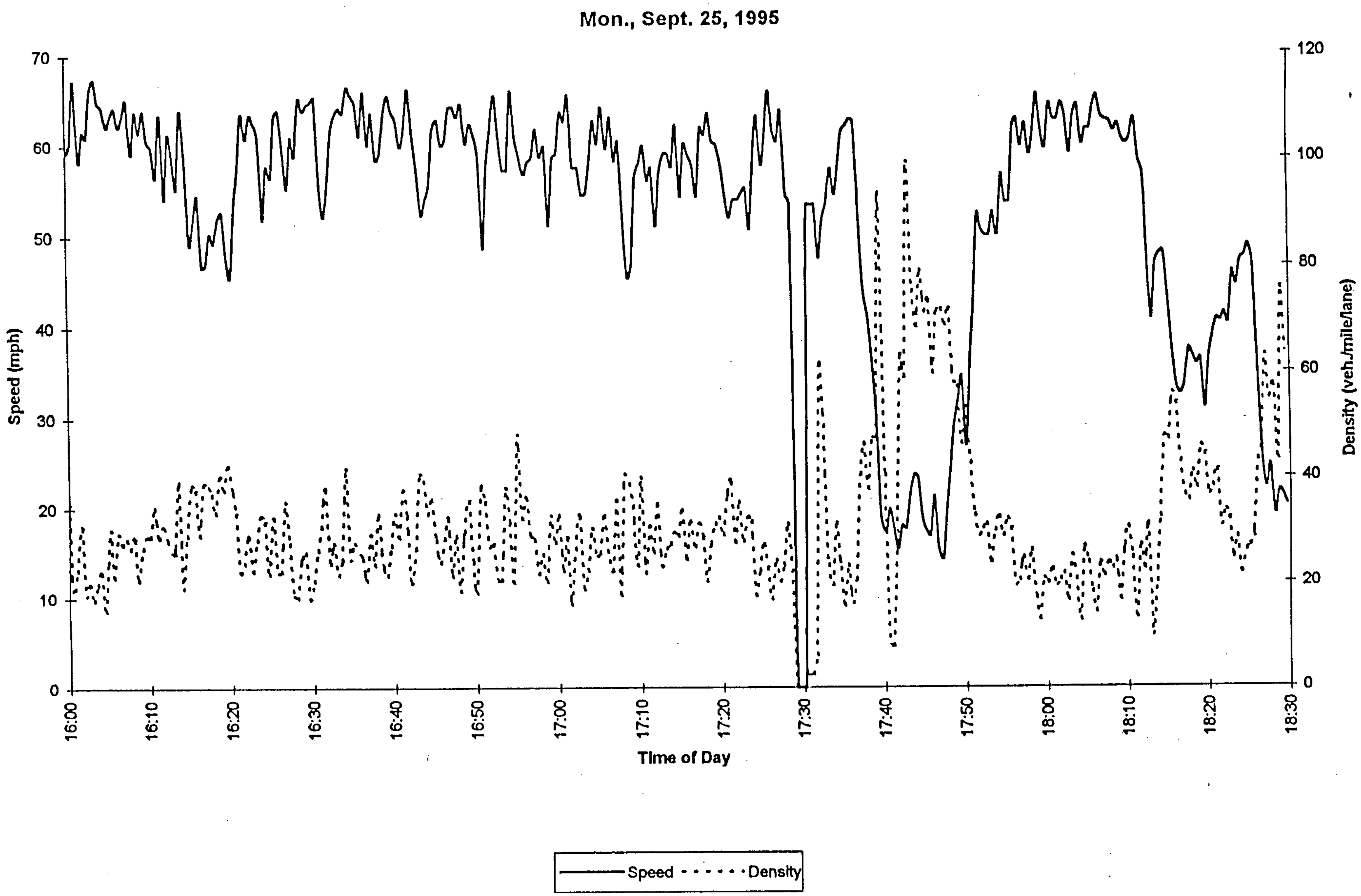
092095 Chart 1



092295 Chart 1

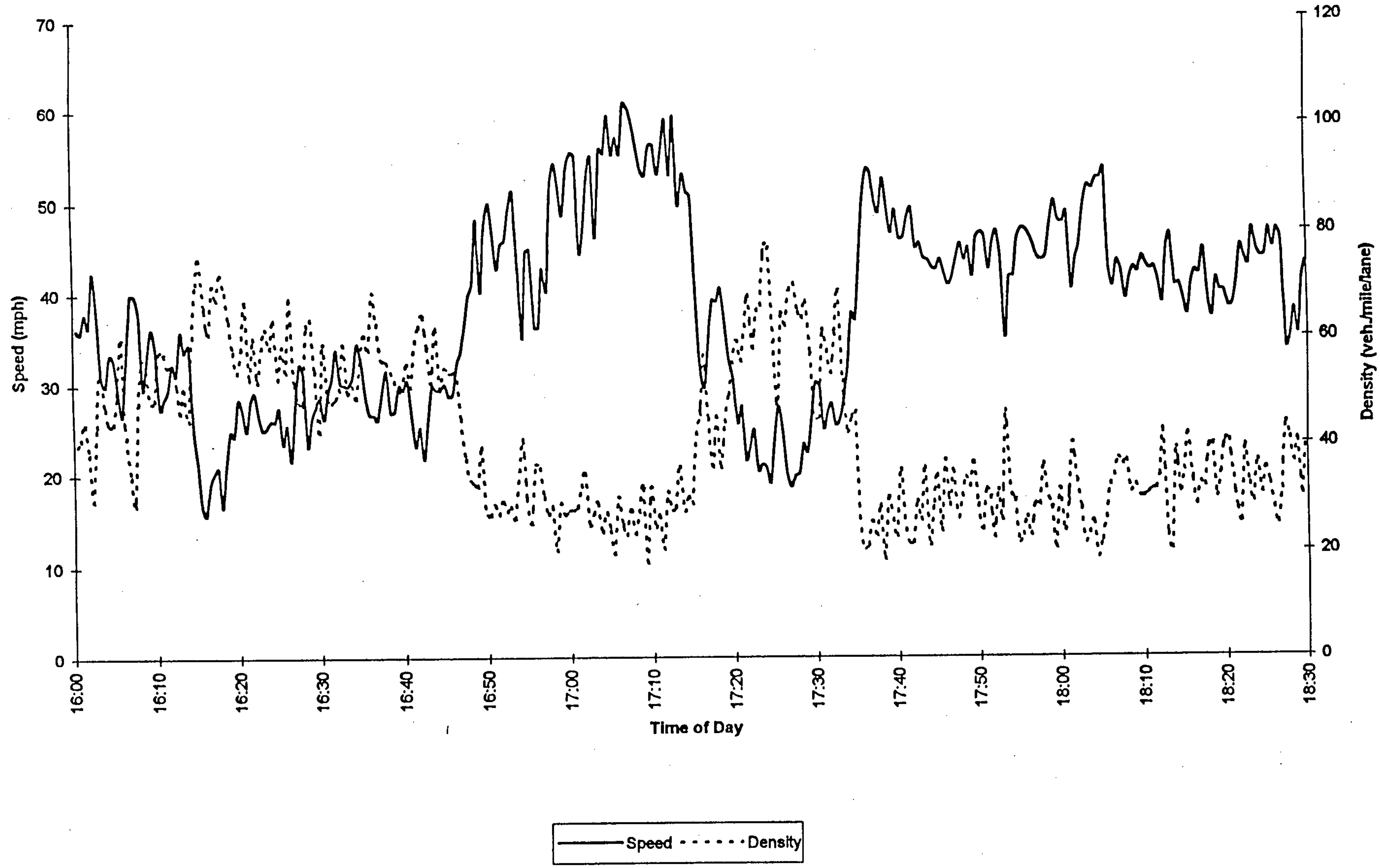


092595 Chart 1

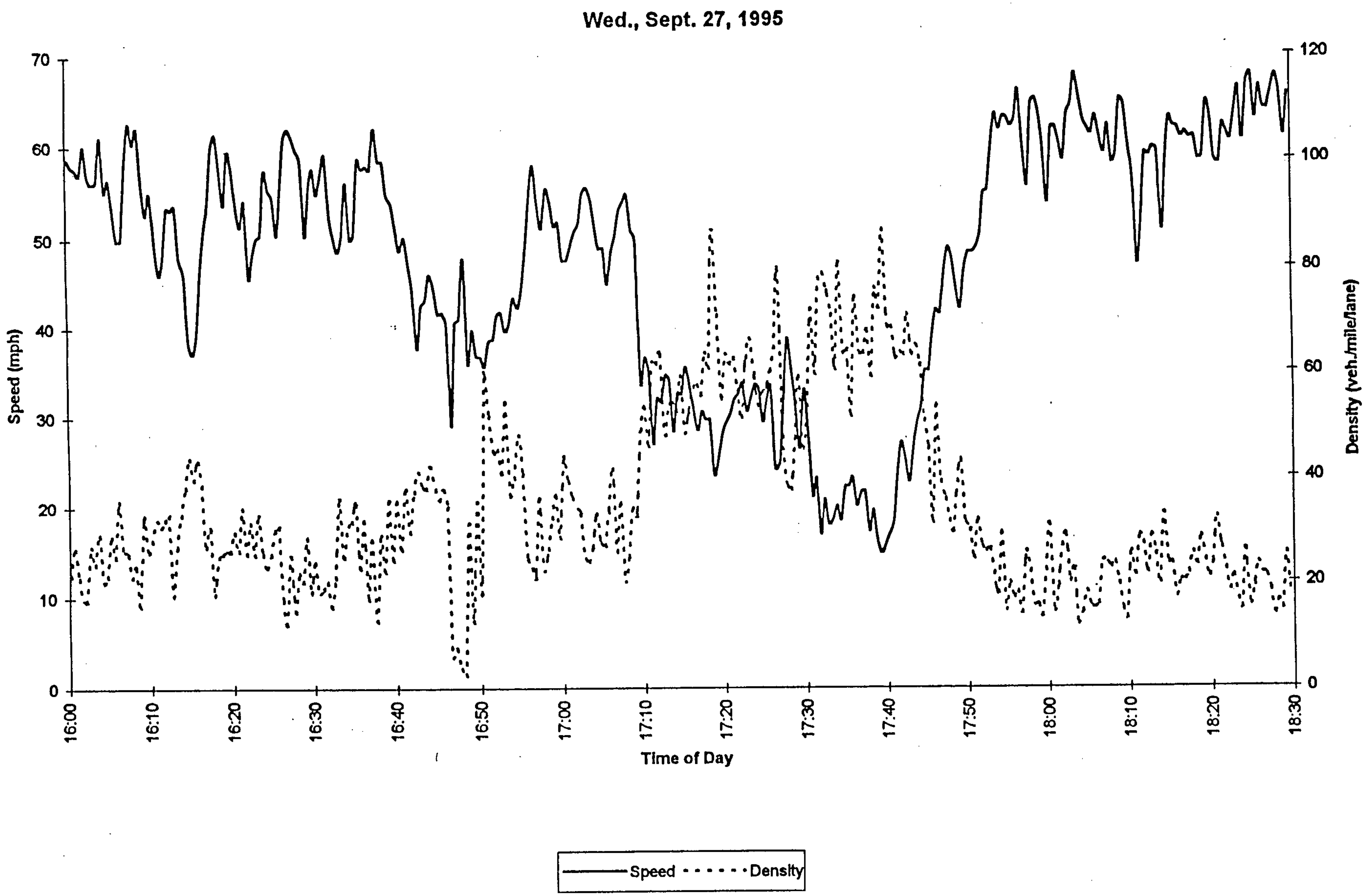


092695 Chart 1

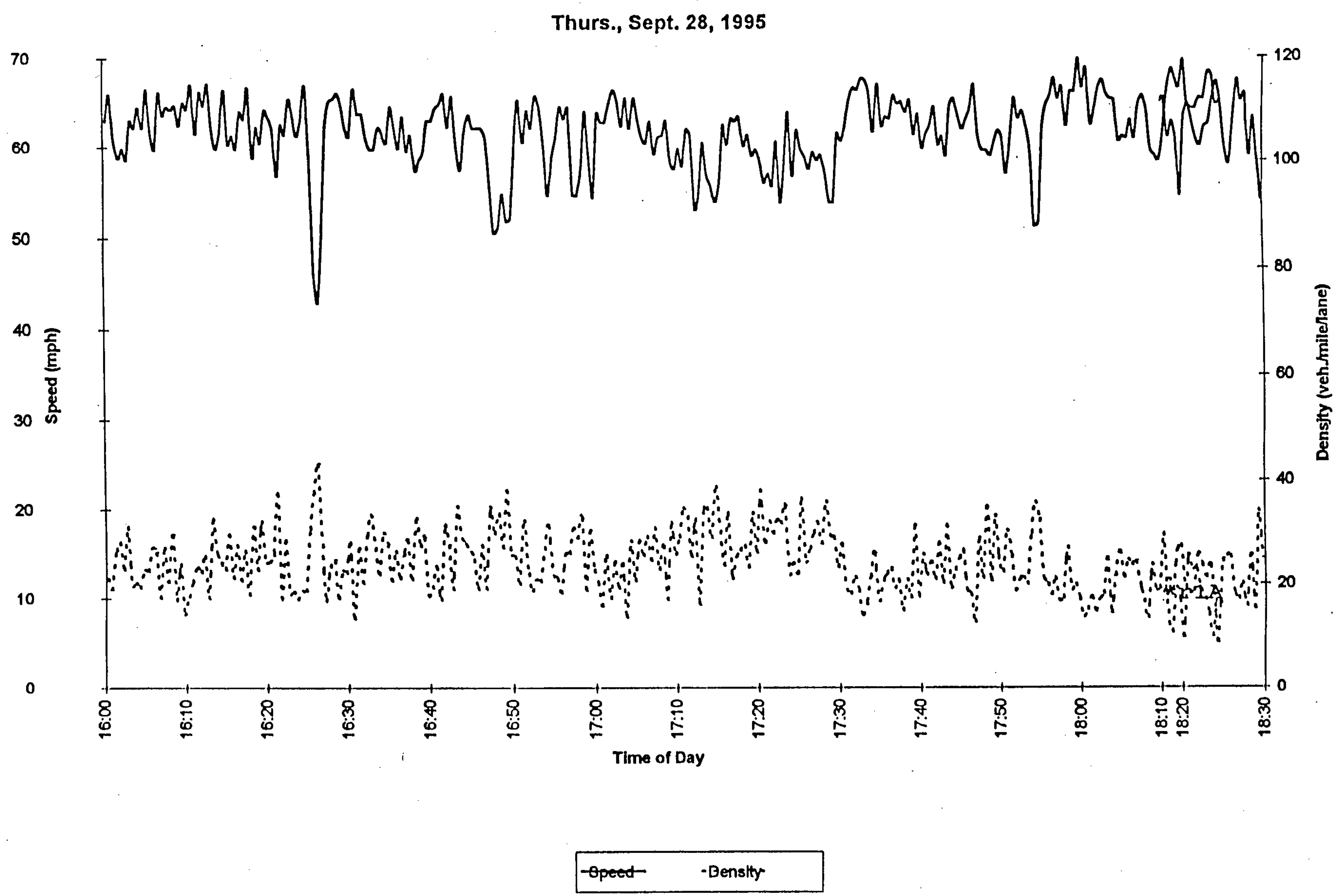
Tues., Sept. 26, 1995



092795 Chart 1



092895 Chart 1



092995 Chart 1