FINAL REPORT

January 31, 2002

Grant Number:
ICAT99-4

Grant Title:
Demonstration of the Use of Fast Charged Electric Ground Support Equipment as a Means of Reducing Airport Emissions

Grantee:
Electric Transportation Engineering Corporation

Conducted under a grant by the California Air Resources Board of the California Environmental Protection Agency

Acknowledgments

This Report was submitted under Innovative Clean Air Technologies grant # 99-4 from the California Air Resources Board.

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Abstract

This document is the final report of work completed under ICAT grant number ICAT99-4, titled "Demonstration of the Use of Fast Charged Electric Ground Support Equipment as a Means of Reducing Airport Emissions".

The purpose of the Project was to promote the reduction of airport emissions from ground support equipment (GSE) by successfully demonstrating an integrated electric GSE solution at a major California airport. Tasks 1-2 encompassed the selection, design and installation of fast charging equipment as well as the placement of 12 battery-powered bag tractors and ancillary equipment at the Sacramento International Airport (SMF) for operation and use by Southwest Airlines. Task 2 also required the development and implementation of a Management Information System for tracking the operation of the equipment for the du ration of the project. Task 3 required operating and monitoring the operation of the equipment, collecting data from both the charger and the electric vehicles.

The project successfully demonstrated that electric ground support equipment can replace fossil-fueled equipment in normal operations at SMF. A system including the charger, batteries, state of charge meter and discharge limiters was developed to allow for normal operations of the ground support equipment. While the charge was seen as a large electric load, its effects on the supply grid's power quality was found to be minimal. Furthermore, the additional cost of electric energy required for the Project was far offset by the fossil-fuel cost savings; a net savings of $1,277 per year. The elimination of fossil-fuel powered equipment resulted in a reduction in emitted pollutants, including 343 tons of CO, 16 tons of HC and 7.4 tons of NOx.

Task 4 was added during the conduct of Tasks 1-3 of the Project and required the procurement of a 13th bag tractor powered by an AC drive system (as different from the DC drives for the original 12 tractors) in addition to laboratory and field testing of sealed lead-acid, golf-cart style battery modules. Task 4 was successfully completed, demonstrating the increased efficiency of the AC drive system. The lighter, lower capacity battery proved its ability to support airport operations in a fast charge environment.

As a result of the successful demonstration of an integrated electric GSE solution at SMF, Southwest Airlines has replaced additional internal combustion equipment at SMF with battery-powered equipment at SMF. In addition, Southwest Airlines has installed similar equipment at the Ontario, California Airport. Furthermore, SMF management has successfully obtained funding to install three systems to service Delta, American and United airlines.

Introduction

This report is the final element of ICAT grant number ICAT99-4, titled “Demonstration of the Use of Fast Charged Electric Ground Support Equipment as a Means of Reducing Airport Emissions”.

Section 1 of this report describes the work performed, data collected and conclusions made for Tasks 1-3 of the Project. Section 2 similarly describes the additional Task 4. Section 3 discusses the Innovative Technology utilized for the Project along with information on commercialization of this Technology.

FINAL REPORT

SECTION 1

Demonstration of the Use of Fast Charged Electric Ground Support Equipment as a Means of Reducing Airport Emissions

TASKS 1-3

I. PROJECT OVERVIEW

A. PROJECT DESCRIPTION

This Project established a fleet of fast charged electric ground support equipment (GSE) for use by Southwest Airlines (SWA) at Sacramento International Airport (SMF). The fleet utilizes the SuperCharge™ energy delivery system developed by Electric Transportation Engineering Corporation (ETEC) and electric bag tractors operated by SWA. This Project fully integrates the electric GSE with SWA management systems, human resources and operating strategies. The participants in the Project believed that a full scale demonstration of fast charged electric GSE at SMF would provide the tangible results necessary for airline companies to accept the use of fast charged electric GSE, eliminating the need for the time and expense required for massive electrical infrastructure upgrades to support conventional electric GSE charging. This Project Report contains the data and information which details the tangible results of this project, as well as specific information relative to electric GSE charging and operation.

B. SYSTEM DESCRIPTION - SuperCharge™

The ETEC SuperCharge™ is a fully integrated battery charging system specifically designed for airport ground support equipment. The SuperCharge™ unit is a single self-contained, temperature controlled enclosure that can be delivered, pre-assembled, to an installation site. Each unit is equipped with four charge ports to which GSE vehicles can be connected for battery charging. The main charger, rated at 33 kW, charges all connected GSE vehicles sequentially. That is, when it has completed the charge on one vehicle, it automatically sequences to the next vehicle until all connected vehicles have been charged. Equalization of batteries is an automatic function of the SuperCharge™, utilizing separate chargers housed within the SuperCharge unit. Equalize charging occurs automatically, on an as-needed basis, after the completion of rapid charging. Equalization frequencies and algorithms are designed to minimize cell grid corrosion, extending battery life. Because equalization is performed by a separate charger, it may proceed concurrent with other equipment receiving a high power charge from the main charger on another charge port.

The SuperCharge™ will typically charge a GSE vehicle discharged from one day of use in one hour or less. This rapid turnaround allows multiple vehicles to be effectively charged throughout the working day. The sequencing capability allows vehicles to be placed on the SuperCharge™ at the end of the workday and charged during the night, keeping the unit working 24 hours per day. With the rapid energy delivery provided by the system, the energy requirements of up to twenty GSE vehicles can be provided by a single SuperCharge™, rotating vehicles on and off of the unit for charging throughout the day and night. By spreading the charging out over the entire 24 hour day, the peak electrical demand resulting from charging activity is reduced by as much as a factor of 10. The rapid turnaround also allows vehicles to be on the tarmac working 23 out of 24 hours in the day. This increases vehicle availability and eliminates the need to have a charging space for each GSE vehicle. This provides a fully integrated energy delivery system for up to twenty GSE vehicles.

Photo of SuperCharge™ Station with three TUG M3A Electric Baggage Tractors connected for charge.

The SuperCharge™ utilizes an access control system to prevent unauthorized use and to provide use records for fleet management. Using the access control system, the unit is capable of recognizing various battery capacities and voltages. The access control system also allows collection and storage of operating data by vehicles using the ETEC Management Information System.

The Management Information System collects and stores battery performance data each time a vehicle is charged. These data are automatically collected from the SuperCharge™ using a master computer at the ETEC home office. The data are then processed to develop information characterizing the performance of the vehicle battery. This information is organized into a series of Internet pages that can be accessed over the Internet by airline personnel using password protected. Each page is designed for use by a specific level of the airline organization. Pages present data on both vehicles (individually and for an operating unit) as well as for chargers (individual, airport and system wide). In addition to this performance data, the Management Information System is designed to provide alert messages when performance parameters are outside predetermined limits, allowing airline management to focus on performance exceptions.

C. TUG M3A BAG TRACTOR

The bag tractors utilized in this Project were M3A Electric tractors manufactured by Stewart & Stevenson (S&S) TUG. These tractors are equipped with Exide SmartHog 80-volt sealed gel batteries with a C/6 rating of 480Ah (Model E120S-9-40 IronClad). The tractors were modified by the installation of a new charge connector isolation box, which includes a high-power charge connector inlet. The tractors were further modified to utilize an over-discharge limit controller, which prevents the operator from over-discharging the batteries. A Red Indicator Lamp was installed on the tractor dashboard to alert operators when the tractor is in an over-discharged condition. The tractors have also been modified to use a Cruising Equipment E-meter for State of Charge indication. One tractor (BTE-06) had a multi-channel data acquisition system installed.

II. PROJECT EVALUATION PARAMETERS

The SuperCharge™ unit is only a portion of the system. To properly evaluate the project's impact from both a charger and GSE perspective, it was necessary to use a variety of performance indicators. While specific metrics were assigned to a number of these indicators, their use was not solely sufficient to evaluate overall project performance. In fact, the use of more subjective criteria was also warranted. The desire of ramp personnel to accept the technology, along with their ability to perform the requisite tasks, must be part of the evaluation. Each of the Evaluation Parameters, as well as the data collected, are presented here.

MANAGEMENT INFORMATION SYSTEM

The Management Information System (MIS) is an automated data collection system designed to obtain, record and store data from each charge event that occurs at the SuperCharge™. The data are then downloaded to the eTec master computer where it is processed, and then uploaded to the eTec website (etecevs.com) for review by authorized individuals. During the course of the Project data were collected for all 12 baggage tractors and the charger. The data were also made available to eTec engineers for additional analysis and review. The parameters monitored include those for both the charger and the tractors. Some of these are described here:

Tractor Parameters

- Date
- Vehicle ID
- Battery ID
- Time vehicle arrives at charger
- Length of time until the vehicle leaves the charger
- Nominal pack voltage of the battery
- Charge reference voltage
- Number of cells in the battery
- Battery Capacity
- Maximum allowed charging current

- Battery type
- Equalizer algorithm number
- Number of fast charge cycles equalization
- Current number of amp hours charged to the battery since equalization
- Current number of fast charge cycles since equalization
- Charge Port vehicle is connected to
- Amount of time vehicle is at the charging station in various modes (equalize charge, fast charge, standby time, etc.)
- Battery temperatures at various times
- Battery voltages at various times
- Number of amp hours returned to the battery during charge
- Charging current at end of charge
- Total number of amp hours returned to the battery
- Charger ID number
- Charge record number

These data points are stored and used to monitor or modify the behavior of the charge profile. They also form the basis for the Tractor parameters displayed in the MIS System. These include:

- Vehicle Type (Mfg, Service Type, etc.)
- Battery Type (Flooded, Gel, Absorbed Glass Mat, etc.)
- Battery Capacity (in Ampere-hours)
- Average % Successful Charges (number of charges allowed to finish without interruption)
- Hours Since Last Charge
- Battery ID (unique battery identifier)
- 10 Day Average Power Charges per Day
- 10-Cycle Average Percent Power Charge Faults (recorded instances where charge cycle was interrupted)
- 60 Day Average Battery Utilization (Average % SOC utilization per day)
- Hours Since Last Power Charge
- Current Cycle Equalization Status (number of charges remaining before equalizing is required)
- 30-Cycle Average Connect Standby Time (average time vehicle has parked at the charger without being connected to the charger)
- 30-Cycle Average Power Charge Standby Time (average time the vehicle has been connected to the charger and waiting to start charging)
- 30-Cycle Average Time on Power Charge (average time on charge while at the charger)
- 30-Cycle Average Disconnect Standby Time (average time vehicle is parked at the charger after being disconnected from the charger following a charge)
- 30-Cycle Average Total Time at Charger (average total time at the charger for each charge cycle; includes both standby connect and disconnect times).

Charger Parameters

These parameters are specific to the charger. They are calculated based upon the data either retrieved or generated during a vehicle's charge activity. This information is available through the MIS system, and includes:

- Data Based Write date (the date of the most recent data base refresh)
- 30-Day Average charges per day (average number of charges per day)
- 30-Day average percent charge faults (average percentage of times the charge cycle was interrupted, either by manual or automatic means)
- 30-Day average percent charge manual termination (average percentage of times the charge was manually interrupted by the operator pushing the Stop button)
- 30-Day average percent full charges (average percentage of times the charger completed its normal charge cycle without interruption)
- 30-Day Average energy per charge per day
- 7-Day average energy per charge per day
- Maximum charger power in the last 7 days
- Maximum charger power in the last 30 days

The MIS displays the some or all of these parameters, depending upon the specific individual's approved Access Level. Project personnel are able to review all of the data points to develop information relative to the Metrics established in the Project Evaluation Plan.

A. CHARGE EFFECTIVENESS

Electric Bag Tractors

The intent of the project was to allow rapid charging of the GSE to maximize vehicle availability on the ramp. To this end, Project participants decided upon a number of metrics to measure the effectiveness of the SuperCharge in maintaining the electric GSE availability. The specific metrics chosen were those that (1) could be monitored and recorded by the SuperCharge system, and (2) could be replicated using the on-board data acquisition system installed on bag tractor BTE-06.[1] Appendix A contains the graphs from each of the individual tractors as recorded by the SuperCharge system. They are arranged by Vehicle Tag Number and presented as follows:

- Total Charges per Day
- Time Between Charge
- Average Charge Time
- Equalize Charge Times
- 10-Day Average Charge Time[2]
- 60-Day Average Charge Time[3]
- Individual Charge Cycle Connect Standby Time[4]
- 10-Cycle Average Connect Standby Time
- Time of Day per Charge
- Ampere-Hours (Ah) Returned per Charge (non-equalize charge)

[1] Data collected from system installed on tractor BTE-06 contains only information relative to the charging events. Additional data, such as drive cycle data, are presented later in the Report.
[2] The 10-Day Average Charge Time is the rolling average of that specific vehicle's time on charge averaged over ten days.
[3] The 60-Day Average Charge Time is the rolling average of that specific vehicle's time on charge averaged over 60 days.
[4] Connect Standby time is the hours and minutes between the time the charge cable was connected to the vehicle and the time when charging actually begins. These graphs are also located in Appendix C.

A. CHARGE EFFECTIVENESS (continued)

SuperCharge™

Data collected for the tractors can be used to generate a great deal of information, but most are specific to the particular tractor. To gauge the effectiveness of the charger, it was necessary to collect similar data for the SuperCharge. These data provide a look at the effectiveness of the SuperCharge as it relates to supporting "on the ramp" operation of the electric GSE. To support these metrics the following information was collected for the SuperCharge and graphed. The graphs are contained in Appendix B in the following order:

- Total Charges per Day, All Vehicles, by Day of the Week
- Total Charges per Day, All Vehicles, by Frequency
- Average Charges per Day, All Vehicles
- Average Time on Charge, by Charge Event
- Charges per Day, Chronologically
- Frequency of Charge Events in One Hour Increments, Time of Day Analysis
- Time Spent on Standby with valid Charge Events
- Time Spent on Standby, with No Charge Event[5]

[5] There were occasions when a vehicle was connected to the charge station but no charge occurred. In most cases these non-charging events resulted from the charge sequence request being terminated by the operator prior to the SuperCharge commencing a charge. These events typically occurred when the operational needs of the bag tractor outweighed the need to charge the tractor.

1. Time To Charge

One measure of success was the amount of time necessary to recharge the vehicle. The use of non-rapid chargers results in charge times that can easily exceed 6 hours. A long charge cycle reduces the efficiency of the equipment, as it is no longer available for service. Reducing the time spent on charge allows the equipment to be placed back into service much quicker, allowing the fleet to operate with a lower population of equipment. The average charge time per day was determined for all of the vehicles charged during any given day, as well as for each individual vehicle in the fleet.

During this Project, the time targeted for recharge was one hour or less. The Average Time on Charge of all charges was 55 minutes. This is the average of all charging events for all baggage tractors that involved the flow of current. The average recharge time for Tractor BTE-06 was 0% longer than the highest of the other eleven tractors and 38% longer than the average for all other tractors.[6]

The Average Time on Charge for each bag tractor is listed in Table 1. However, the average of these values does not equal the average stated previously. Because no two vehicles were charged the same number of times, the average of each of the two subsets is different. [These values do not include equalize charge times.]

TABLE 1

BTE TAG #	SWAir Serial #	AVERAGE CHARGE TIME
BTE01	582	46 minutes
BTE02	588	62 minutes
BTE03	569	55 minutes
BTE04	571	76 minutes
BTE05	580	60 minutes
BTE06	None	76 Minutes
BTE07	586	65 minutes
BTE08	599	52 Minutes
BTE09	581	57 minutes
BTE10	570	64 minutes
BTE11	572	59 minutes
BTE12	583	60 minutes

[6] Data collected from BTE-06 showed that two cells were consistently limiting (e.g., failing), which accounted for the long recharge times The two failed cells were identified early in the project. Because these cells were being protected via the Discharge Current Limiter installed under Task 2.4, it was decided to leave the cells in place and monitor their operation for further degradation. None was noted.

2. Non-Charging Time of Vehicles At The Charge Station

During the project, it became apparent that vehicles were spending more time at the charging station than was required for charging. It was decided to identify these times. Along with the Standby Times contained in Appendix A, a second time frame, Elapsed Time, was determined.

Elapsed Time

Elapsed time is the total amount of time a vehicle is at the charging station, and is independent of the vehicle being connected to the charger. Once the vehicle is parked at the charging station and the vehicle's RFID is read by the charger, the total time the vehicle is at the charging station can be determined. These graphs are presented in order by tractor number (BTE-01 through BTE-12) and are contained in Appendix C.

Composite graphs were also developed. These graphs show the amount of time each vehicle was on charge concurrent with the amount of time the vehicle spent connected to the charge station. While some of the additional time can be attributed to time on standby (see the graphs in Appendix A) as well as time spent connected to the charger overnight, some of the events are considerably longer than either of those two situations can account for. It has not been possible to determine with any degree of certainty the reason for these extended times. These graphs are also included in Appendix C.

B. TRACTOR ENERGY USAGE

The energy usage of the tractor is an important component of the Project. To help determine effectiveness of the electric GSE system as a whole, it was important to monitor tractor operation and energy consumption. To achieve this, a number of tractor parameters were monitored, including average Ampere-hours (Ah) per drive cycle; average time per drive cycle; average time on standby (wait time); and average cycles between charges.

This data was accumulated using an on-board Data Acquisition System (DAQ) installed on Bag Tractor BTE-06. This 30-channel multi-function portable system collected the following data:

- Time-Date Stamp
- Individual Cell Voltages from 25 cells (See cell location map)
- Battery Current
- Battery Temperature

The collected data was reduced to provide the following information, which is included in the Report on Operation of Bag Tractor BTE-06, included in Appendix D. The following graphs are also contained in Appendix D.

- Average Ampere-hours per Discharge Cycle[7]
- Average Ampere-hours per Drive Cycle[8]
- Average Drive Time per Cycle[8]
- Average Number of Drive Cycles Between Charges[8]
- Average Time on Standby[9]

[7] This is defined as the average number of ampere-hours consumed by the tractor between two consecutive charges.

[8] This value was based upon several assumptions, the most important being what constitutes a Drive Cycle. Based upon actual operations at SMF, the specific use duty cycle was determined to be one where the tractor did not sit idle for more than five (5) minutes. Therefore, operations interrupted by more than five minutes of idle time were assumed to be separate use cycles. This allowed a determination of total number of cycles during any given day, and the Project Duration. From this, values associated with an average use cycle were determined.

[9] This value is derived from the Charger Data Set. It represents the time between connecting the vehicle to the SuperCharge and the time the vehicle commences charging. It does not include null events previously described.

C. STATE OF CHARGE (SOC) METER

The SOC meter is installed to provide the operator with an easily recognizable visual indication of the amount of energy remaining until the next charge is required. This is a subjective parameter. No particular data will be recorded; however, comments from operating personnel on the effectiveness of this device will be recorded for review by Project personnel.

In various discussions with both Supervisory and Operating Personnel, the general consensus was that the SOC meter was useful to a point, but when used in conjunction with the Discharge Limit Indicator Lamp, personnel could better understand when the tractor was becoming energy limited. There were several instances when unknown personnel attempted to interface with the meter by utilizing the SET and/or MENU push-buttons on the meter.[10] This resulted in a meter that would not provide displays (active data display is suspended while the meter is being Set or Reset). Because of this, personnel had to rely upon the Discharge Limit Indicator, which in fact provided sufficient information to indicate that a charge was required (this was an expected result, as individuals were not trained in how to use the SET or MENU functions on the meter).

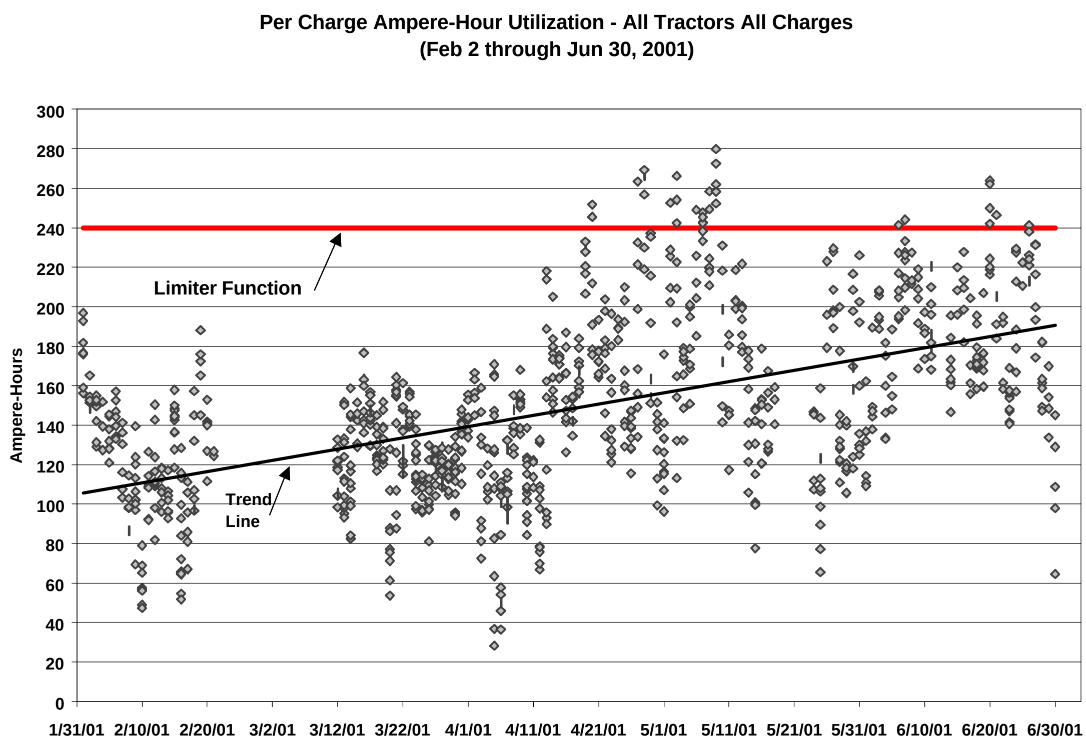
[10] Operating personnel were not trained in how to set the meter. The meter was pre-set by Project Personnel prior to the tractors being delivered. Operating personnel were informed not to attempt any adjustments to the meter, and to use the visual indication only. There were several instances where this guidance was not adhered to. The operation of the bag tractors was not impeded by these instances, other than a lack of indication from the SOC meter. Since the Red Discharge Limit Lamp was the primary datum for identifying a charge was recommended, the loss of meter indication did not provide any impact to the project. GSE maintenance personnel were instructed on how to reset the meter to it’s normal operating condition, and the reported instances decreased to zero.

D. CURRENT OVERDISCHARGE LIMIT DEVICES

A significant contributor to shortened battery life is over-discharge. Vehicles that routinely run the batteries until they are fully depleted will experieince significant reduction in battery life. Information from other airports showed that vehicles would routinely be driven until their batteries were either fully depleted, or depleted to a point where vehicle operation was limited using a step-function in the traction controller.

To ensure the vehicles could be operated continuously without danger of overdischarge or vehicles being placed into mandatory speed-inhibit modes of operation, ETEC designed and installed Current Overdischarge Limit devices. These units were installed into each tractor. By monitoring both battery voltage and current, the limit devices modify the accelerator signal to the controller based upon the state of charge of the battery and the demand rate placed upon the controller. The effect was a modified demand rate, that precluded discharging the battery below a given pack voltage. When the demand rate inhibit function was enabled, the Red CHARGE NOW lamp on the tractor illuminated, notifying the operator that a charge was necessary.

As the Project progressed, charge data show that the Ampere-hour Utilization increased from approximately 106 Ah per day to approximately 191 Ah per day. The Exhibit below shows that along with the increase in utilization operating personnel began to operate the tractors closer to the limiter function, neither overdischarging nor underutilizing the battery. This is seen by the clustering of data points at the right of the graph.



E. AFFECTS ON SYSTEM POWER QUALITY (PQ)

Devices attached to the supply system can impact the quality of power. To ensure that power quality is not adversely impacted, Project personnel have been collecting data from the power supply system with the SuperCharge unit off, operating in stand-by and operating in the charge mode. These Power Quality data have been compiled by SMUD into several individual Reports, all of which are included in Appendix E in their entirety. [The names and phone numbers of the individuals involved in the data collection and reporting have been removed.]

The first report details the results of testing completed on December 7, 2000. During this period, the charger was energized but operating in the idle mode; that is, no vehicles were being charged. The Second Report details the results of testing completed on March 8 through March 13, 2001. During this period, the charger was both operating in the idle mode, and actively charging vehicles. The last report was complied from data taken for the entire Power Section (1EMCCG2) during a 12-hour period on March 14, 2001.

Data indicates there were no significant events during any of the monitoring periods.

F. MANAGEMENT INFORMATION SYSTEM (MIS)

A Management Information System (MIS) was developed for this project. The System is a multi-tier protocol that collects, analyzes and presents information to the customer on the state of the charger and the vehicles being charged. There are a number of specific data points available for trending and evaluation, including number of charges per day, charges per vehicle, time since last charge, interval to next equalize charge, average energy per charge, 10- and 60-day averages for different parameters, and energy throughput.

The data presented to the end user is real-time dependent, and as such is volatile. It changes day to day, as do the rolling average values. Further, the information provided via the MIS is derived from small sub-sets of all the data collected. The information presented in the Report is based upon the MIS capabilities and visible outputs, rather than the specifics of any particular subset.

Pictorial views of the various pages are included in Appendix F.

MIS ACCEPTANCE

During the course of the Project, supervisory personnel were requested to complete surveys in an effort to determine acceptance of the MIS. For a variety of reasons, participation in the survey was less than expected, and insufficient data were returned to generate a position relative to MIS acceptance by operating personnel.[11] Further, since there was so little user interface with the MIS, the data that was collected was not sufficient enough to determine usability of the MIS.

[11] The MIS system can be accessed through the Internet; however, access codes and passwords are required to view the data. Dissemination of access codes and passwords was to be accomplished by Southwest Airlines personnel in accordance with their internal protocols. This activity was apparently not consistently implemented, and not all GSE and Ramp Supervisors were able to access the database. The little feedback received was generally positive. Several modifications were requested, including the ability of Airline personnel to directly access the raw data streams. The ability to control the data streams precludes any potential advantages associated with open access to the data. [Opening access to the data streams would also open access to the Code controlling system operation as well as data collection parameters. ETEC decided not to allow open access to the data streams until such time as the code can be sequestered or sufficiently protected by a firewall. Otherwise, system operating integrity could not be assured.]

G. TECHNOLOGY ACCEPTANCE

Probably the most difficult portion of this project to assess was the acceptance or rejection of the technology by operating personnel. As with all new products, there is a definable life cycle inherent in the adoption and implementation process. However, in the case of a single technology leap coupled with the fact that personnel were not being offered an option for its implementation, there existed a certain probability that a percentage of operating personnel would reject the technology out of hand. This could easily inhibit the Project's effectiveness. [Specifically, a small percentage of personnel becoming staunch non-adopters could have a large percentage impact on the project's success.]

Airport flight operations typically last 18 hours per day. With conventional charging, vehicles are operated until the battery is completely discharged, and then placed on charge. Since conventional chargers have charge cycle duration's lasting 6 to 10 hours, vehicles recharged in this manner typically remain on charge until the following morning, which effectively limits the vehicle to one operation cycle per day. The Supercharge system's PSOC algorithm promotes opportunity charging (less than one hour) allowing vehicles to be returned to service sooner. As such, vehicles are available for multiple discharge cycles per day.

To ensure vehicles were being utilized consistent with the PSOC recharge technology, one method available for determining technology acceptance was to monitor the spread of charge frequency, or how often and at what times of the day vehicles were placed on charge. A histogram was developed from all the charge data which shows the relative times of day vehicles were placed on charge. As expected, charge times were fairly consistent throughout the day, indicating that opportunity charging, the crux of successful fast charging in an airport environment, was effectively implemented. Further, the data showed that this acceptance was voluntary and consistent. This graph is contained in Appendix G.

A second method to evaluate the project was to conduct surveys among operating personnel to gauge the level of acceptance of the project, and more specifically the effectiveness of the Training. [The subjectivity of the surveys made it difficult to accurately assess technology acceptance; this was accomplished using the data collected from the charge station and the tractor BTE-06.] While eTec had hoped to conduct multiple surveys, conducting the surveys in a bargaining unit environment provided sufficient obstacles to repeat sampling. The results are presented relative to the general acceptance of the Project. There was no assessment of understanding of the technology by the operating personnel. Results of the Survey are provided in Table 2. Graphical survey results are contained in Appendix H.

Training

Training programs both impart knowledge and set expectations. The Training Program was originally designed to be provided prior to the eGSE being placed into service. Due to a variety of factors, this did not occur; training did not occur until the project was well under way. This could be responsible for the survey results indicating the use of the charging station, which is reflected in the questions concerning having sufficient time to charge the tractors.

One of the foci of training was the SuperCharge indicating system. This system provides the operators with status of the charger (charging, equalizing, charge complete, standby, etc.). Once the charger was in service, it was determined the original design of the lamps in the indicating system was insufficient for the location. This determination was made with the input of Southwest Airlines operating personnel, who noted both in interviews and in the survey that the indicating lamps were not reliable. ETEC conducted an investigation of the lamps, and determined that the incandescent lamps used to identify the status of the charge ports were not bright enough to be seen in direct sunlight. ETEC redesigned the indicators, replacing the incandescent lamps with long-life high-intensity cluster-LED lamps. While these new lamps provided adequate illumination for all ambient lighting conditions, shortly after their installation these lamps began to experience high failure rates. Further investigation by ETEC determined the lamps were becoming extremely hot (~165°F), which was much higher than the manufacturer's stated design. Working with the lamp manufacturer, new cooler lamps were designed and subsequently installed. The failure rate dropped significantly. ETEC is continuing to review the design of these lamps in an effort to provide better indication to the operating personnel.

During discussions with Southwest Supervisory personnel, it was learned that tractors were routinely left in various states of discharge at locations remote to the charger, they were not returned for charging when the opportunities arise, and they were not routinely charged each day. These same personnel stated there were two main causes for these actions: inability to accurately determine the state of charge using the onboard SOC meter (previously discussed) and the failure of the SuperCharge indicating lamps to accurately depict the status of the tractor's charge operation. This information, coupled with the data collected and the redesign of the indicating lamps, indicate that training should be completed earlier in the implementation process and should be regularly repeated.

Survey Results

It is necessary to provide some background information prior to discussing the survey results. Prior to the implementation of electric baggage tractors at SMF, Southwest Airlines reports that refueling of internal combustion engine tractors was a difficult task. In fact, it became necessary for SWA to designate an individual to be responsible for the fueling of all GSE, to ensure vehicles were adequately fueled. When the eGSE was installed, the task of "fueling" the tractors (with electricity) reverted to the individual operators. This issue was not identified prior to the Project start, and may have led to issues identified in the survey.

The survey was conducted among 70 individuals, including ramp agents and their supervisors. These individuals are responsible for the day-to-day use of the electric bag tractors. The survey was designed to assess the effectiveness of the training, versus the acceptance of the technology. These individuals were also responsible for charging the electric bag tractors on a daily basis. The survey results show that the majority of users did not disagree that the tractors and charge station were easy to use. This is not distracted by the fact that operators would prefer to use gasoline or diesel fueled tractors, as no information was gathered concerning their ease of use.

TABLE 2

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
The electric tractors are easy to use.	5.7%	22.9%	18.6%	25.7%	27.1%
The charging station is easy to use.	20.0%	27.1%	14.3%	22.9%	15.7%
Waiting for a tractor to charge has not kept me from doing my job	30.0%	24.3%	25.7%	8.6%	11.4%
I have enough time to charge a tractor between work assignments	28.6%	27.1%	30.0%	8.6%	5.7%
I prefer using the electric tractors	48.6%	14.3%	22.9%	5.7%	8.6%
I prefer using the gasoline tractors	4.3%	7.1%	18.6%	14.3%	55.7%
I prefer using the diesel tractors	12.9%	7.1%	34.3%	12.9%	32.9%
I do not charge the vehicle until the red "Charge Now" light comes on	12.9%	14.3%	35.7%	17.1%	20.0%

To the questions: “I have enough time to charge a tractor between work assignments.” and “Waiting for a tractor to charge has not kept me from doing my job.” the results indicate that respondents believed the time available to charge was insufficient to support their mission. This perception of the respondents is not supported by the data. Data collected from the charge station shows that on average, the charger conducted approximately 6.5 charges per day with an average charge time of 55 minutes. This is an average total charge time of 5 hours and 55 minutes per day. With this average per tractor charge time of 55 minutes and a population of 12 tractors, the total charge time required is approximately 11 hours per day (~46% of the available charge time). Further, graphical data (Elapsed Time) presented in Appendix C shows that once vehicles were placed on charge, they tended to remain at the charge station for periods much longer than that required for charging. These data show that when placed on charge, the average vehicle remained at the charge station for 4 hours 51 minutes, or more than five times longer than was required for charging. This clearly indicates that there was more than adequate time to charge.

H. FUEL COSTS

One of the advantages of the SuperCharge™ system was the ability to supplant the costs of fossil fuel with the relatively lower costs of electricity. Additionally, since the SuperCharge™ system is designed for continuous use, the potential for high electricity cost due to high demand factors was significantly reduced (but not quantified). [Consecutively charging twelve vehicles throughout the day versus charging twelve vehicles concurrently will significantly reduce demand charges, and resultantly, total costs.] Further, because the efficiency of the SuperCharge™ unit is higher than SCR or FerroResonant units, the amount of energy consumed should have been reduced, which would further reduce the project's electrical energy usage.

There were also the direct benefits of not using fossil fuels on the tarmac. A history of fuel usage of all Southwest Airlines GSE at Sacramento was available for the period starting in May 2000 (approximately 7 months before the electric GSE were placed into service. By utilizing the project start date, the direct cost savings attributable to fossil-fueled GSE were quantified.[12] While no specific target values for reduction in energy costs were assigned, the general trend in the consumption of fuel, and the resultant changes in stabilized costs were determined.

Gasoline Consumption

While gasoline bag tractors were in use at SMF, the average daily consumption of unleaded fuel was approximately 65.2 gallons per day. After the electric tractors were placed into service the average daily consumption of unleaded gasoline decreased to approximately 36.5 gallons per day. This equates to a 45% reduction in consumption of unleaded gasoline by Southwest airlines during the project. From a cost standpoint, the annual reduction in costs to Southwest Airlines associated with not purchasing unleaded gasoline for GSE operations at SMF is approximately $19,100 per year.

Appendix I contains the following graphs:

- Gasoline consumption in Gallons per Day
- Gasoline Cost in Dollars per Month

Electricity Consumption

The consumption in electric energy is another measure of the success of the project. Along with the change in consumption of unleaded gasoline, the electric energy consumption of the charge station was observed. This allowed a comparison of costs to determine the net savings for the user as a result of implementing fast charging. Based upon readings taken from the kWh meter installed on the SuperCharge, during the project the system used approximately 37,155 kWh, with a corresponding total cost of approximately $2,188 (based upon an average price of $0.05889 per kWh). The yearly cost for electricity extrapolates to $365 per tractor, or a cost savings over gasoline of $1,227 per tractor.

[12] The monthly average per gallon costs varied between $1.1069 and $1.4892. An average per gallon fuel cost of $1.3261 per gallon (unloaded) was assumed for all fuel purchases.

To further identify cost savings associated with the Supercharge, a comparison of costs associated with fueling the same number of tractors using conventional charging was completed. Conventional chargers in use by another airline were reviewed. These chargers are rated at 26A/480VAC. Using their rated output, with a nominal charge time of 6 hours per charge, the cost to fuel the same number of tractors at the same kWh rate of $0.05889 was $1,393 per tractor. Since gasoline costs are approximately $1,592 per tractor per year, conventional charging provides a cost saving of $199 per tractor per year. This is significantly higher than the costs associated with operating the tractors using the SuperCharge System.

In conclusion, fueling the electric tractors with the SuperCharge system provides a yearly per tractor cost savings of $1,227 over gasoline and $1,028 over conventional charging.

I. EMITTED POLLUTANT REDUCTION

The indirect benefits of the reduced usage of fossil fuels by Southwest GSE can be determined using information from the Air Quality Management District and the Department of Airports. Using the Model provided by the Federal Aviation Administration in their Inherently Low Emission Airport Vehicle (ILEAV) Program, the reduction in emitted pollutants was calculated. These reductions are presented in Table 3. The values presented are for all 12 electric baggage tractors.

TABLE 3

Pollutant Reduction (based upon replacing 12 gasoline tractors)

	NO_X (tons)	HC (tons)	CO (tons)	PM (tons)	SO_2 (tons)
Project Life[13]	**3.12725**	**6.85356**	**145.09244**	**0.04569**	**0.01015**
Per Year	**7.39200**	**16.20000**	**342.96000**	**0.10800**	**0.02400**

[13] Project Life is the period between the day the tractor(s) were placed in service and June 30, 2001. Tractors were phased in over a 6-week period, commencing in January, 2001.

CONCLUSIONS AND RECOMMENDATIONS

The project scope of work was successfully completed and all project goals were attained. A SuperCharge™ system and twelve bag tractors were installed and operated at Sacramento International Airport (SMF). Data was successfully retrieved from the tractors and charge r to evaluate the effectiveness of the SuperCharge™ system.

The following conclusions concerning the effectiveness of the SuperCharge™ system installed at SMF were developed based on the data collected from operations.

Conclusions:

1. Vehicles are remaining at the charge station for periods (4 hours 51 minutes) that far exceed the time required for charge (0 hours 55 minutes).
2. The SOC meter parameters are settable from the meter face. This is an inherent design feature and cannot be overridden. SOC meter settings are being manipulated by the operators, resulting in the meters providing inaccurate and unreliable outputs. As such, the information the provided by the meters cannot be used by the operators to assess the condition of the vehicle’s battery. Install a plastic shield on stand-offs over the E-meter as EcoStar has done with their glass gauge.
3. Current Limiters installed in the eGSE successfully prevented over discharge of the tractor batteries. The red indicating light is functioning to provide a single point of reference relative to the need to charge. [Battery utilization increased during the project. The scatter graph indicates the current limiter was effective in limiting discharge.] However, when used in conjunction with the SOC meter, the two devices frequently provide the operators with contradictory information. This inhibits the usefulness of the Current Limit Device Indicator (red light).
4. The training program was not implemented in a timely manner, nor was it implemented in an environment that provided the opportunity for direct feedback with Project Personnel. This has resulted in operating personnel forming perceptions about the equipment that are not supported by the data collected.
5. Charge station indicators have not been reliable. Operators believe they cannot accurately determine when a vehicle is charging or finished charging. Their resulting perception is the charger is not reliable, although this is disputed by the data that clearly shows the charge station works correctly. The lack of consistent indication and indication that is easily read may be the underlying reason for vehicles remaining at the charging station for such long periods (Conclusion #1).
6. The charger operated reliably. There were several instances of computer lock-up (control computer) which resulted in the charger not functioning. The control computer was reset, and the charger returned to service without comment. Investigation of the lock up conditions revealed software bugs that were repaired and new software uploaded to the charger via the serial link. There were also three instances when the charger lost its feed from the Motor Control Center (1EMCCG2) which supplies power to the charge station. Once power was restored from the MCC, the charger returned to service.

7. The SuperCharge™ system, including the use of VRLA batteries, partial state of charge /fast charge operation and opportunity charging, operated successfully. Operators accepted opportunity charging, with charge frequency distribution rapidly spreading evenly over the 24-hour day. Partial state of charge/fast charge operation provided less than one hour charging without battery heating or gassing. The single charger proved fully capable of servicing the twelve test tractors, with the average charger duty cycle reaching only 20.2%. The health of the batteries was maintained during the test period; battery utilization (Ah consumed per day) increased from ~106Ah to approximately 191Ah, or an 80% increase during the Project period. There were, however, instances of failed cells as a result of poor manufacturing quality control. Failures included case cracks incurred during battery assembly which were detected by the SuperCharge™ system leakage current monitor.
8. The Management Information System (MIS) was successfully deployed. Use of the MIS by Southwest Airlines was minimal. However, several improvements were identified in the way data are presented to the user.
9. The Data Collection system that provides information and data to the MIS was successfully deployed. The data collected by this system formed the bases for the data in the report. Several inconsistencies within the data reduction software were identified during the Project. These centered on calculation methodologies during the reduction process and have been resolved.
10. Surveys completed among Southwest Airlines personnel provided significant macroscopic information on the operation of the system, as well as its' component parts (charger and tractors).
11. The SuperCharge™ system successfully minimized electrical demand and energy use. To service 12 tractors for Southwest Airlines, electrical demand on the MCC was limited to a maximum of 45.77kW. This compares to a maximum demand of 86.4kW for conventional chargers servicing only four tractors for Delta airlines. The use of electric bag tractors resulted in a $19,100.00 annual fuel savings ($1,592.00/tractor). Electrical energy cost for the test period was only $2,188.00 for 12 tractors, resulting in a $1,227.00/tractor annualized savings with use of the SuperCharge™ system over gasoline tractors, and $1,028.00/tractor in annualized savings over conventional charging.

Recommendations

The following Recommendations are based upon the above conclusions, and are presented using the same numbering sequence.:

1. Time at Station. See Recommendation #5.
2. SOC meters. Remove the SOC meters, or cover with a plastic shield to prevent unauthorized access to meter functions.
3. Current Limiters. Concurrent with Recommendation #2, the Red Charge Now light on the tractor will be the only indicator the operators will have relative to battery

State of Charge. Since the red lamp illuminates when the battery SOC has decreased to the point charging is necessary, and illumination is dependent upon the Current Limit device's determination of SOC and not operator input, this indicator will not provide contradictory information and will in fact, be reliable.

4. The training program. Conduct a second training program, preferably delivered by ETEC project personnel. It should be delivered to the operators in situ, with both hands on and classroom components. Training materials should include the VHS tape developed under Task 1 and new handouts developed specifically for this effort.
5. Charge station indicators have not been reliable. The single most important recommendation involves the indicators on the SuperCharge station. These should be modified to provide consistent indication and then observed to ensure they are providing consistent and reliable information to the operators. To validate this, instrumentation should be procured and installed on Tractor BTE-06. Continue to collect data from this tractor and the Charge Station. Data retrieved should be reviewed against the charge station data for the same time period, and compared to data collected in Tasks 1 through 3. Data should include Time on Charge, Time on Standby, Total Time at the Charge Station and Energy transferred. Additionally, compare the data from these two sets to the data being collected from the MX4 AC Drive tractor being tested under Task 4.
6. The SuperCharge™ is working correctly. Continue to evaluate charge station data, concurrent with Recommendation #5.
7. The Management Information System (MIS). Conduct training with Southwest Airlines supervisory personnel on its use.
8. The Data Collection system. Continue to evaluate the effectiveness of data collection through the reduction of data collected as part of Recommendations #5 and #6.
9. Surveys. Conduct follow-up surveys at the point of training completion (Recommendation #4) and 30 days after completion of training. Add a second set of questions to the survey that includes the AC Drive Tractor being tested as part of Task 4 (TUG MX4 with Eco-Star Drive System).
10. No recommendation.
11. Use of the SuperCharge System results in significant savings over both gasoline tractors and conventionally charged electric GSE.

FINAL REPORT

SECTION 2

Demonstration of the Use of Fast Charged Electric Ground Support Equipment as a Means of Reducing Airport Emissions

TASK 4

I. PROJECT OVERVIEW

A. PROJECT DESCRIPTION

This Project placed an AC Drive baggage tractor with a 78VDC parallel-string battery pack for use by Southwest Airlines (SWA) at Sacramento International Airport (SMF). This tractor fleet utilized the SuperCharge™ energy delivery system developed by Electric Transportation Engineering Corporation (ETEC) and installed under Task 2.0 of this Cooperative Agreement (see Task 1-3 Final Report). This complete system fully integrated the electric GSE with SWA management systems, human resources and operating strategies. The participants in the Project believed that an AC-Drive tractor would allow the use of lighter, more cost-efficient batteries with shorter recharge times. The Project included the following tasks:

- Task 4.1 - An optimization study of golf cart battery capacity and GSE on-board energy requirements to determine a sealed 6-volt golf-cart mono-block that optimizes cost per ampere-hour delivered. Construct and evaluate the structural integrity of a prototype battery pack. Based on successful structural demonstration, fabricate battery packs for performance testing;
- Task 4.2 - An evaluation of leakage current from the prototype battery pack. Optimize the pack design to minimize leakage current.
- Task 4.3 - Conduct laboratory charge/discharge cycling of individual battery modules and assembled battery packs to evaluate battery performance under parallel string, partial state of charge operation.
- Task 4.4 - Install the prototype battery pack in an AC drive tractor. Develop and install instrumentation to monitor battery and tractor performance.
- Task 4.5 - Test the AC drive bag tractor for three months in actual GSE operations and collect data on battery performance.
- Task 4.6 - Prepare and submit a written report detailing the results of Tasks 4.1 to 4.5.

This Project Report, constitutes Task 4.6 and contains the data and information detailing the tangible results of this project, as well as specific information relative to electric GSE charging and operation.

B. OPTIMIZED BATTERY PACK AND BAG TRACTOR

The bag tractor utilized in this Project was an MX4 Electric tractor manufactured by Stewart & Stevenson (S&S) TUG. This tractor is equipped with a 78-VDC battery pack consisting of two series strings of 6V Sonnenschein modules arranged in a parallel configuration. These are sealed lead-acid batteries employing gel-technology with a C/6 rating of 180Ah per string, or 360Ah total available energy. This tractor uses an AC-Drive system developed by EcoStar. The tractor was modified installing a new charge connector isolation box, which included a high-power charge connector inlet. The tractor was further modified to include a 30-channel portable data acquisition system to monitor both charge and discharge operations.

II. PROJECT EVALUATION PARAMETERS

The SuperCharge™ unit is only a portion of the electric GSE system. To properly evaluate the battery's and tractor's capabilities, it was necessary to use a variety of performance indicators. While specific metrics were assigned to a number of these indicators, their use was not solely sufficient to evaluate overall tractor performance. In order to obtain subjective information, verbal feedback from ramp operations personnel, their supervision and maintenance personnel were also collected. Each of the Evaluation Parameters, as well as the data collected, is presented here.

The Management Information System (MIS), installed under Task 2.0, was used to collect charger data. These data were then downloaded to the eTec master computer where they were processed, and then uploaded to the eTec website (etecevs.com) for review by authorized individuals. During the course of the Project, data from the tractor as well as the charger, were collected. The data were reviewed and analyzed by eTec engineers, as well as being uploaded to the eTec website.

Battery and tractor data were collected using an on-board data acquisition system. The acquisition system was comprised of a tractor-mounted 30-channel data recorder. This system recorded individual battery cell voltages, current flows in each of the two parallel strings, and the temperature of one module in each string. These data were processed and reduced to provide specific information on the tractor drive cycles, battery performance during the drive cycles and charge information.

III. PROJECT TASKS

A. TASK 4.1 - BATTERY PACK OPTIMIZATION STUDY

The valve regulated lead acid (VRLA) batteries currently used for GSE vehicles are expensive and typically have high internal resistance requiring extended charge times. To improve both the cost and performance of VRLA batteries used in GSE applications, a study of golf cart battery capacity and GSE on-board energy requirements was completed to determine if a sealed 6-volt golf-cart mono-block could improve cost per ampere-hour delivered, while providing acceptable power and energy for GSE operations. The results of this study are presented in Appendix J.

The study was based upon a review of operating data obtained from various airports where Southwest Airlines operates electric GSE. From this review it was determined that the capacity required to complete a day of electric GSE operation varies from 50 Ah to 150 Ah. Using this requirement, two batteries were selected for evaluation, Sonnenschein Dry-Fit Traction and Deka Dominator. The nominal capacity of these batteries is 180 Ah. At a C1 discharge rate the capacity was determined to be 110 AH. Therefore, parallel strings of batteries were required to achieve the requisite capacity. The battery modules were cycled using partial state of charge/fast charge operation. Based upon the results of this cycling, the Sonnenschein 6-volt, 180-Ah Dry-Fit Traction battery was selected for further evaluation, and a prototype pack fabricated.

The prototype battery pack design utilized a multi-tier rack allowing for the use of parallel strings, doubling the total on-board capacity to 360Ah. Each tier was designed with an air gap sufficient to allow the free movement of inter-cell cables without chafing, and heat rejection of the cells. The pack assembly was also designed to provide sufficient spacing between the pack and the tractor battery-cavity walls to allow the use of non-conducting spacers, which also inhibited unwanted motion of the pack during tractor movement (something not present in most electric bag tractors). The battery pack is shown in Figure 1.

FIGURE 1 - Sonnenschein Battery Pack

The structural integrity of the prototype battery pack using Sonnenschein 6V180 batteries was evaluated by installing the battery pack in a bag tractor operated by Southwest Airlines at Sky Harbor airport in Phoenix, Arizona. The pack was operated for a period of 6 weeks, and then examined for any structural failures (bending, cracking or looseness). No structural problems were found in the battery pack. Based on this successful structural demonstration, additional battery packs were fabricated for performance testing.

B. TASK 4.2 - BATTERY LEAKAGE CURRENTS

An evaluation of leakage current from the prototype battery pack was conducted and the results used to optimize the design of the battery pack to minimize leakage current. This included the use of a multi-tier rack, insulated inter-cell connector cables with individual terminal boots, and sealed-gel, monoblock battery modules. Each tier has sufficient air gap to allow free movement of cables and heat rejection of the cells. The pack assembly was also designed to provide sufficient spacing between the pack and the tractor battery cavity walls to allow the use of non-conducting spacers, which also inhibited unwanted motion of the pack during tractor movement. A report detailing the results of the leakage current study is included as Appendix K.

C. TASK 4.3 - BATTERY CYCLING

To verify that the Sonnenschein batteries would provide the required cycle life to support operation on the ramp, laboratory charge/discharge cycling of individual battery modules was conducted. Cycling was conducted using a discharge cycle developed from actual electric GSE discharge data. The results of this cycling are presented in Appendix J. Based upon cycling results, it is expected that the Dry-Fit Traction modules will provide 800 days of operation in GSE duty. This is comparable with expectations for the industrial 2-volt VRLA cells currently in use. Therefore, further testing of the Dry-Fit Traction batteries was conducted by cycling of assembled battery packs.

Cycling of assembled packs allowed ETEC to validate operation of the charge algorithm for parallel string operation and determine if differential heating effects would cause problems with unequal charging of battery strings and modules. The battery pack cycling reports is included in Appendix L. The pack cycling showed no problems with unequal charging between strings and modules, and no problems with differential module heating.

In addition to cycling of a new battery pack to determine acceptability of the Sonnenschein Dry-Fit Traction battery for GSE operation, battery packs were placed in actual operation to determine pack life. A pack in service for 18 months was returned to the laboratory for evaluation and found to be at 100% of nominal C1 capacity.

D. TASK 4.4 - EQUIPMENT DEVELOPMENT

Because the Sonnenschein Dry-Fit Traction battery pack (with parallel strings) provides less than the 150 Ah daily maximum requirement for operation of electric GSE determined in Task 4.1, the prototype battery pack was installed in a bag tractor utilizing an AC drive system. It was anticipated that the AC drive system would supply a substantial increase in energy efficiency over a traditional DC drive system, offsetting the capacity deficit of the prototype battery pack. A TUG brand model MX4 bag tractor utilizing an AC drive supplied by EcoStar was chosen for the project. A prototype battery pack was installed and a 30-channel portable data acquisition system was installed to monitor both charge and discharge operations as shown in Figure 2.

To ensure that the prototype battery pack was not over discharged, the AC drive was tuned for use with the prototype battery to limit discharge to no less than 30% state of charge.

FIGURE 2 - TUG MX4 Bag Tractor

E. TASK 4.5 - PERFORMANCE TESTING

The AC drive bag tractor was field tested for three months in actual GSE operations. During this operation, data was collected on battery performance to validate the design assumptions. The data and results of this performance testing are discussed in Section IV of this report.

IV. PROJECT DATA

To assess the effectiveness of the prototype battery and the AC Drive system, it was necessary to evaluate several independent parameters. Data were collected from the charger and the tractor, and performance information developed for both the AC drive tractor and the prototype Sonnenschein Dry-Fit Traction battery.

A. CHARGE EFFECTIVENESS

Electric Bag Tractors

The intent of the project was to validate the use of smaller, lighter-weight battery modules in a tractor using an AC Drive System. [Most, if not all, eGSE at airports use a DC drive system with large, heavy batteries.] Along with allowing rapid charging of the battery to maximize vehicle availability on the ramp, these batteries resulted in a lighter-weight vehicle with better handling characteristics with virtually no loss in payload capability. To ensure vehicle operation was properly evaluated, a number of metrics to measure the effectiveness of the SuperCharge system to maintain the electric GSE availability were used. The specific metrics chosen were those that (1) could be monitored and recorded by the SuperCharge system, and (2) could be replicated using the on-board data acquisition system installed on the MX4 tractor. Appendix M contains the graphs from the MX4 as recorded by the SuperCharge system. They are presented as follows:

- Total Charges per Day
- Average Charge Time
- 10-Day Average Charge Time[1]
- Time of Day per Charge
- Ampere-Hours (Ah) Returned per Charge (non-equalize charge)

SuperCharge™ System

Data collected for the MX4 generated a significant amount of information. To gauge the effectiveness of the charger relative to the MX4 versus a standard M3A, it was necessary to collect similar data for the SuperCharge system. These data provided a look at the effectiveness of the SuperCharge system as it related to supporting operation of the GSE. To support this the following information was collected for the SuperCharge system and graphed. The graphs are contained in Appendix N in the following order:

- Frequency of Charges per Day, MX4
- Total Charges per Day, by Frequency
- Average Charges per Day, MX4
- Average Time on Charge, by Charge Event
- Charges per Day, Chronologically
- Frequency of Charge Events in One Hour Increments, Time of Day Analysis

Time To Charge

During this Project, the time targeted for recharge was one hour or less. The Average Time on Charge for the MX4 was 19 minutes 51 seconds. This is the average of all charging events for the MX4 that involved the flow of current. The average recharge time for tractors evaluated under Task 3 was 55 minutes. The MX4 recharge time was approximately 64% less than eGSE baggage tractors using the larger 480Ah battery packs.

B. TRACTOR ENERGY USAGE

The energy usage of the tractor is an important component of the Project. To help determine effectiveness of the MX4 tractor relative to other eGSE as a whole, it was important to

[1] The 10-Day Average Charge Time is the rolling average of that specific vehicle's time on charge averaged over ten days.

monitor tractor operation and energy consumption. To achieve this, a number of tractor parameters were monitored, including average Ampere-hours (Ah) per drive cycle; average time per drive cycle; and average cycles between charges.

These data were accumulated using an on-board Data Acquisition System (DAQ) installed on the rear deck of the MX4 tractor. This 30-channel multi-function portable system collected the following data:

- Time-Date Stamp
- Individual Cell Voltages from 26 cells (See cell location map)
- Battery Current in each string
- Battery Temperature in each string

The collected data were reduced and graphed to provide the following information, which is included as Appendix O:

- Average Drive Time per Cycle
- Average Number of Drive Cycles per Day
- Average Ampere-hours per Drive Cycle[2]
- Average Time on Standby[3]

C. DETAILED TRACTOR STUDY

Appendix P contains a report detailing the specific energy consumption and usage of the MX4 tractor for the month of September. This report contains expanded data for the tractor, including average and specific energies consumed during drive cycles, times on charge and other data.

D. MONTHLY SUMMARIES

Appendix Q contains summaries for each month data were collected from the MX4 tractor. These summaries include the specific number of drive cycles per day, the amount of energy consumed, energy regenerated by the tractor during operation and the net energy consumed by the tractor. Monthly averages are also included.

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[2] This value was based upon several assumptions, the most important being what constitutes a Drive Cycle. Based upon actual operations at SMF, the specific use duty cycle was determined to be one where the tractor did not sit idle for more than five (5) minutes. Therefore, operations interrupted by more than five minutes of idle time were assumed to be separate use cycles. This allowed a determination of total number of cycles during any given day, and for the Project Duration. From this, values associated with an average use cycle were determined.

[3] This value is derived from the Charger Data Set. It represents the time between connecting the vehicle to the SuperCharge station and the time the vehicle commenced charging. It does not include null events previously described.

V. CONCLUSIONS AND RECOMMENDATIONS

The project scope of work was successfully completed and all project goals were attained. The MX4 tractor was installed and operated by Southwest Airlines at Sacramento International Airport (SMF). Data were successfully retrieved from the tractors and charger to evaluate the effectiveness of the MX4 tractor.

The following conclusions concerning the effectiveness of the MX4 tractor used in conjunction with the SuperCharge system installed at SMF were developed based on the data collected from operations.

A. Conclusions:

1. The use of 6-volt monoblock modules provides sufficient energy and power to support airport bag tractor operations. The reduced weight of the tested configuration (the battery pack weighs about 1,000 pounds less than a standard GSE battery) should reduce maintenance costs for the tractor relative to brake pads, wheels and tires. [Southwest personnel at SMF stated they did not have to change any tires on the MX4, while tire changeout on the M3As with the heavier battery packs were routine.]

   The AC Drive System provides operating characteristics that easily meet the requirements of extended operations in an airport ramp environment. The system is responsive and energy-conservative while still providing adequate tow capabilities necessary for operation at Sacramento International Airport. [SMF is a relatively flat facility without steep grades or long distances. Use at facilities with long, steep grades will require additional testing and evaluation.]

2. Cycling of the Sonnenschein Dry-Fit Traction battery showed the battery will provide life that is consistent with the larger, heavier batteries presently in use with most electric GSE without the need for frequent recharging.

3. Operations personnel used the MX4 tractor frequently. In fact, the MX4 averaged more drive cycles per day than any other eGSE at SMF. Because the MX4 is lighter and slightly larger, it isn’t possible to objectively determine the basis for this more frequent operation; however, the MX4 was generally viewed by operating personnel in a positive light.

B. Recommendations:

1. Implement the use of lower-capacity, lighter weight battery packs in electric GSE.

2. Current Limiters. Current limiting schemes or devices can and should be employed wherever possible. Other than reduced power operation, the SOC meter provides the operators with their only means of determining when a charge is required. As such, the SOC meter should be set to provide full scale deflection at less than full discharge of the battery (e.g., that is, the meter should indicate 0% SOC when the battery has a remaining capacity of approximately 30%). This will ensure the battery has sufficient energy reserve and is not damaged due to repeated over-discharge events. When used together they will provide sufficient margin to limit battery over-discharge events while ensuring the tractor has sufficient energy to complete its assigned mission. Because ramp personnel have such a high reliance upon this indication for determining when a charge is required, additional research into indication schemes should be conducted.

FINAL REPORT

SECTION 3

Innovative Technology and
Commercialization

INNOVATIVE TECHNOLOGY

Introduction

This Project established a fleet of fast charged electric ground support equipment (GSE) for use by Southwest Airlines (SWA) at Sacramento International Airport (SMF). The fleet utilized the fast charge SuperCharge System developed by Electric Transportation Engineering Corporation (eTec) and electric bag tractors operated by SWA. This Project fully integrated the electric GSE with SWA management systems, human resources and operating strategies. The participants in the Project believe that a full scale demonstration of fast charged electric GSE at SMF will provide the tangible results necessary for airline companies to accept the use of fast charged electric GSE, eliminating the need for the time and expense required for massive electrical infrastructure upgrades to support conventional electric GSE charging and reducing the barriers to adoption of electric GSE with its concomitant air quality benefits..

Technology

The eTec SuperCharge™ System is a fully integrated battery charging system specifically designed for airport ground support equipment. The SuperCharge System is contained in a single, temperature controlled enclosure that can be delivered, pre-assembled, to an installation site. Exterior color and finish may be selected to match the airport environment.

Each SuperCharge System is equipped with four charge ports to which GSE vehicles can be connected for battery charging. The main SuperCharge System charger, rated at 33 kW, charges all GSE vehicle connected to a SuperCharge System port sequentially. That is, when it has completed the charge on one vehicle, it automatically sequences to the next vehicle until all connected vehicles have been charged. Equalization of batteries is an automatic function of the SuperCharge System. Equalization charging occurs automatically after the completion of rapid charging. Equalization frequencies and algorithms are designed to minimize cell grid corrosion, extending battery life. All SuperCharge System ports are capable of performing equalizing charges. Equalization is performed by a separate charger and may proceed concurrently with other equipment receiving a high-power charge from the main charger on another charge port.

The SuperCharge System will typically charge a GSE vehicle discharged from one day of use in one hour or less. This rapid turnaround allows multiple vehicles to be effectively charged throughout the working day. The sequencing capability allows vehicles to be placed on the SuperCharge System at the end of the work day to be charged during the night, keeping the SuperCharge System working 24 hours per day. With the rapid energy delivery provided by the SuperCharge System, the energy requirements of up to twenty GSE vehicles can be provided by a single SuperCharge System, rotating vehicles on and off of the SuperCharge System for charging throughout the day and night. By spreading the charging out over the entire 24 hour day, the peak electrical demand resulting from charging activity is reduced by as much as a factor of 10. This allows a significant savings in the cost of wire, circuit breaker, transformers and switchgear from that which would typically be required for conventional charging. The rapid turnaround also allows vehicles to be on the tarmac working 23 out of 24 hours in the day. This increases vehicle availability and eliminates the need to have a charging space for each GSE vehicle. With reduced electrical infrastructure and space requirements and modular design, the SuperCharge System is ideally suited to retrofit electric GSE at existing airports. The SuperCharge

System can often be powered off existing electrical circuits and placed in a space only 8' X 24'. This provides a fully integrated energy delivery system for up to twenty GSE vehicles.

The SuperCharge System uses the SuperCharge protocol combining rapid charging and partial state of charge operation to turn vehicles around quickly during charge, yet maintain excellent battery life. The charge protocols eliminate the destructive battery overcharging and gassing common with conventional ferroresonant and SCR chargers. This reduction in overcharge reduces gassing (with its collateral vehicle corrosion) and water use (with its increased maintenance requirements) in flooded batteries. It also allows the use of sealed gel electrolyte and absorbed glass mat batteries, achieving true maintenance-free and odor-free operation. By eliminating overcharge, the efficiency of the SuperCharge System is increased significantly over that of conventional chargers. This increase in efficiency can result in significant savings in energy costs over conventional chargers

The SuperCharge System utilizes an access control system to prevent unauthorized use and to provide use records for fleet management. Using the access control system, the SuperCharge System is capable of recognizing various battery capacities, voltages and types (e.g. flooded vs. gel). This feature allows a single SuperCharge System to be the energy supply device for multiple types of GSE vehicles and eliminates the need to install a new (and often different) charger each time a new electric vehicle is added to the GSE fleet. The access control system also allows collection and storage of operating data by vehicle using the eTec Management Information System.

The Management Information System collects and stores battery performance data each time a vehicle is charged. These data are automatically collected from the SuperCharge System using a master computer at the eTec home office. Once collected the data are processed using algorithms created by eTec to develop information characterizing the performance of the vehicle battery. This information is organized into a series of internet pages that can be accessed by password from the internet. Each page is designed for use by a specific level of the airline organization. Pages present data on both vehicles (individually and for an operating unit) as well as for chargers (individual, airport and system wide). In addition to this performance data, the Management Information System provides alert messages when performance parameters are outside predetermined limits, allowing airline management to focus on performance exceptions. This is particularly important with the use of sealed batteries, as they are relatively intolerant of over-discharge and over-charge

Southwest Airlines believes that the use of sealed batteries in airport environments is critical to personnel safety, environmental compliance and flexible operating strategies. The energy delivery system proposed is particularly well suited to charging sealed batteries as it uses an extremely sophisticated algorithm to protect batteries from over-charge. However, protecting the batteries from over-discharge is not a function within the control of the charger. Over-discharge protection must be resident on the GSE vehicles in the form of a discharge limiter that prevents over-discharge.

To assure that the sealed batteries proposed for SMF were not over-discharged, a discharge limiter that accurately limits battery discharge by reducing vehicle speed and functionality when a pre-determined battery state-of-charge is reached was designed and installed. In addition, a training module was developed for GSE operators to describe how the fast charge energy delivery system is designed to operate and to stress the deleterious effects of over-discharging the batteries. In combination, eTec and SWA believe these actions will significantly reduce and perhaps eliminate episodes of battery over-discharge.

By integrating the fast charge energy delivery system with a Management Information System, incorporating improved state-of-charge and battery discharge limiting hardware, and utilizing sealed propulsion batteries, SMF was the first airport to address all of the known issues with introducing electric GSE

Results

The project successfully replaced twelve gasoline fueled bag tractors with electric tractors. This resulted in the following annual reductions in air emissions calculated using the Federal Aviation Administration's ILEAV Program model.

EMISSION REDUCTIONS FOR 12 BAG TRACTORS AT SMF

	***NO_x* (tons)**	***HC* (tons)**	***CO* (tons)**	***PM* (tons)**	***SO_2* (tons)**
Annual Emission Reduction	7.392	16.20	342.9	0.108	0.024

Additionally, the project has resulted in Southwest Airlines adding electric pushback tractors, lavatory trucks and belt loaders to its fleet of vehicles at SMF.

Conclusion

Successful demonstration of an integrated approach to electric GSE was critical to its adoption by airlines. By providing a clear path for resolving issues surrounding electrical infrastructure requirements, space requirements, sealed batteries, over-discharge, training and management information, the expansion of electric GSE has been accelerated within Southwest Airlines and the airline industry. Additional equipment suppliers have entered the market, indicating a perception of potential market growth and most major airlines now consider fast charging as the appropriate way to implement electric GSE.

Commercialization

As a result of the successful project results, the SuperCharge system for electric GSE is currently offered as a commercial product. Marketing efforts for the Supercharge system include a web site at www.etecevs.com and various collateral materials and recent advertising in an industry trade magazine (Figure 1) and a sales brochure (Figure 2). Additional sales of the charge system have been made in California at Ontario Airport for Southwest Airlines. Sales outside California include Houston Hobby Airport and Dallas Love Field.

FIGURE 1 - Supercharge System Trade Advertising

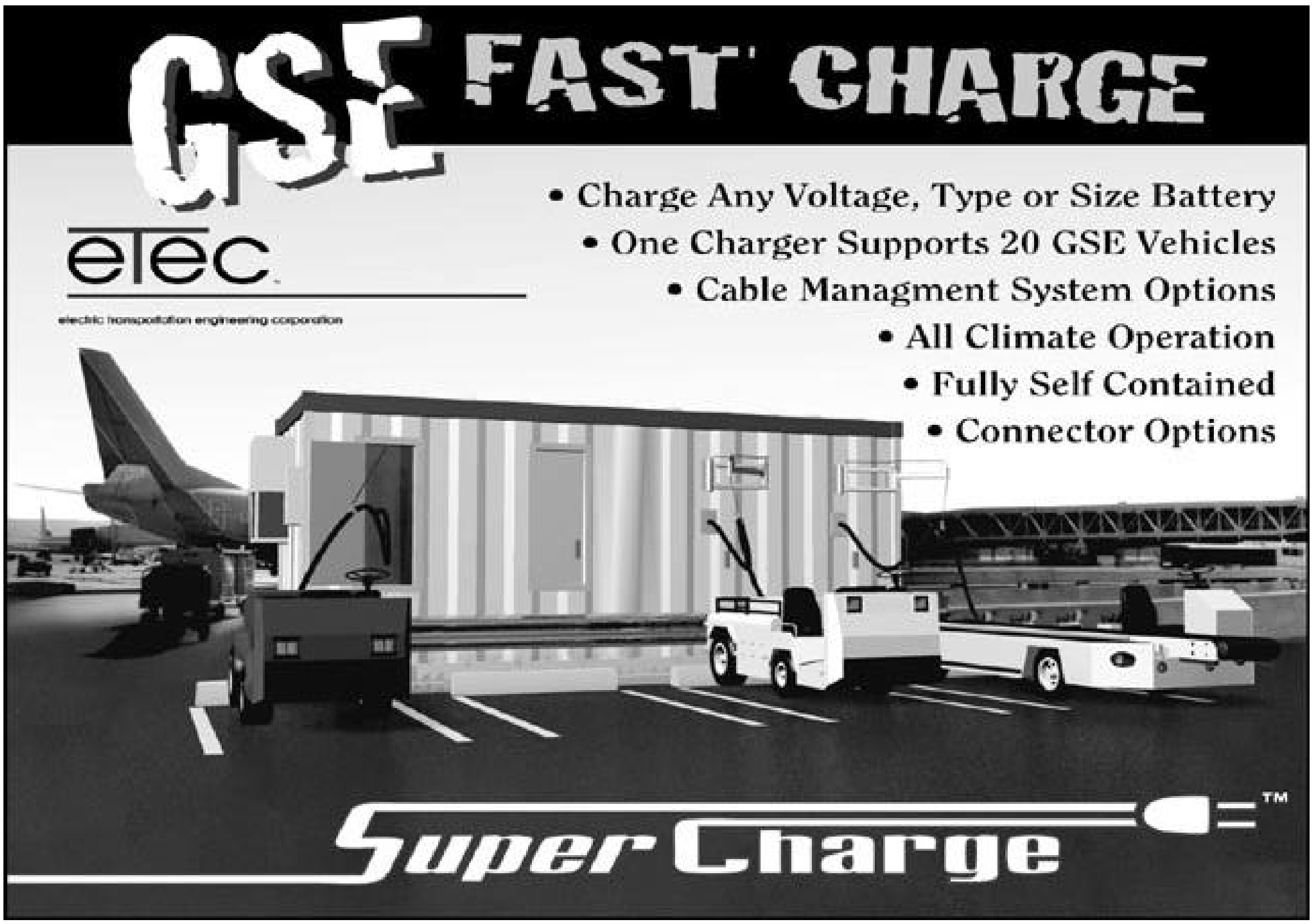
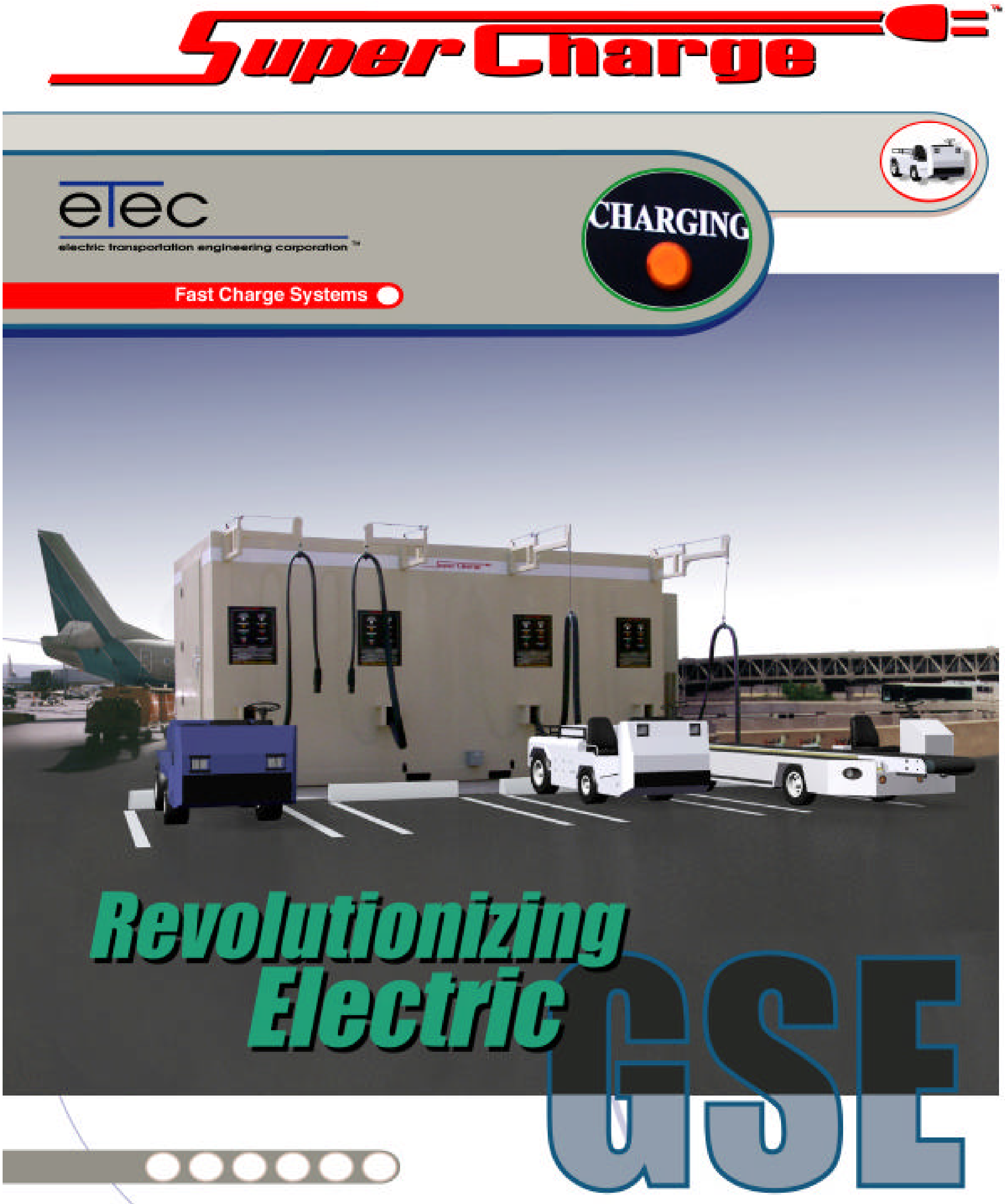
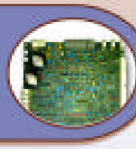


FIGURE 2 – SuperCharge™ System Sales Brochure



eTec
electric transportation engineering corporation™



Cost Savings

The SuperCharge system revolutionizes charging on the ramp:

- Opportunity charging throughout the day reduces peak electrical demand resulting from charging activity - reductions of 80% are typical.
- Reduced electrical demand allows less electrical infrastructure to be installed to support charging - significant savings result.
- Increased operational flexibility improves GSE equipment availability.
- One SuperCharge system meets all ramp charging needs from golf carts to pushbacks - never install another charger

Cost Comparison

Cost Category	Conventional Chargers	SuperCharge System
Number of GSE Units	40	40
Chargers Required	40	2
ELECTRICAL INFRASTRUCTURE COST		
Charger Breaker Ampere Rating	25	100
Total Amperes Required	1000	200
Electrical Hardware Cost/kVA (1)	$150	$150
Electrical Installation Cost/kVA (1)	$100	$100
Total Cost to Supply Ampere Requirement	$208,300	$41,700
SPACE REQUIREMENTS		
Linear Feet Required/GSE Unit	6	6
Linear Feet Required/Charger	6	24
Total Linear Feet Required	240	48

(1) 1 kVA = 1.2 A @ 480 VAC 3ph

Design Benefits

The SuperCharge system is specifically designed to retrofit electric GSE at existing airports:

- Reduced electrical infrastructure requirements - the SuperCharger can often be powered off existing electrical circuits.
- Reduced space requirements and modular design - only 8' X 18' is required for twenty tractors.
- Extremely low harmonic distortion - easily meeting IEEE 519 requirements.
- Rated for outdoor electric vehicle use - meeting all safety requirements for installation anywhere on the ramp.

Operational Benefits

The SuperCharge system provides great operational flexibility including:

- Only the patented SuperCharge algorithm maximizes charge rate without battery overcharging and overheating.
- The SuperCharge system charges all electric vehicles on the ramp - any battery voltage, size or type can be charged from one SuperCharge system.
- The cable management system allows quick and easy connection of vehicles for charge, keeps connectors off the ground for safety and long life, and will breakaway without damage.
- Only the SuperCharge system is proven on the ramp to assure reliable operation - over 98% availability in GSE use.
- Charge times of one hour or less increase vehicle availability by 30% over conventional charging - one hour on charge, twenty-three hours available for work.
- No need to have a charge location for each vehicle - one SuperCharge system charges up to twenty electric vehicles reducing charging space requirements by 80%.

www.etectevs.com

The ETEC SuperCharge system is a fully integrated battery charging system specifically designed for airport ground support equipment. The SuperCharge system revolutionizes charging on the ramp by applying the advanced SuperCharge battery charging algorithm to reduce charge times to one hour or less. With reduced charge times, vehicles can be charged conveniently throughout the day, whenever the battery requires charging. The SuperCharge system allows significant reductions in electric power infrastructure, electrical demand and physical space required for charging, thereby reducing cost and increasing operational flexibility for GSE operators. Using the SuperCharge Information System, the system also assists with management of the electric GSE fleet, assuring that batteries are maintained in excellent condition for increased reliability and reduced cost.

Advanced Charge Protocol: the SuperCharge system combines rapid charging and partial state of charge operation to charge vehicles quickly, yet maintain excellent battery life. The patented SuperCharge battery charging algorithm eliminates destructive battery overcharging common with conventional ferro-resonant and SCR chargers as well as with other systems claiming to be "*fast chargers*". The reduction in overcharge, reduces gassing (with its collateral vehicle corrosion) and water use (with its increased maintenance requirements) in flooded batteries. It also allows the use of sealed gel electrolyte and absorbed glass mat batteries, achieving true maintenance free and odor free operation. By eliminating overcharge, the efficiency of the SuperCharge system is increased significantly over that of conventional chargers. This increase in efficiency can result in a 50% savings in energy costs over conventional chargers.

Charging: The system is equipped with four charge ports to which GSE vehicles can be connected for battery charging. The main charger is rated at 33kW. The system will typically charge a GSE vehicle, discharged from one day of use, in one hour or less. This rapid turnaround allows multiple vehicles to be charged throughout the working day. With the rapid energy transfer provided by the main charger, the energy requirements of up to twenty GSE vehicles can be provided by a single SuperCharge system, rotating vehicles on and off of the system for opportunity charging throughout the day.

Sequencing: Sequencing allows vehicles to be placed on the system at the end of the workday to be charged at night, keeping the SuperCharge system working 24 hours per day. When charging is complete on one vehicle, the system automatically sequences to the next vehicle until all connected vehicles have been charged.

Equalizing: This is an automatic function of the SuperCharge system. Equalization charging occurs automatically after the completion of fast charging. Equalization frequencies and algorithms are controlled by the SuperCharge system and are designed to minimize cell grid corrosion, extending battery life. All SuperCharge sequencing ports are capable of performing equalizing charges.

Access Control: Using the access control system, the SuperCharger is capable of recognizing various battery capacities, voltages and types (e.g. flooded vs. gel). This feature allows a single system to be the energy supply device for multiple types of GSE vehicles and eliminates the need to install a new (and often different) charger each time a new vehicle is added to the GSE fleet. The access system also allows each GSE vehicle to be tracked individually and information on battery health and vehicle operation provided through the SuperCharge Information System.

SuperCharge Information System: The SuperCharge Information System collects and stores battery performance data each time a vehicle is charged. Data is automatically collected from the SuperCharge system using a master computer at the ETEC home office. Once collected, the data is processed using proprietary algorithms to develop information characterizing the performance of the vehicle battery. This information is organized into a series of Internet pages that can be accessed, with a password, from the Internet anywhere in the world. Each page is designed for use by a specific level of airline management. Pages present data on the vehicles (individually and for an operating unit) as well as for the chargers (individual, airport and system wide). In addition to this performance data, the SuperCharge Information System provides alert messages when performance parameters are outside safe limits, allowing airline management to focus on performance exceptions. This is particularly valuable with the use of sealed batteries.

eTec

electric transportation engineering corporation ™

- Simple operator interface
- Each vehicle uniquely identified
- Charge fault indication
- Automatic start & stop

- Patented supercharge algorithm
- Charge rate adjusts once per second
- Charge at maximum battery capability
- Never overcharge a battery
- Minimize battery heat generation

- Ergonometric cable handling
- Self retracting and stowing
- Withstands GSE abuse
- Connector never touches the ground
- Breakaway eliminates damage

- Single 480 VAC connector
- Power quality meets IEEE519
- Continuous ground fault monitoring
- Built to UL electric vehicle requirements
- Rated for outdoor installation

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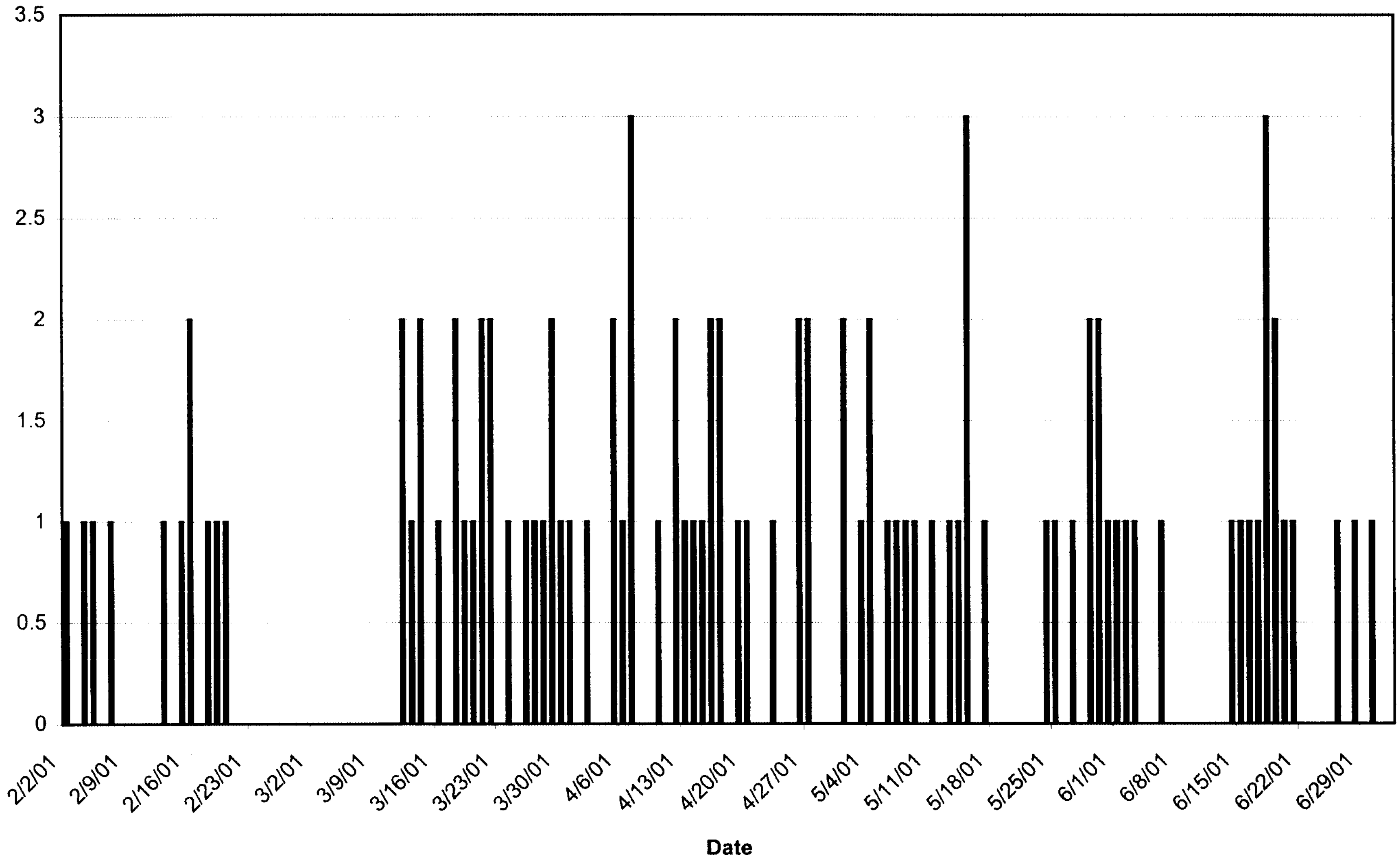
APPENDIX A

CHARGE DATA ELECTRIC BAG TRACTORS

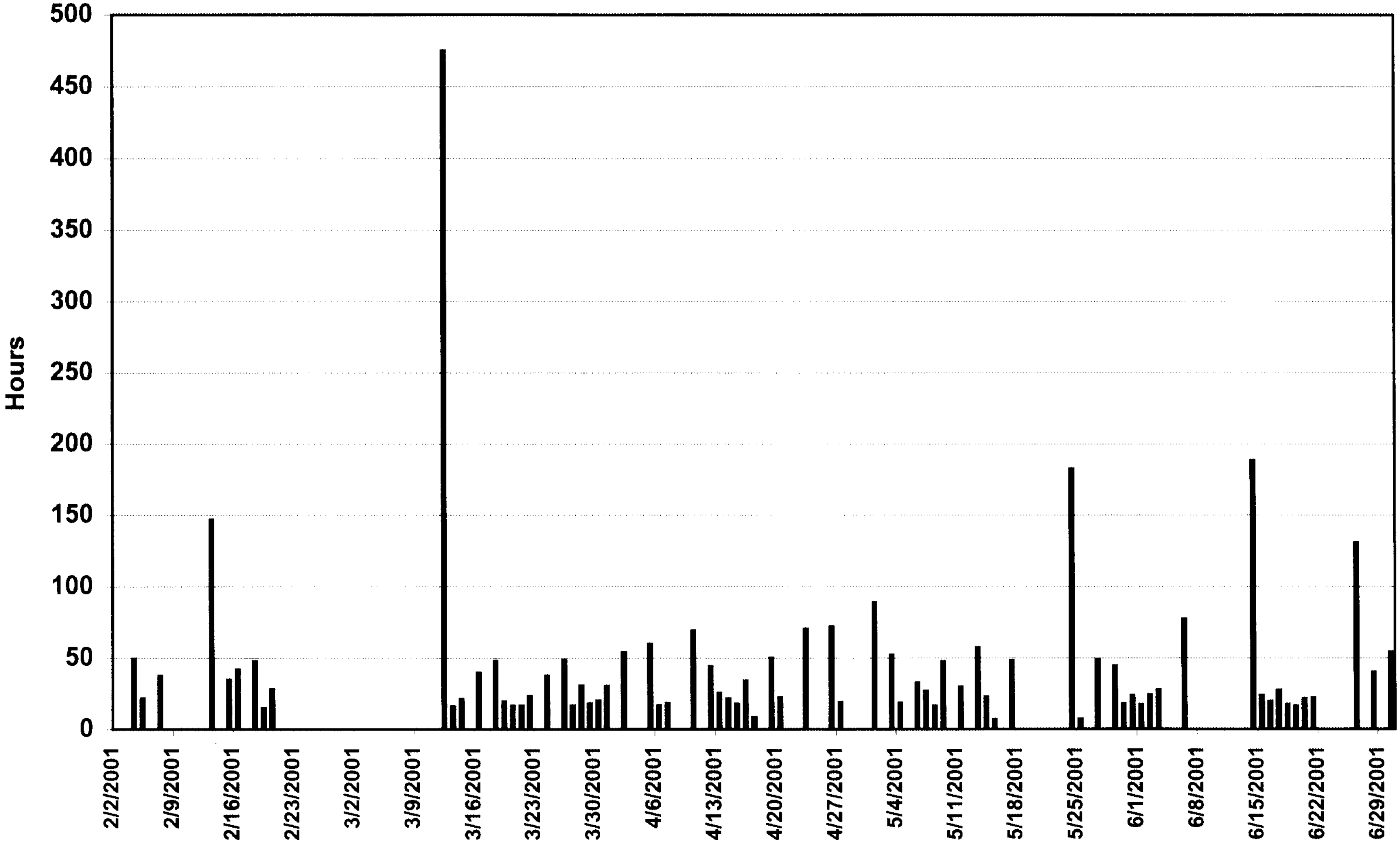
DATA GRAPHS

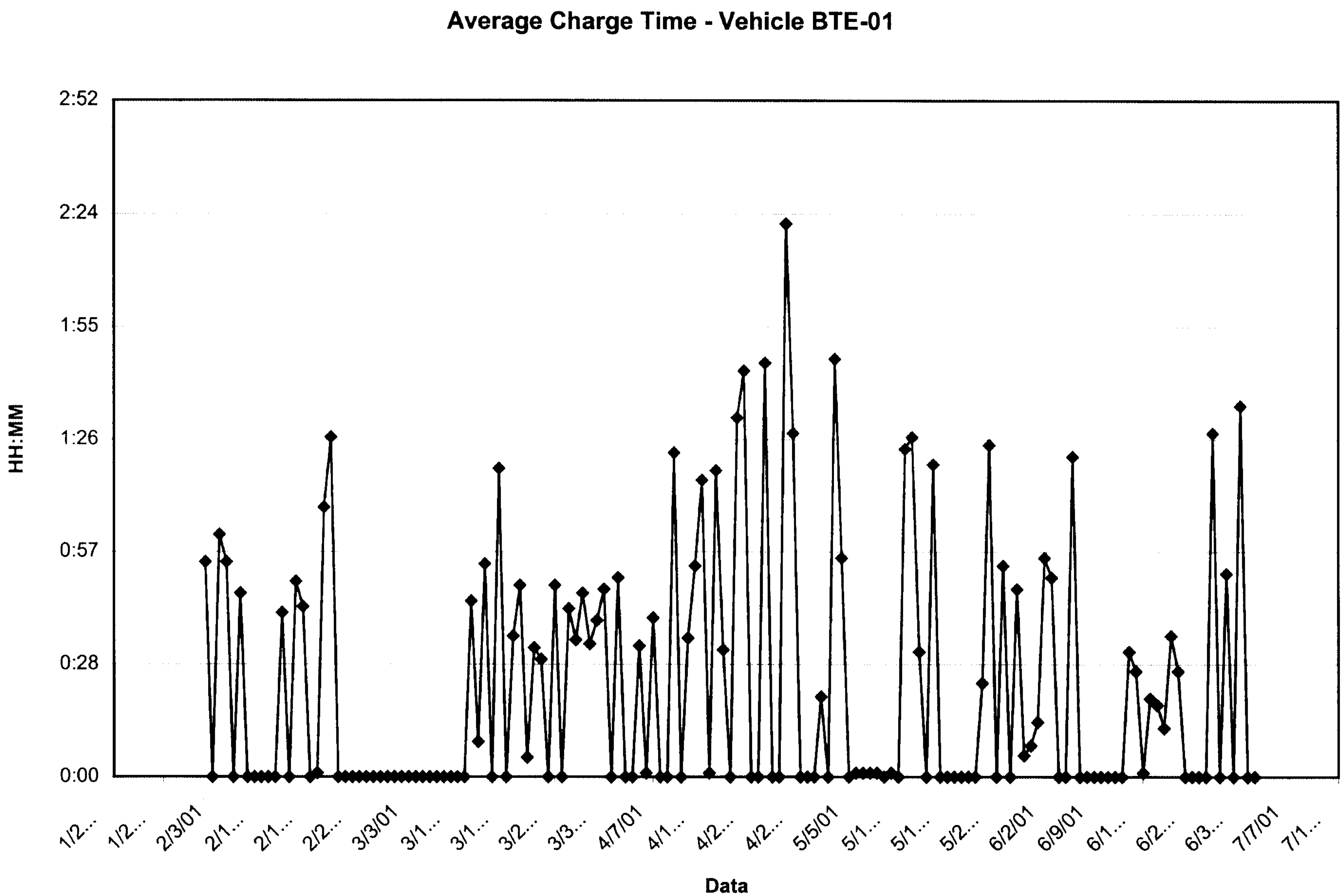
TRACTOR
BTE-01

Charges Per Day - Vehicle BTE-01



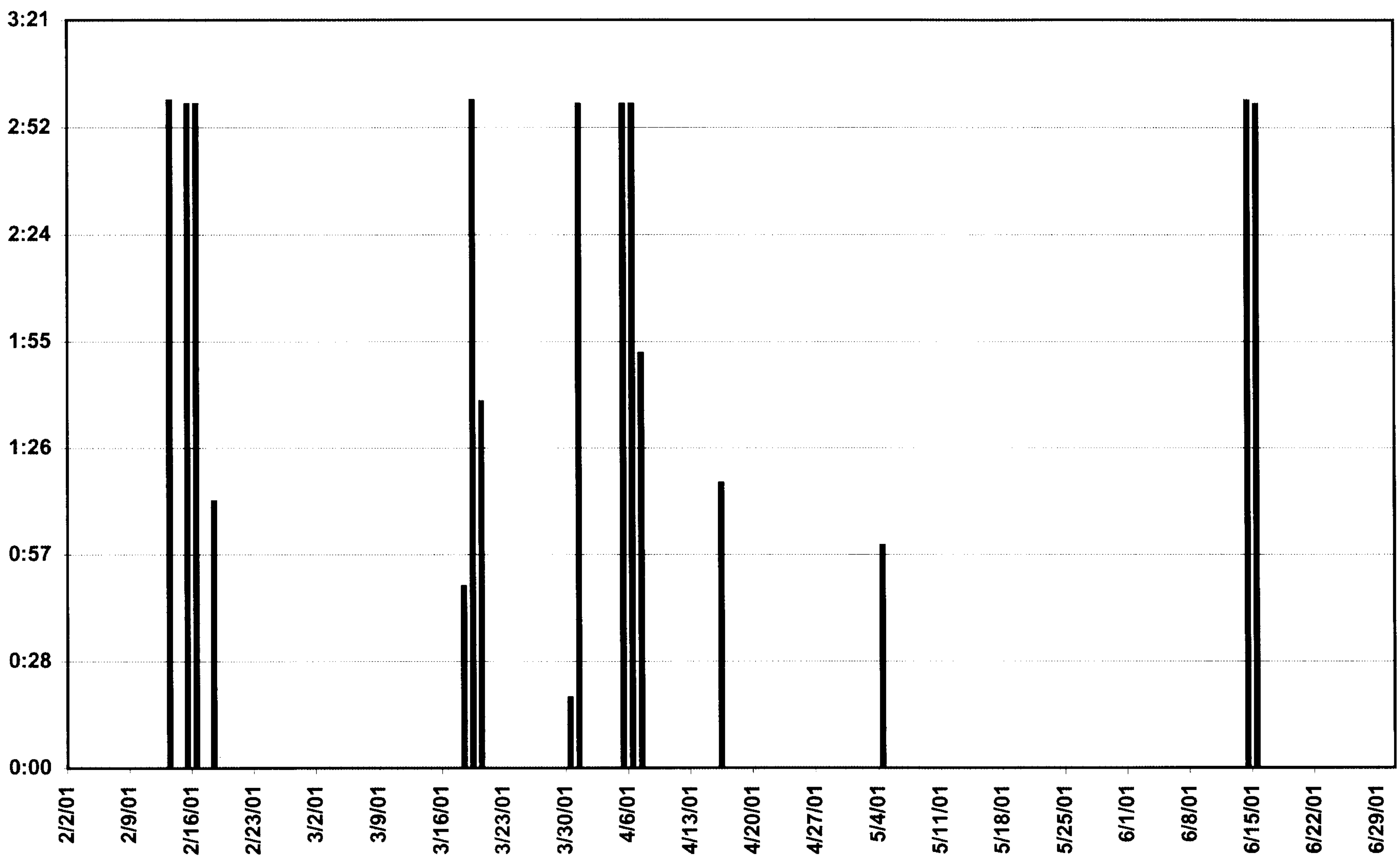
Time Between Charges - Vehicle BTE-01



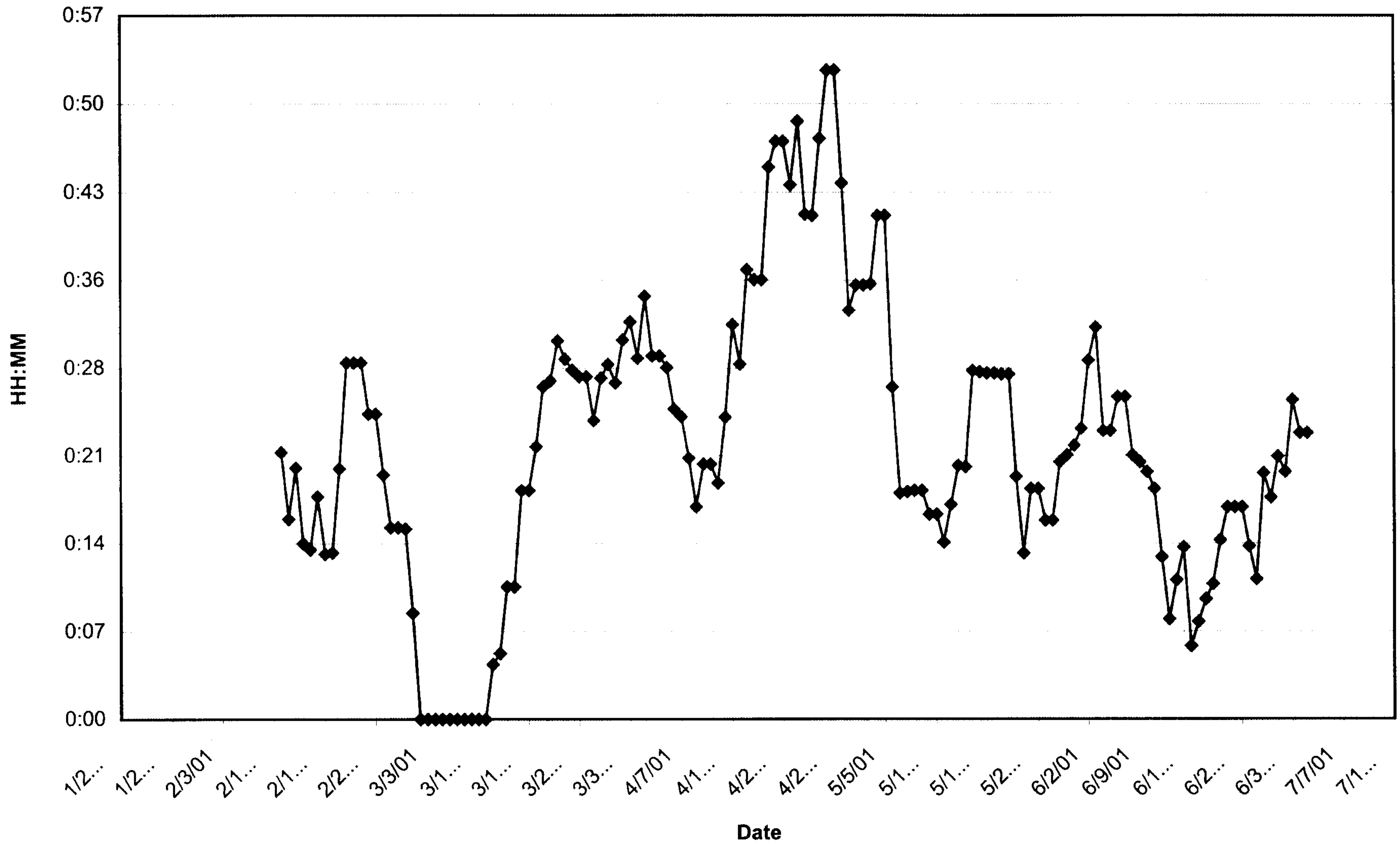


Average Charge Time - Vehicle BTE-01
HH:MM
2:52
2:24
1:55
1:26
0:57
0:28
0:00
1/2...
1/2...
2/3/01
2/1...
2/1...
2/2...
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
7/1...
Data

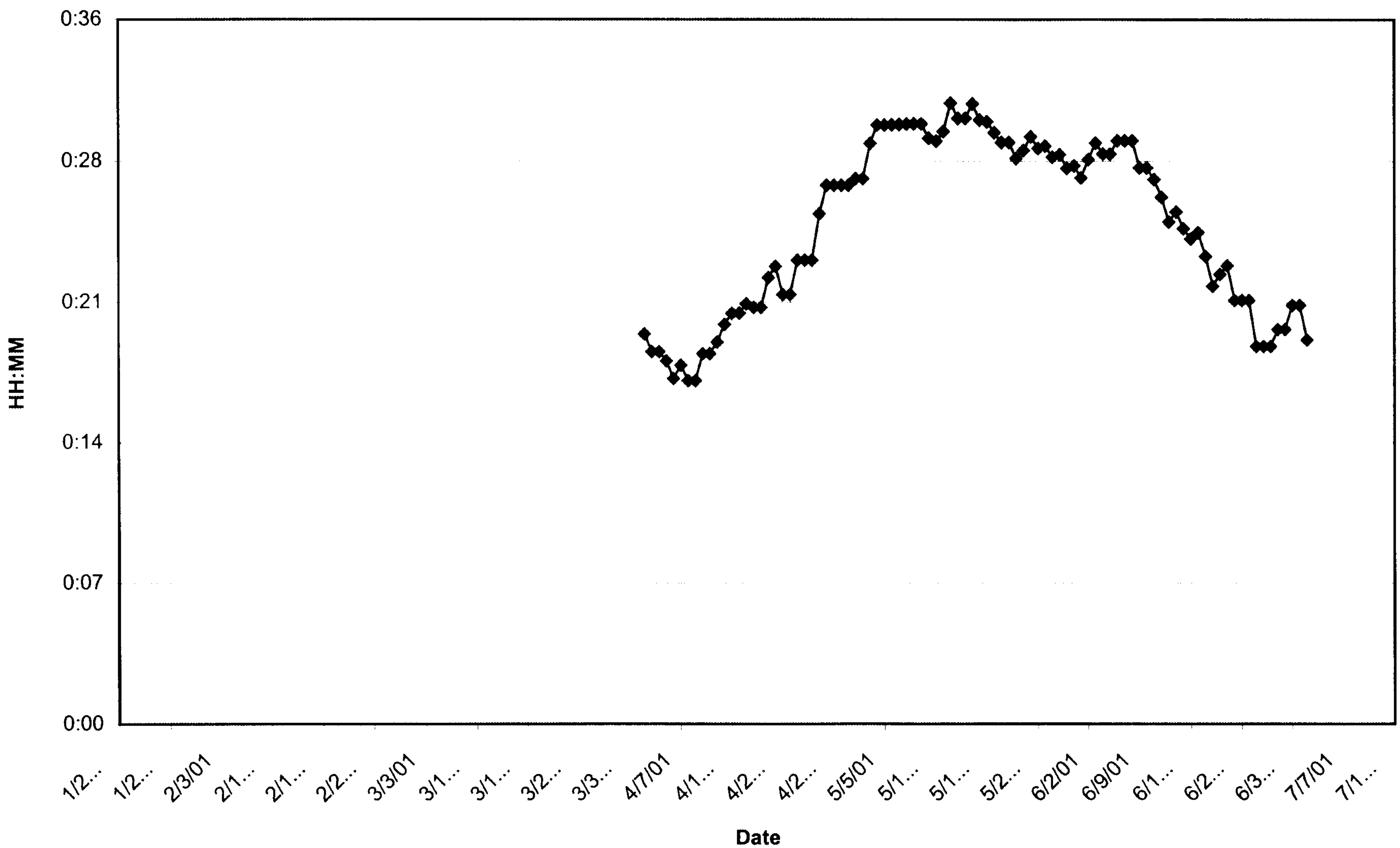
Time on Equalize Charge - Vehicle BTE-01



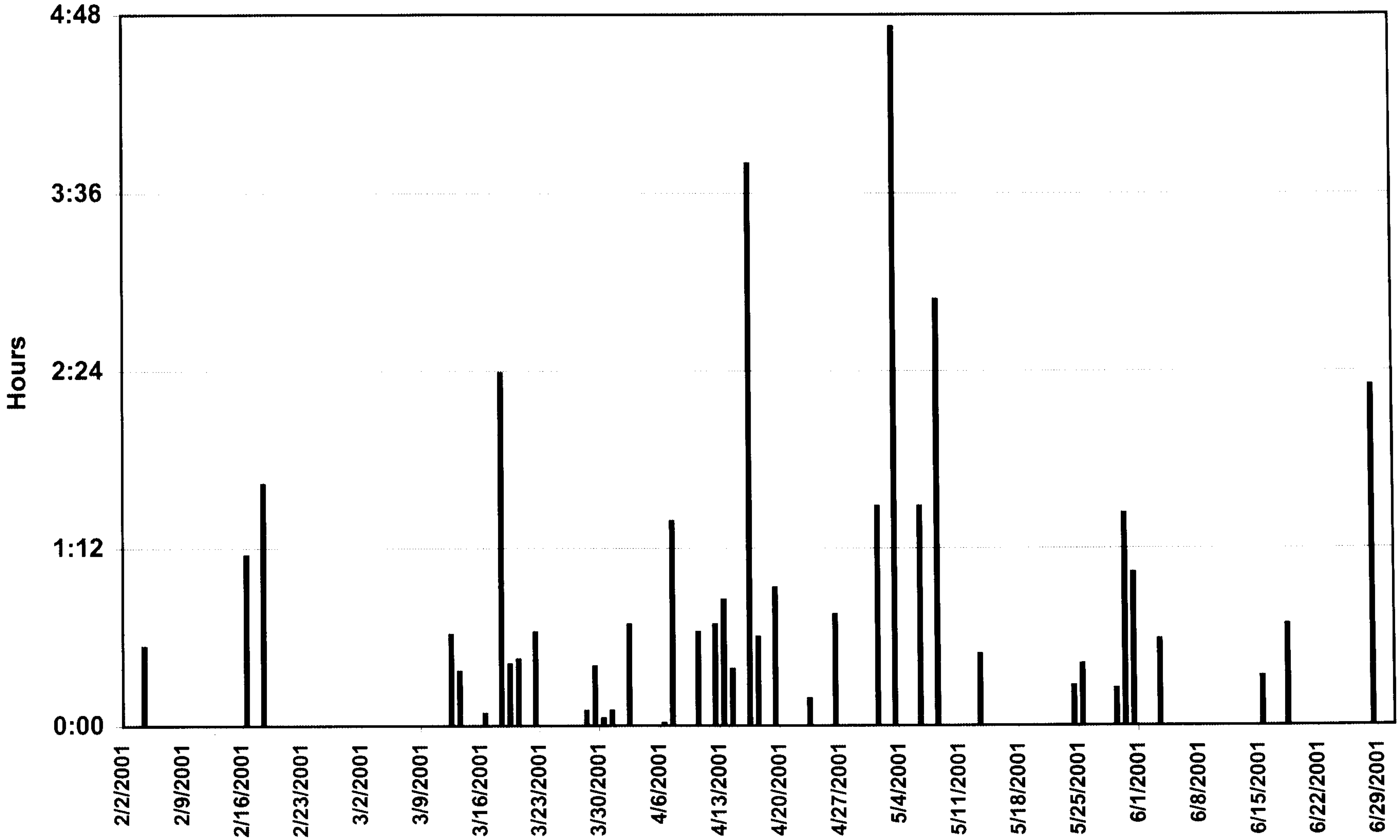
10-Day Average Charge Time - Vehicle BTE-01

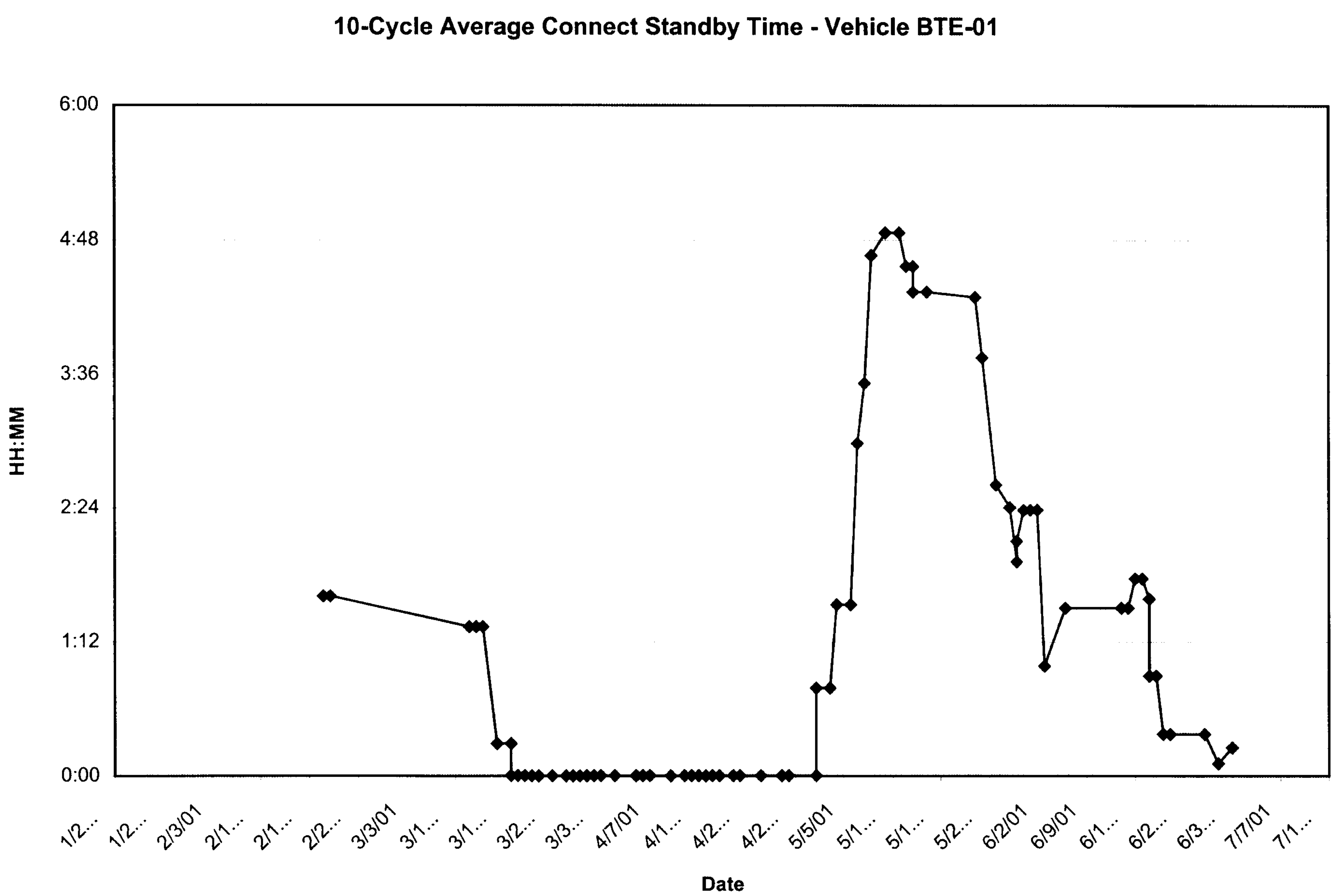


60-Day Average Charge Time - Vehicle BTE-01

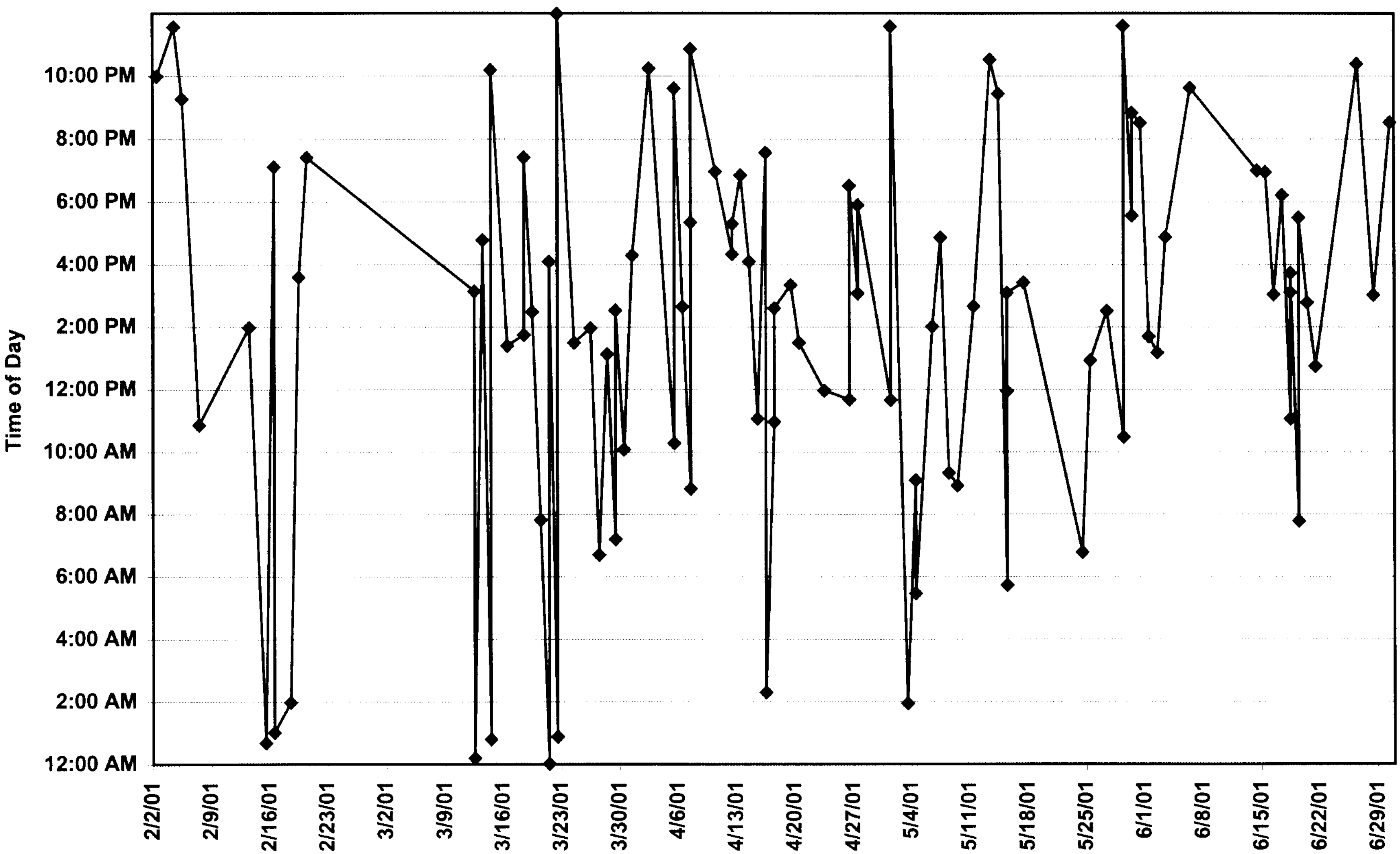


Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-01

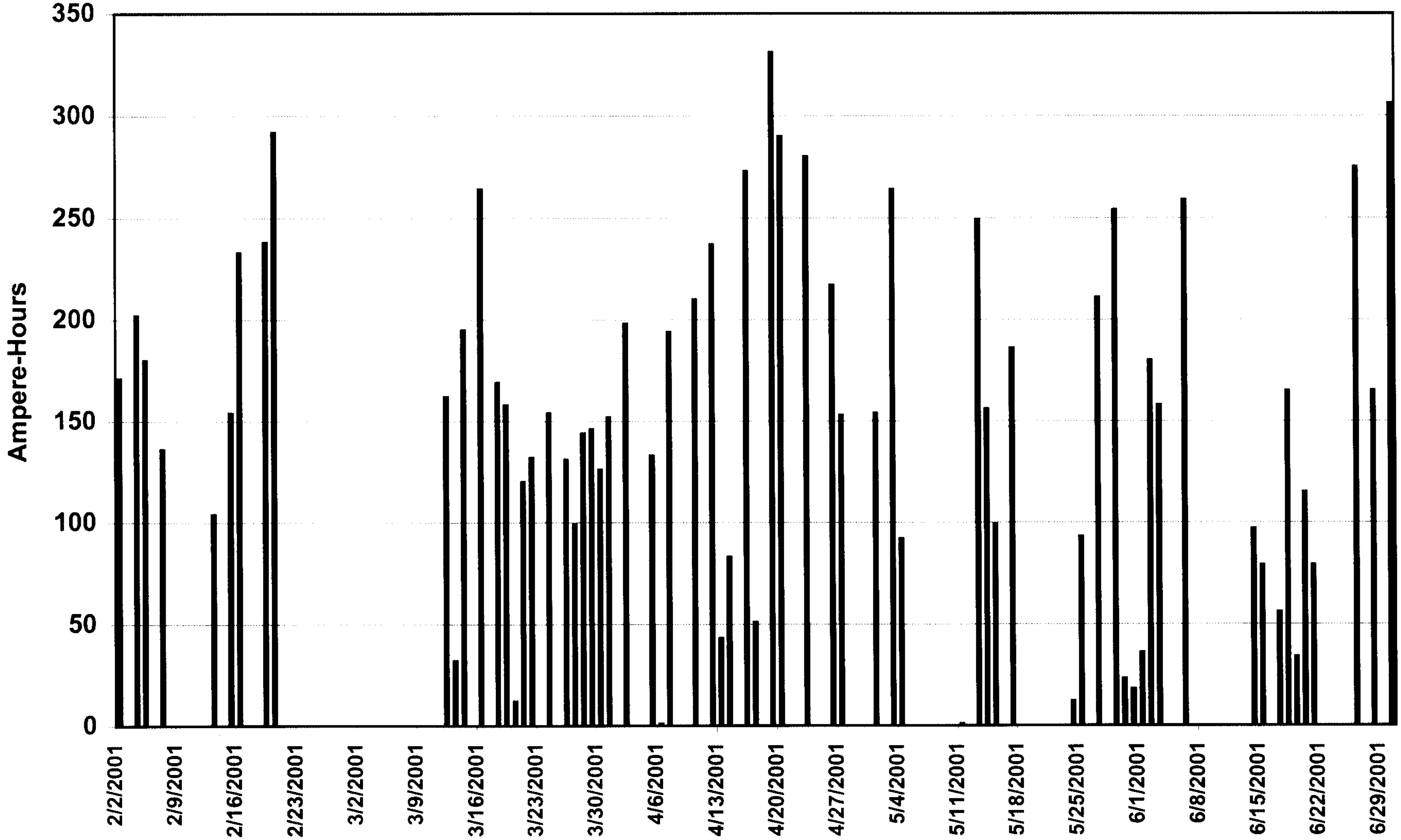



10-Cycle Average Connect Standby Time - Vehicle BTE-01
HH:MM
6:00
4:48
3:36
2:24
1:12
0:00
1/2...
1/2...
2/3/01
2/1...
2/1...
2/2...
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
7/1...
Date

Charge Start Times - Vehicle BTE-01



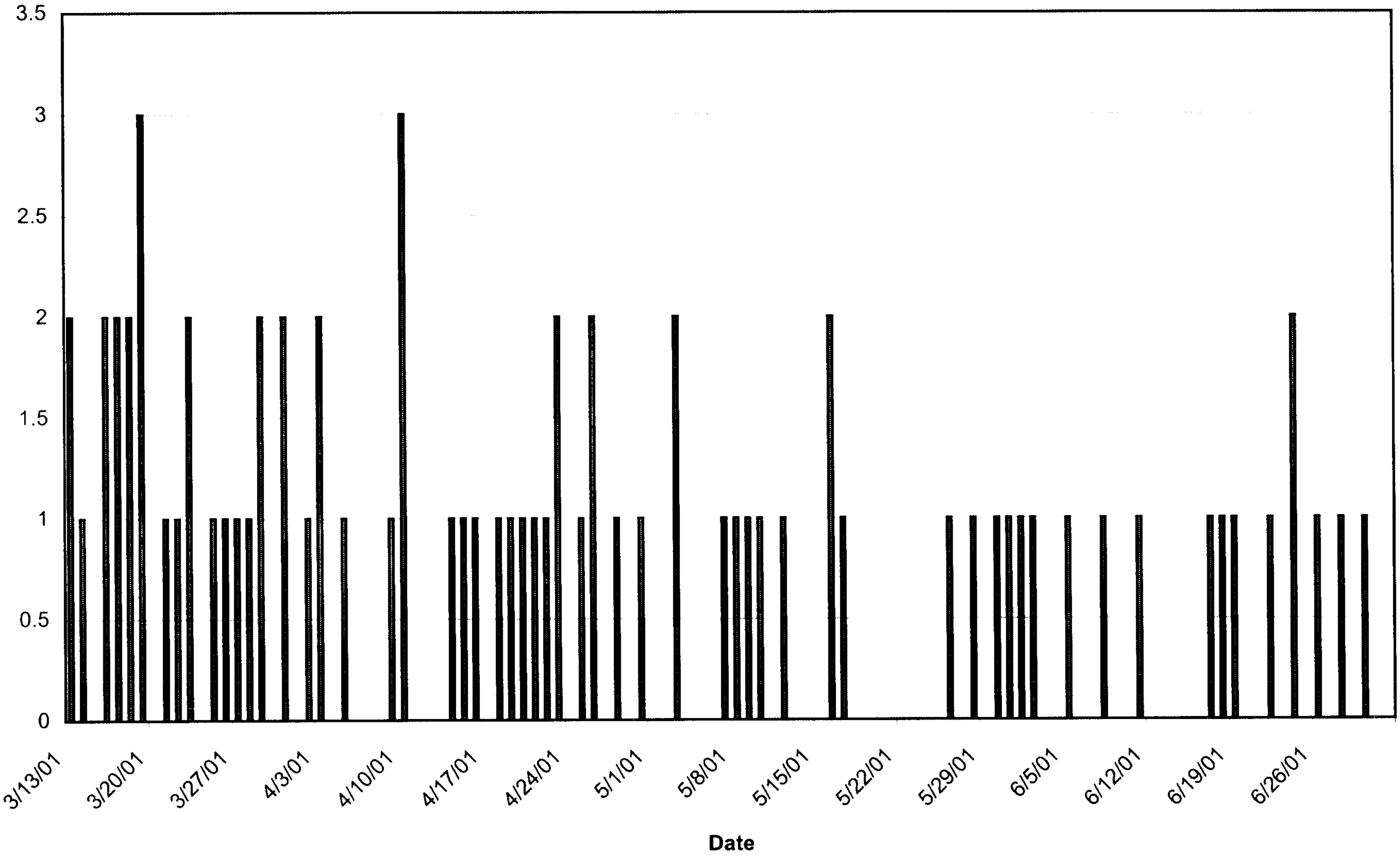
Ampere-Hours Returned per Charge - Vehicle BTE-01



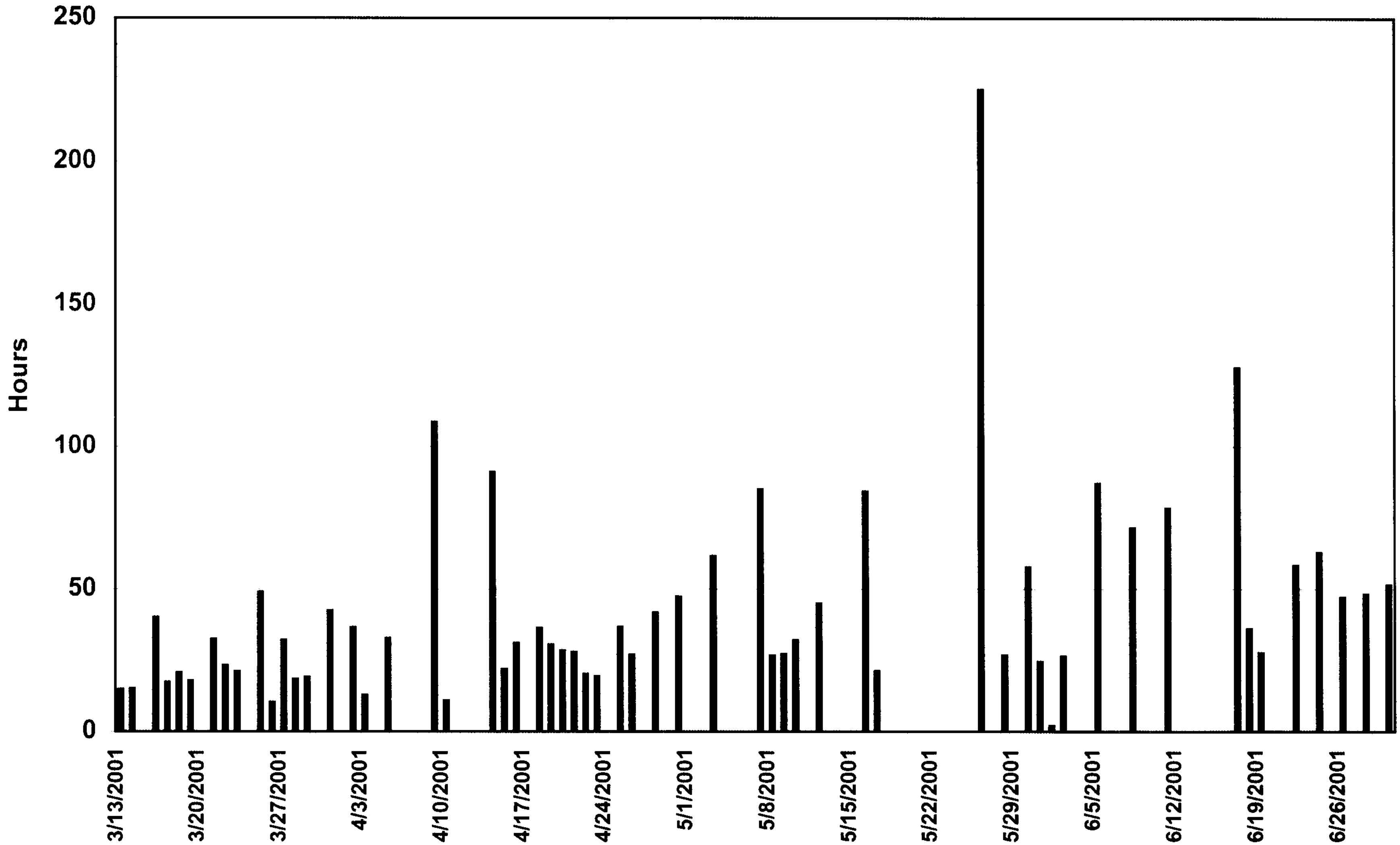
DATA GRAPHS

TRACTOR
BTE-02

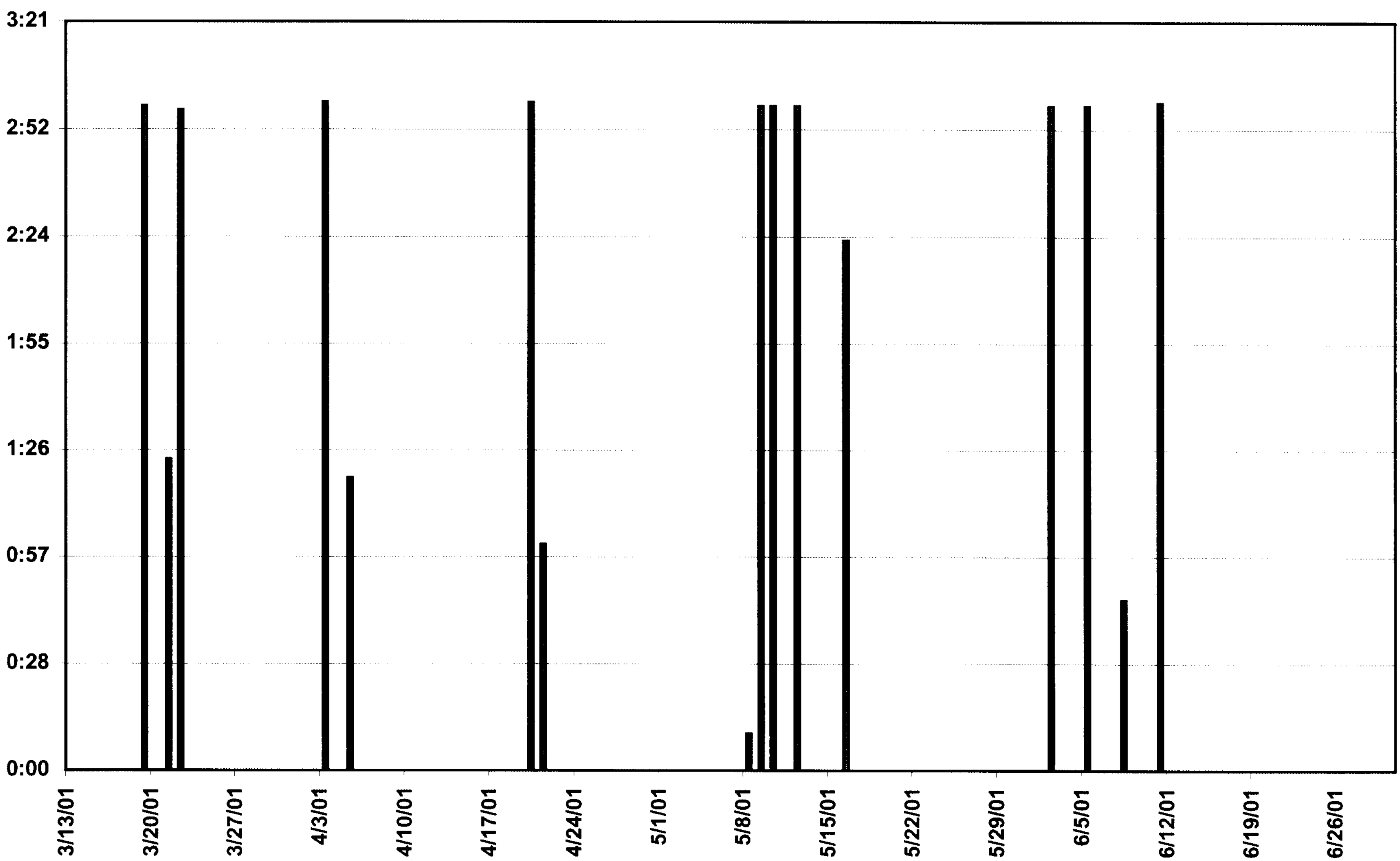
Charges Per Day - Vehicle BTE-02



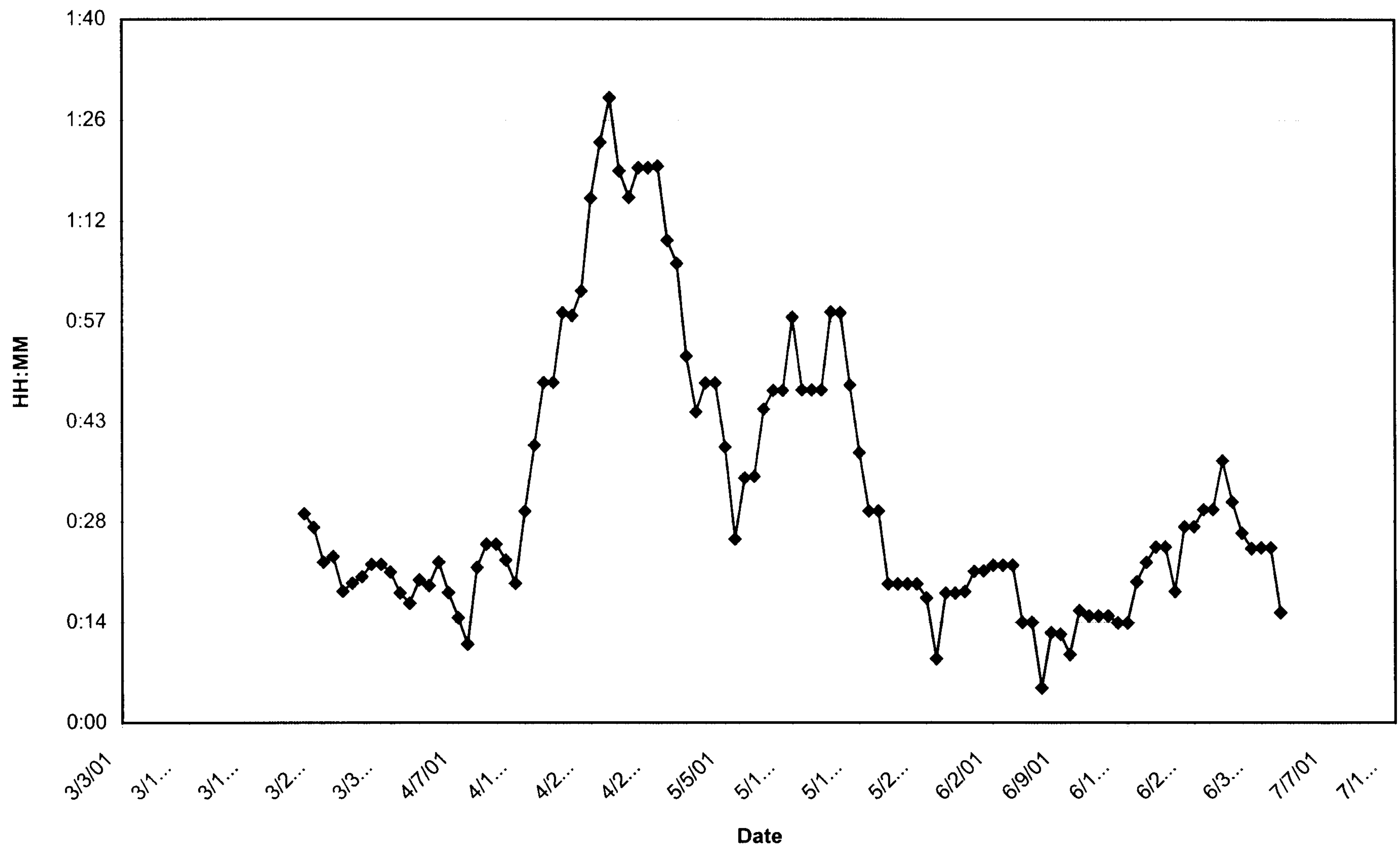
Time Between Charges - Vehicle BTE-02

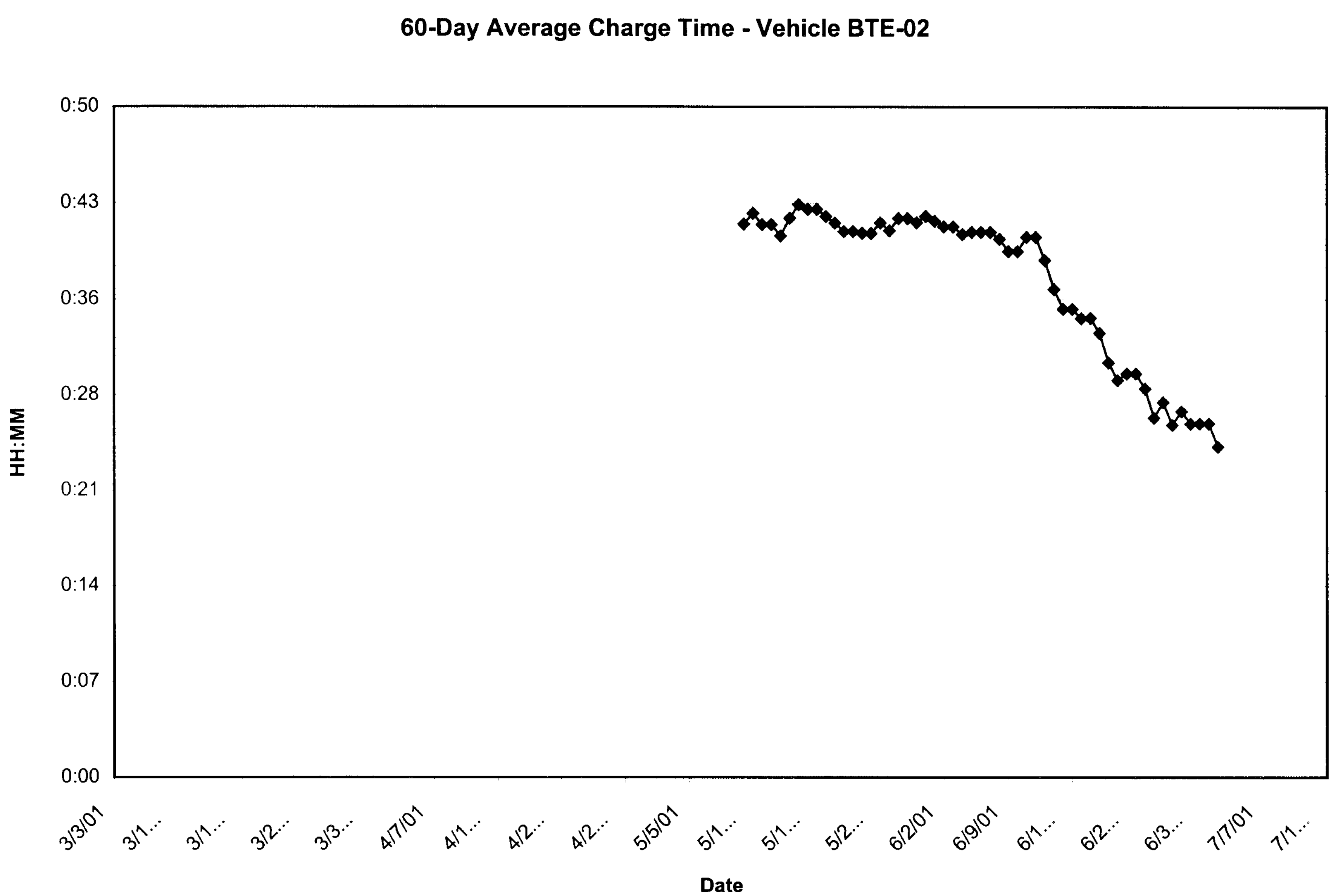


Time on Equalize Charge - Vehicle BTE-02

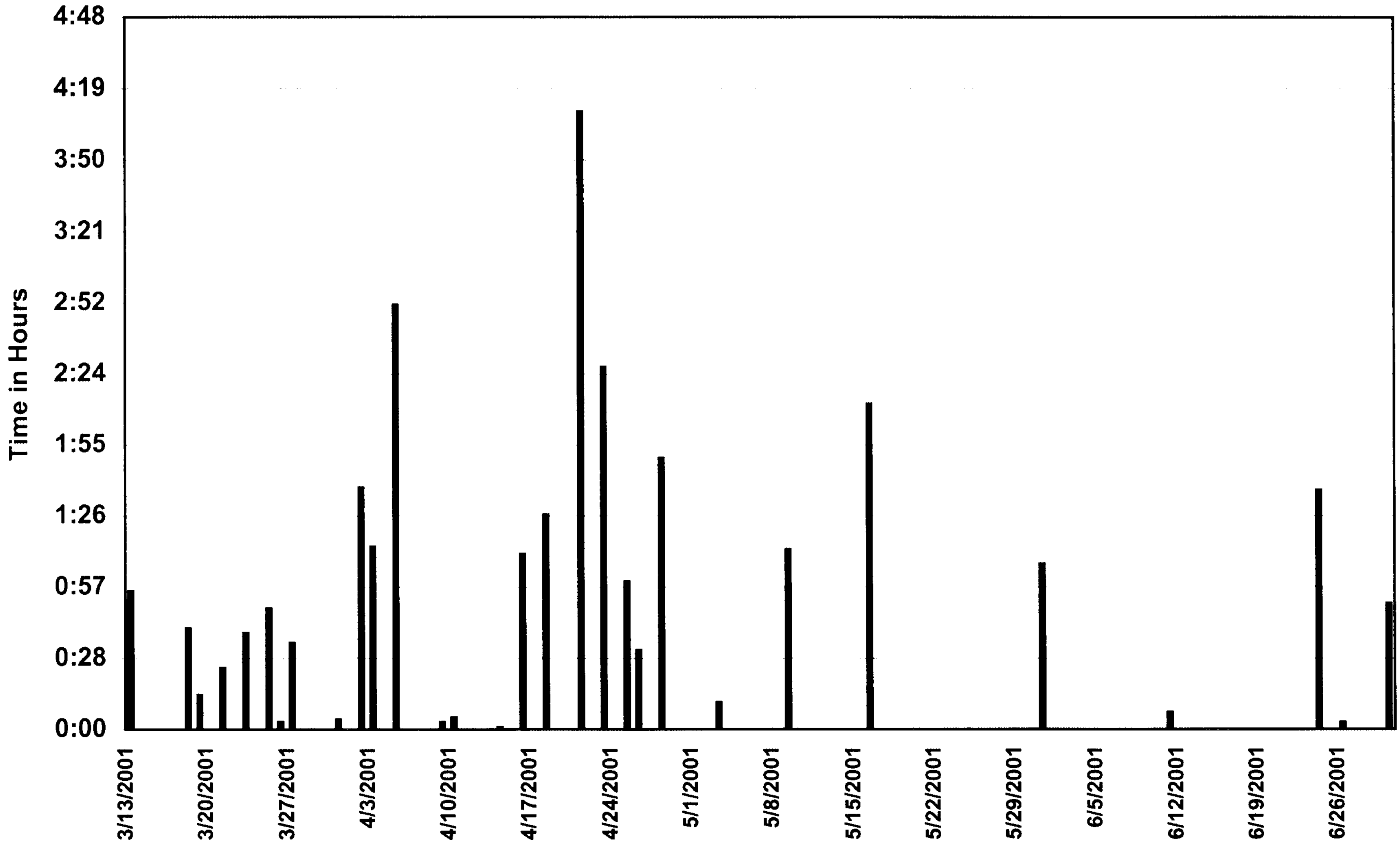


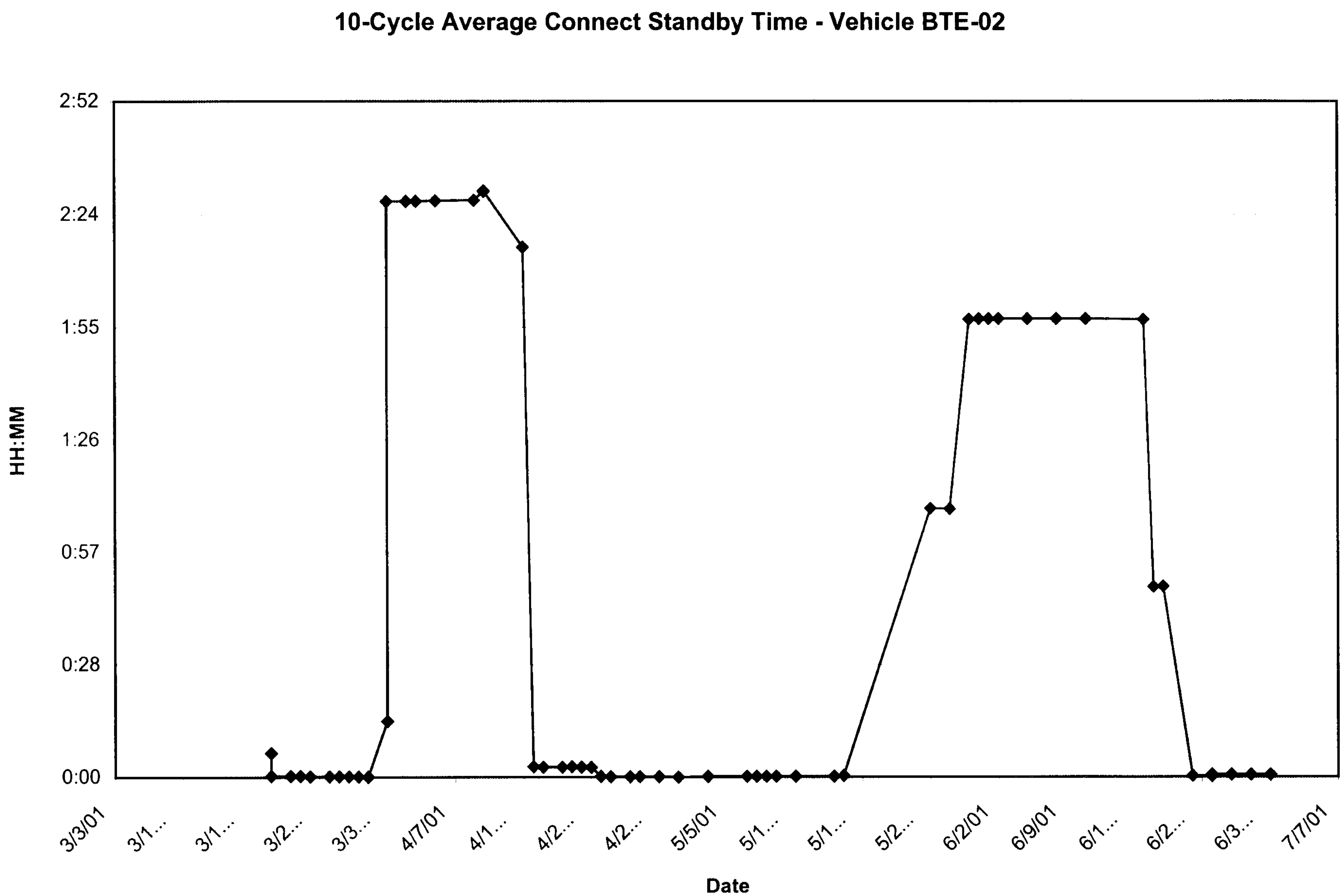
10-Day Average Charge Time - Vehicle BTE-02



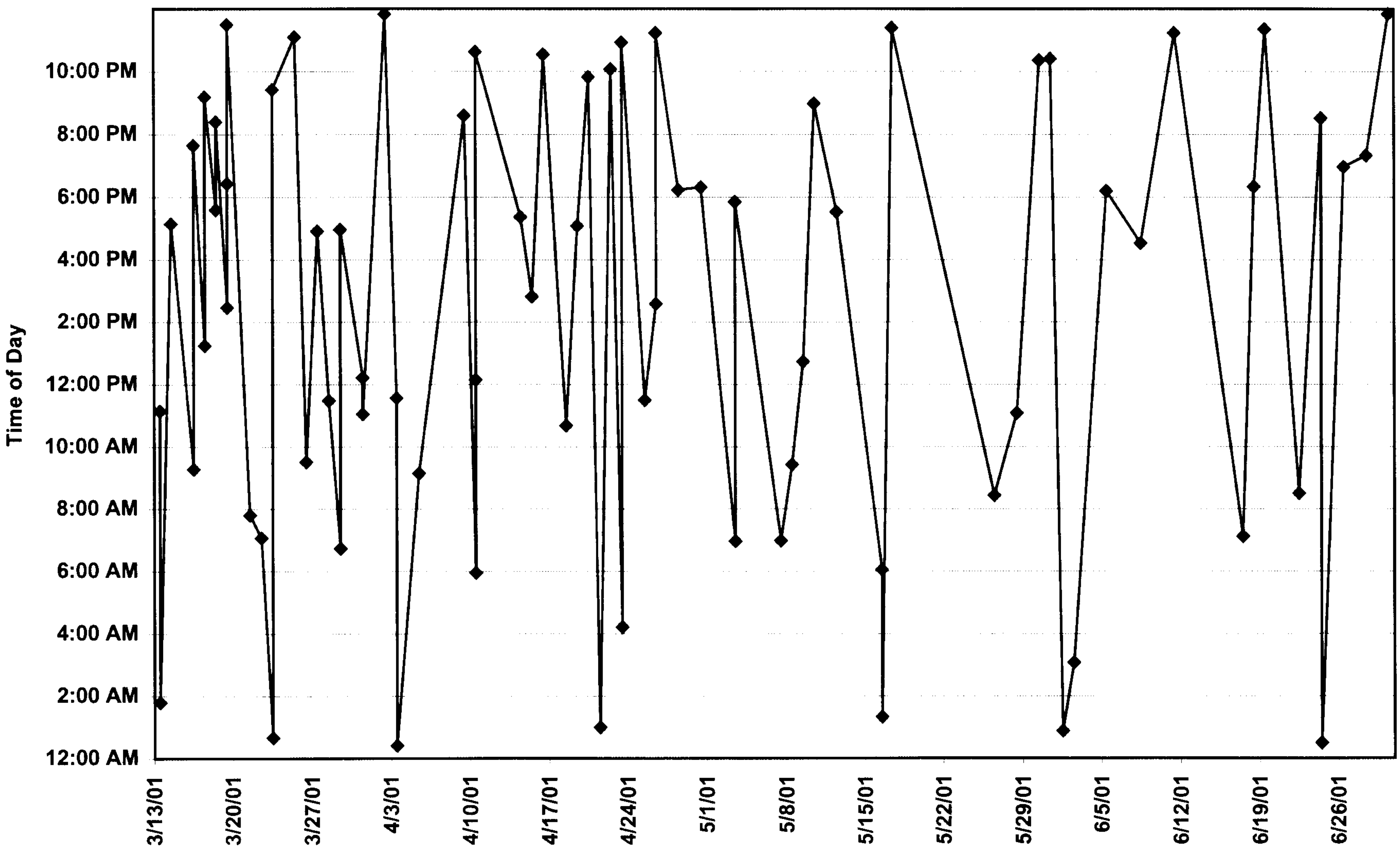

60-Day Average Charge Time - Vehicle BTE-02
HH:MM
0:50
0:43
0:36
0:28
0:21
0:14
0:07
0:00
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
7/1...
Date

Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-02

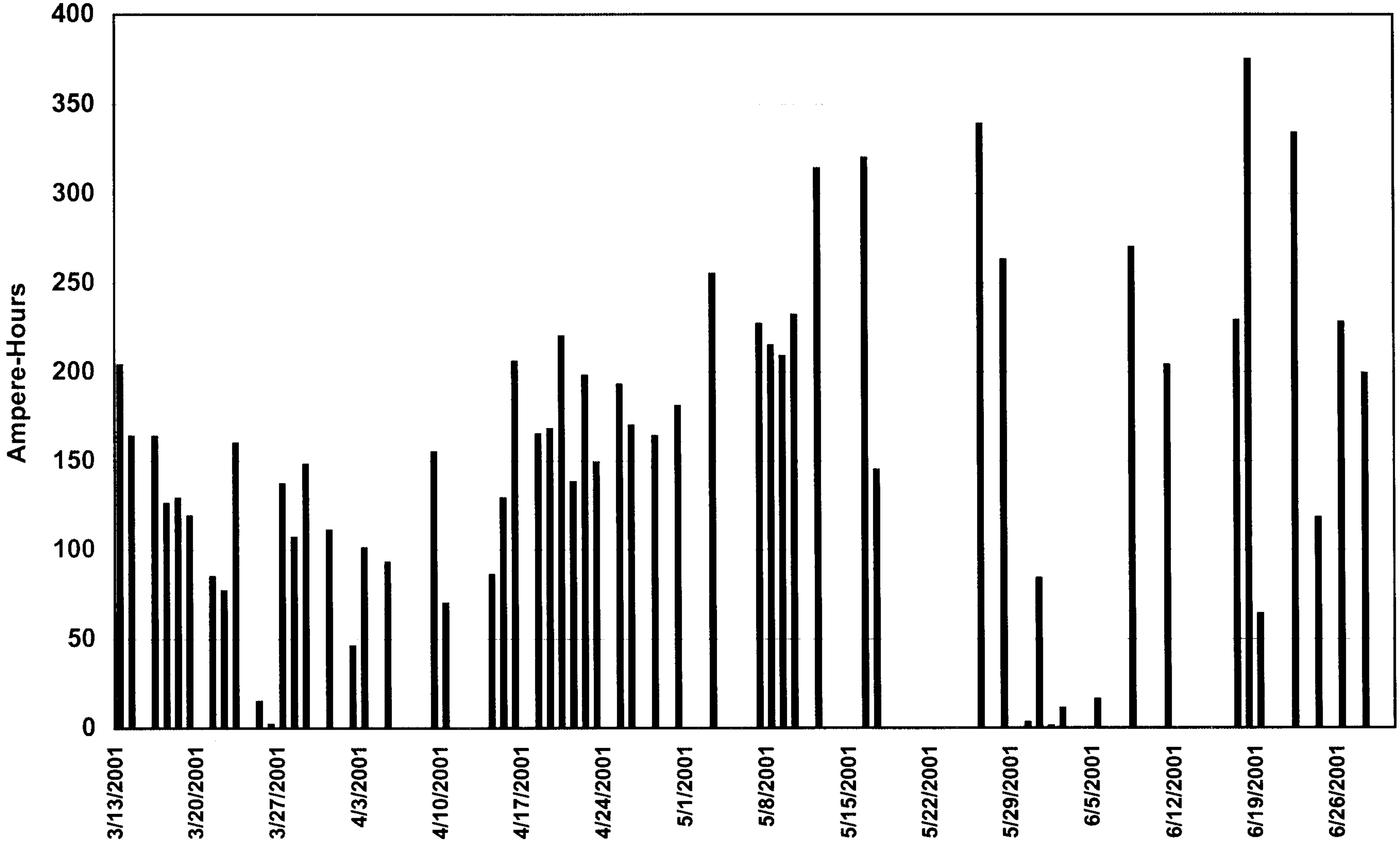



10-Cycle Average Connect Standby Time - Vehicle BTE-02
2:52
2:24
1:55
1:26
0:57
0:28
0:00
HH:MM
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
Date

Charge Start Times - Vehicle BTE-02



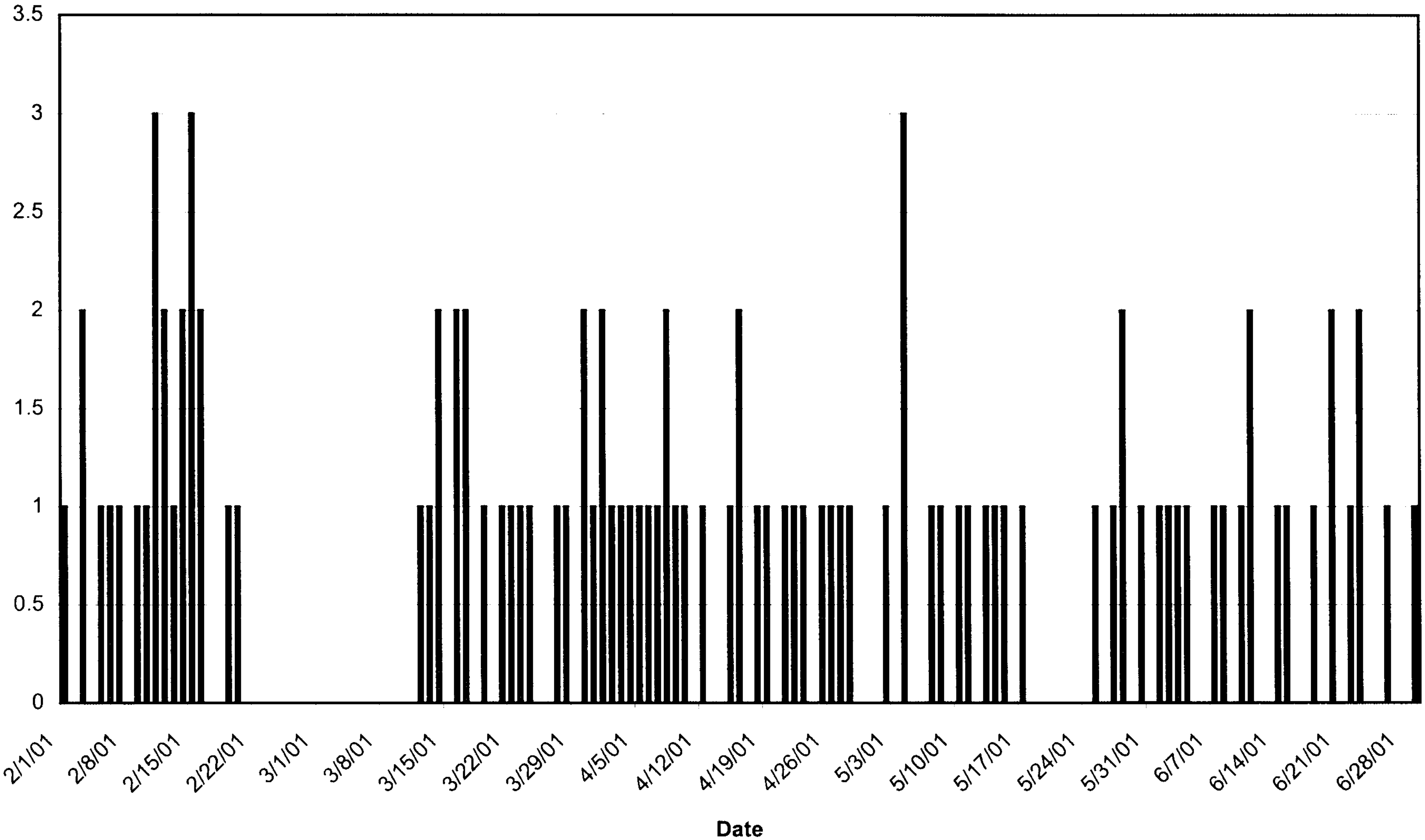
Ampere-Hours Returned per Charge - Vehicle BTE-02



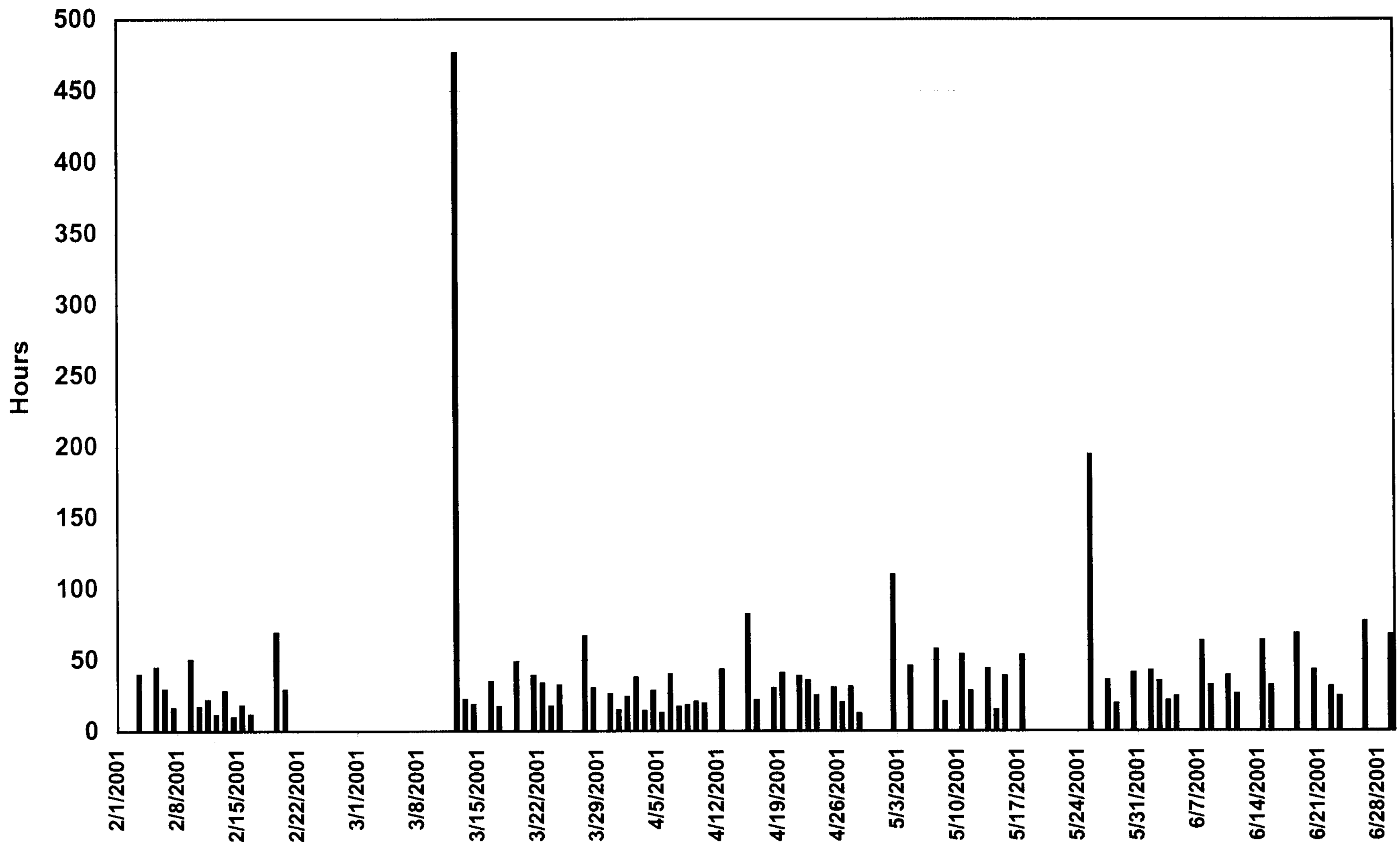
DATA GRAPHS

TRACTOR
BTE-03

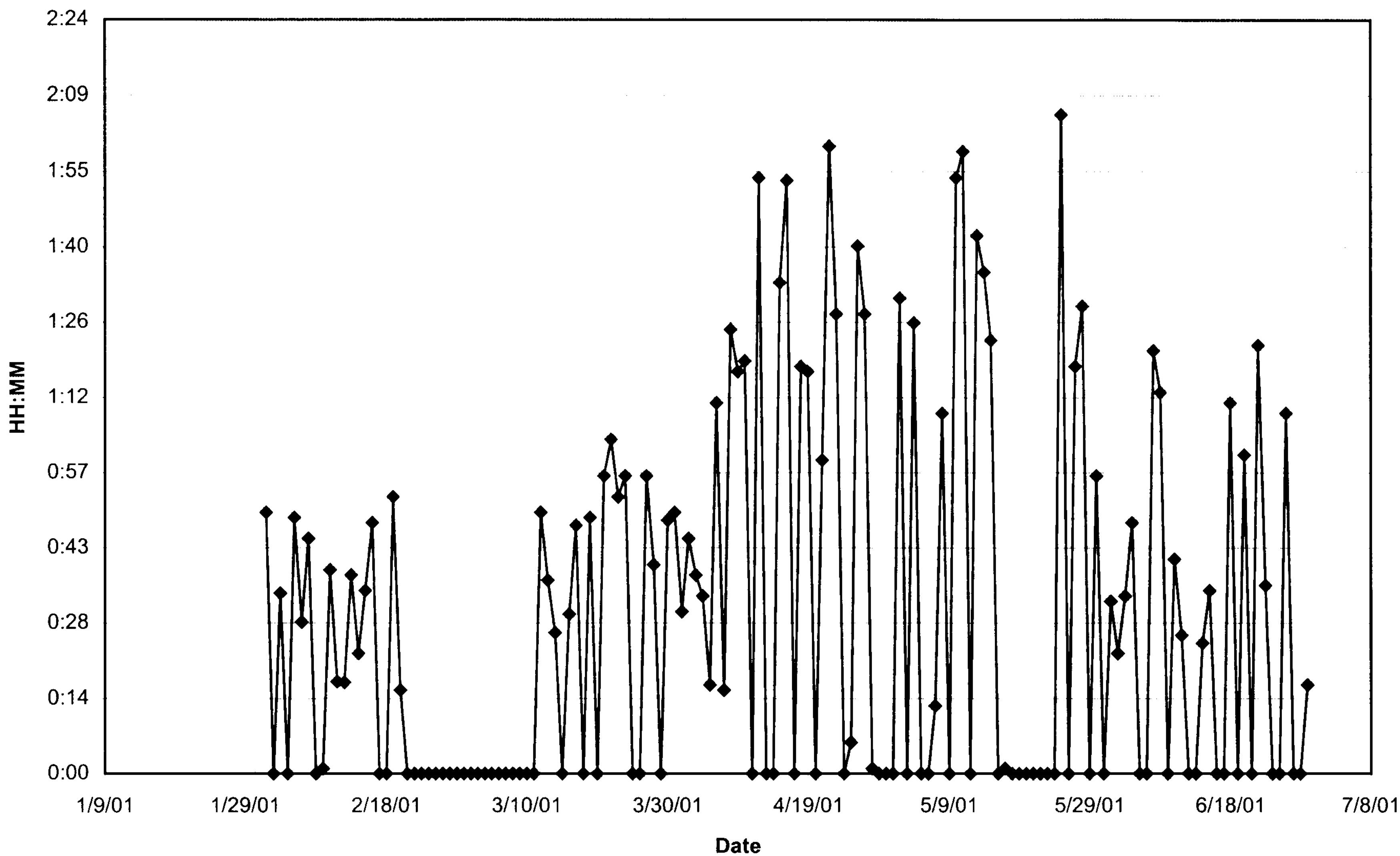
Valid Charges Per Day
Vehicle BTE03



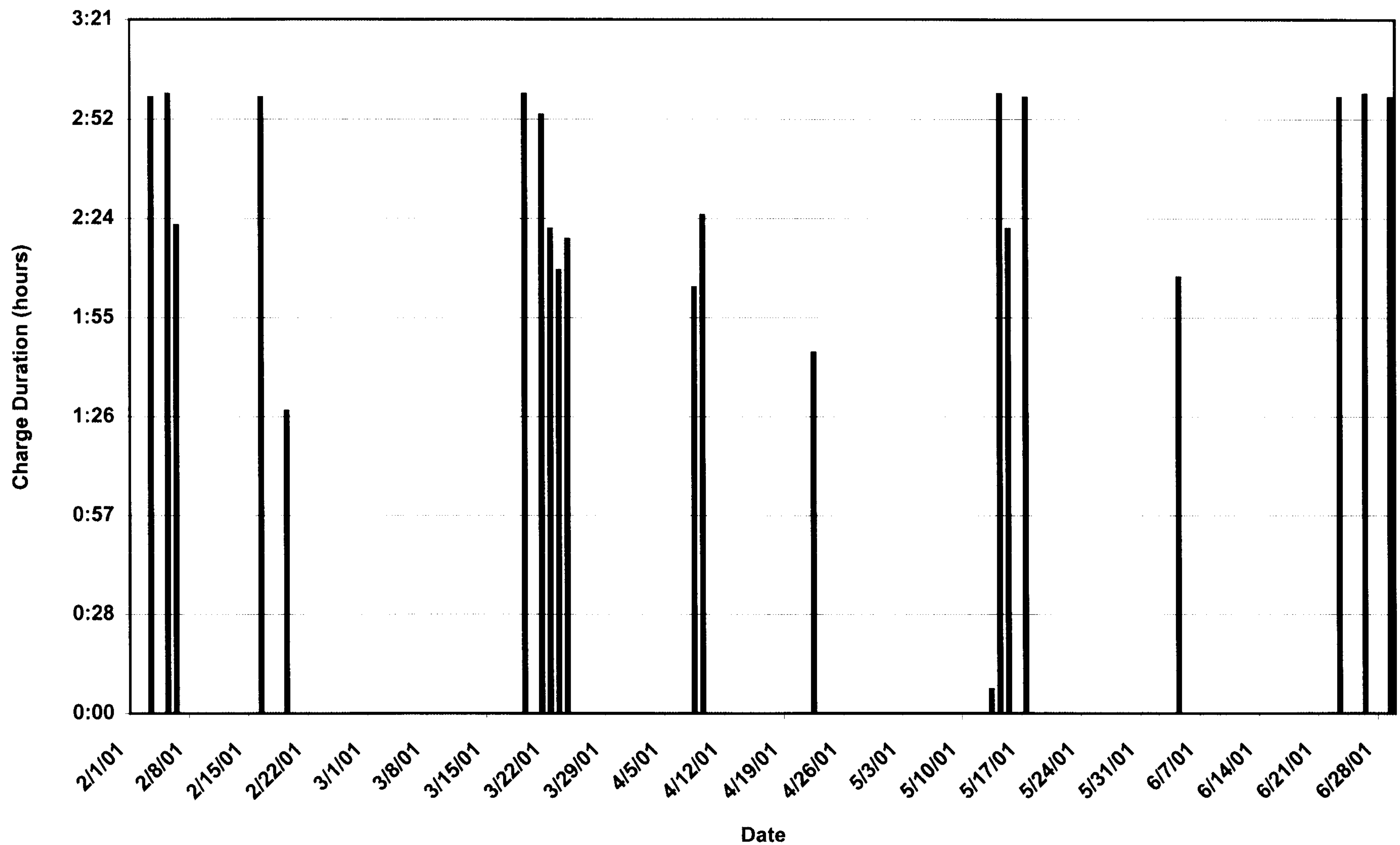
Time Between Charges - Vehicle BTE-03



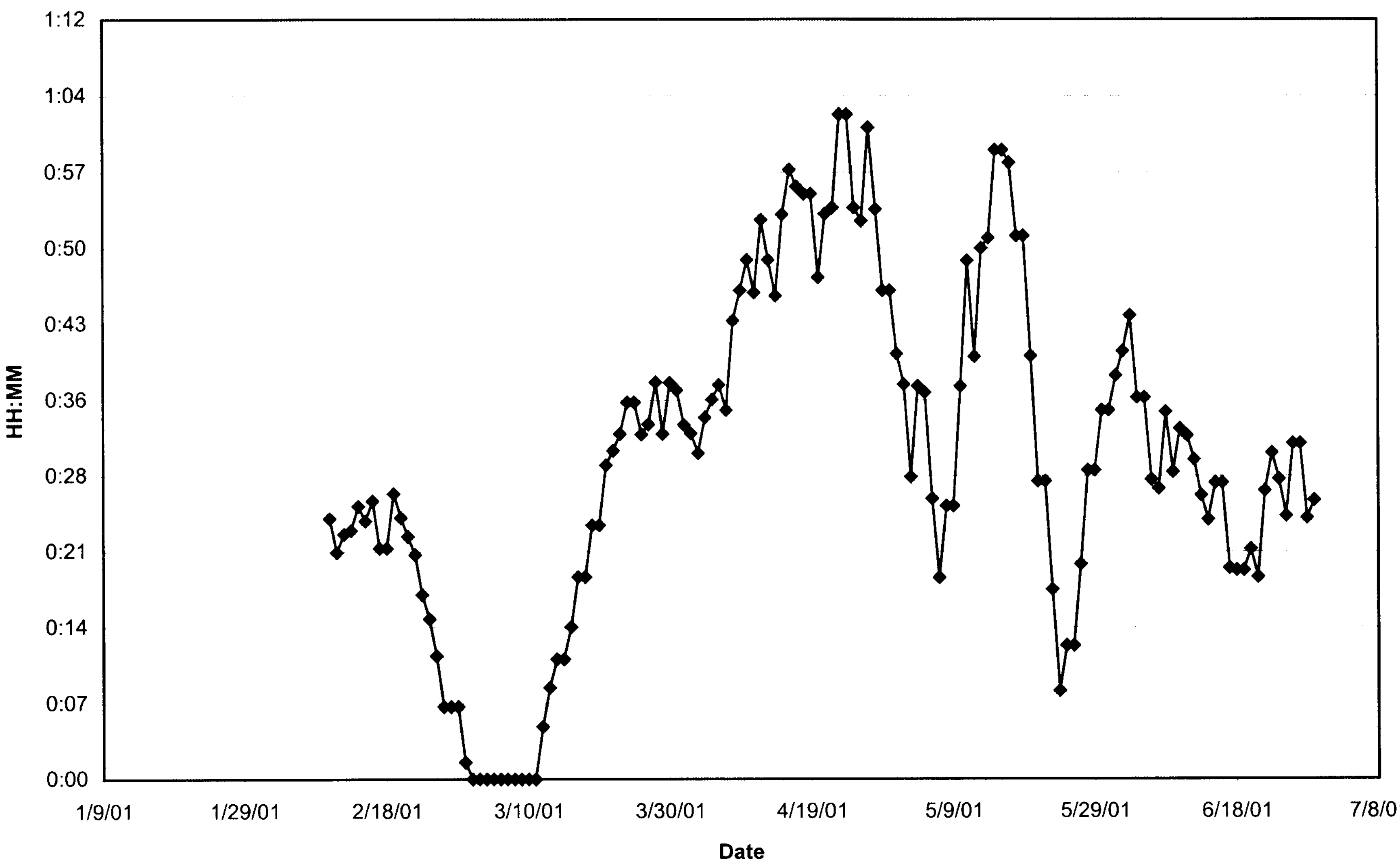
Average Charge Time - Vehicle BTE-03



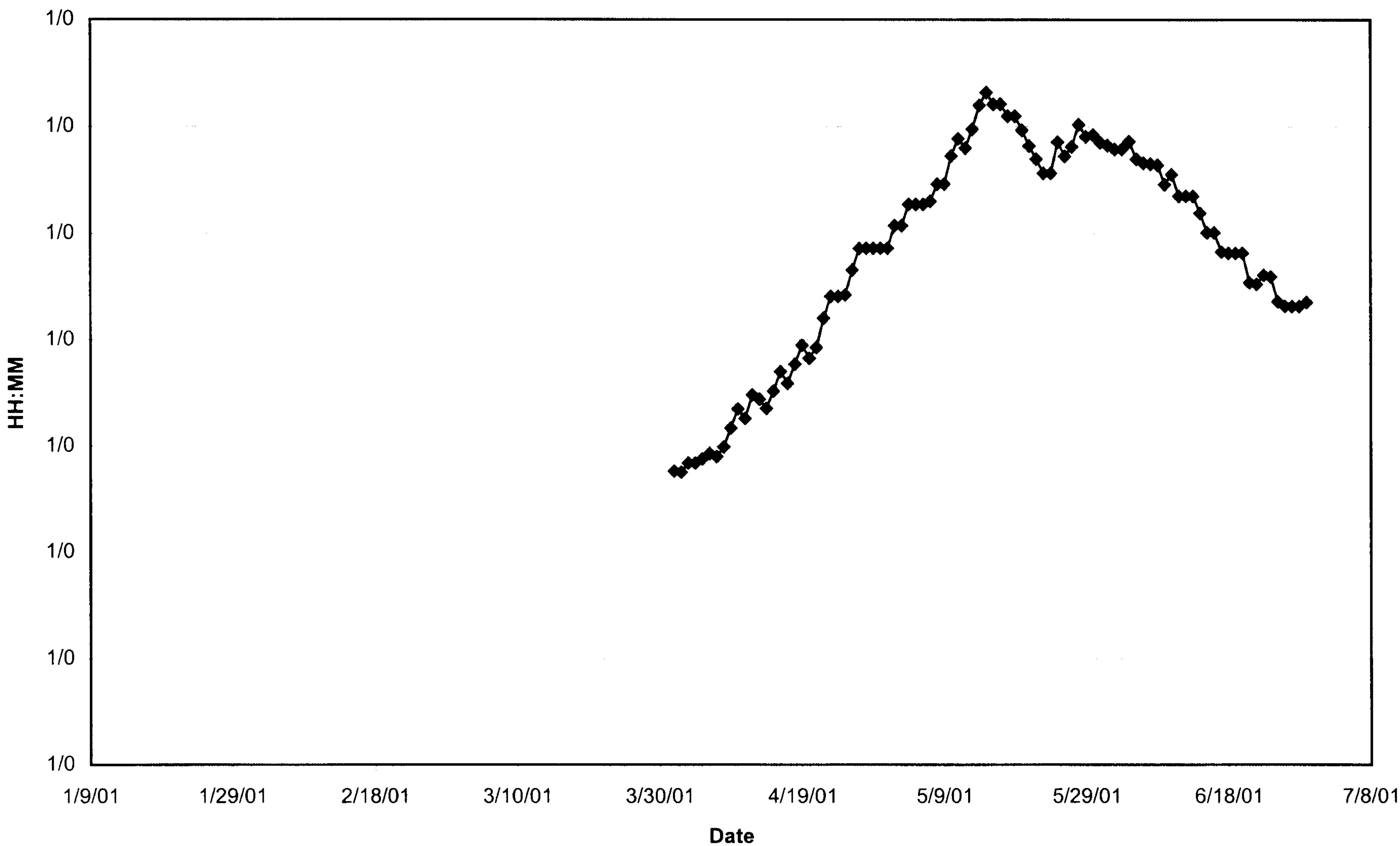
Time on Equalize Charge - Vehicle BTE-03



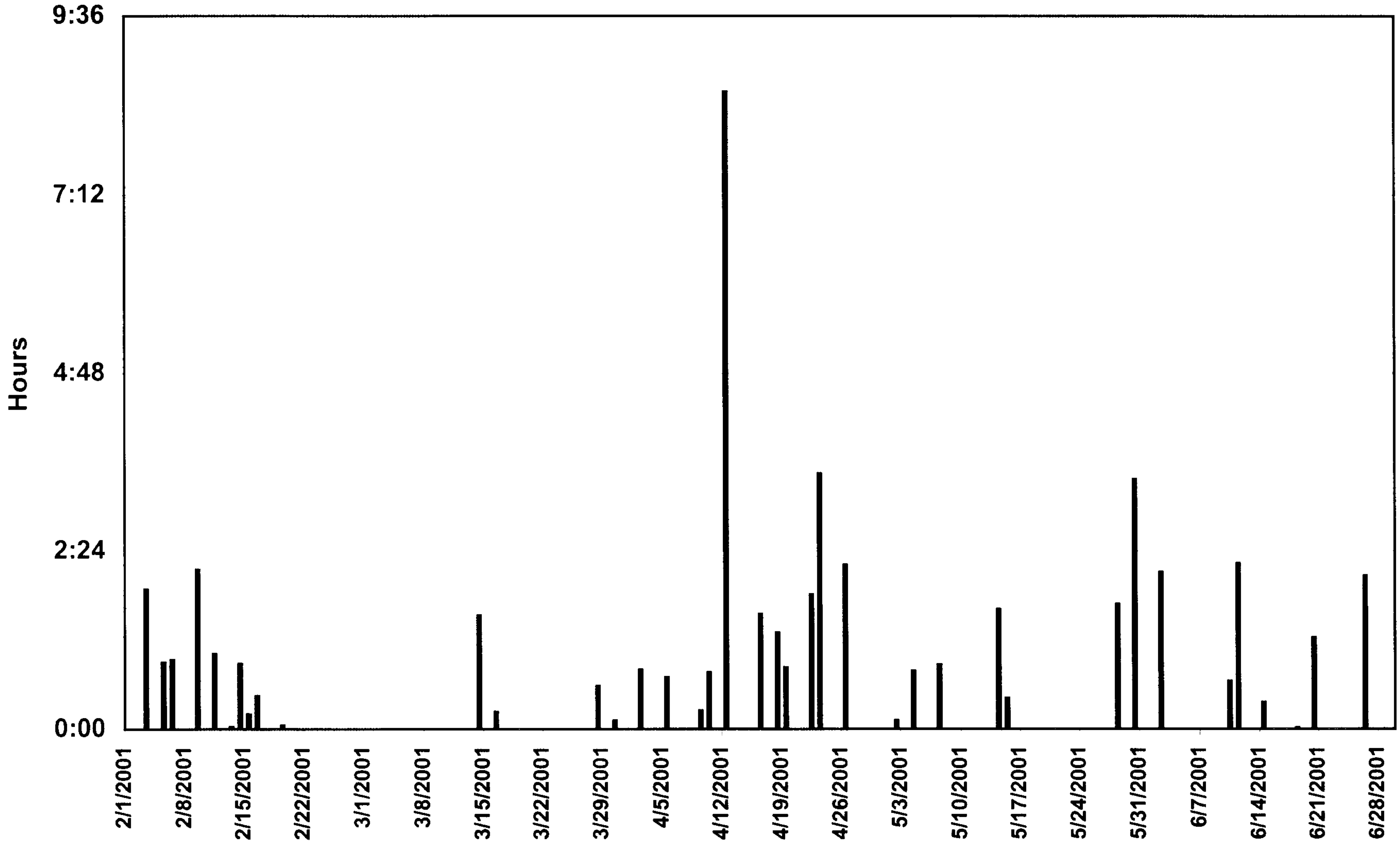
10 Day Average Charge Time - Vehicle BTE-03



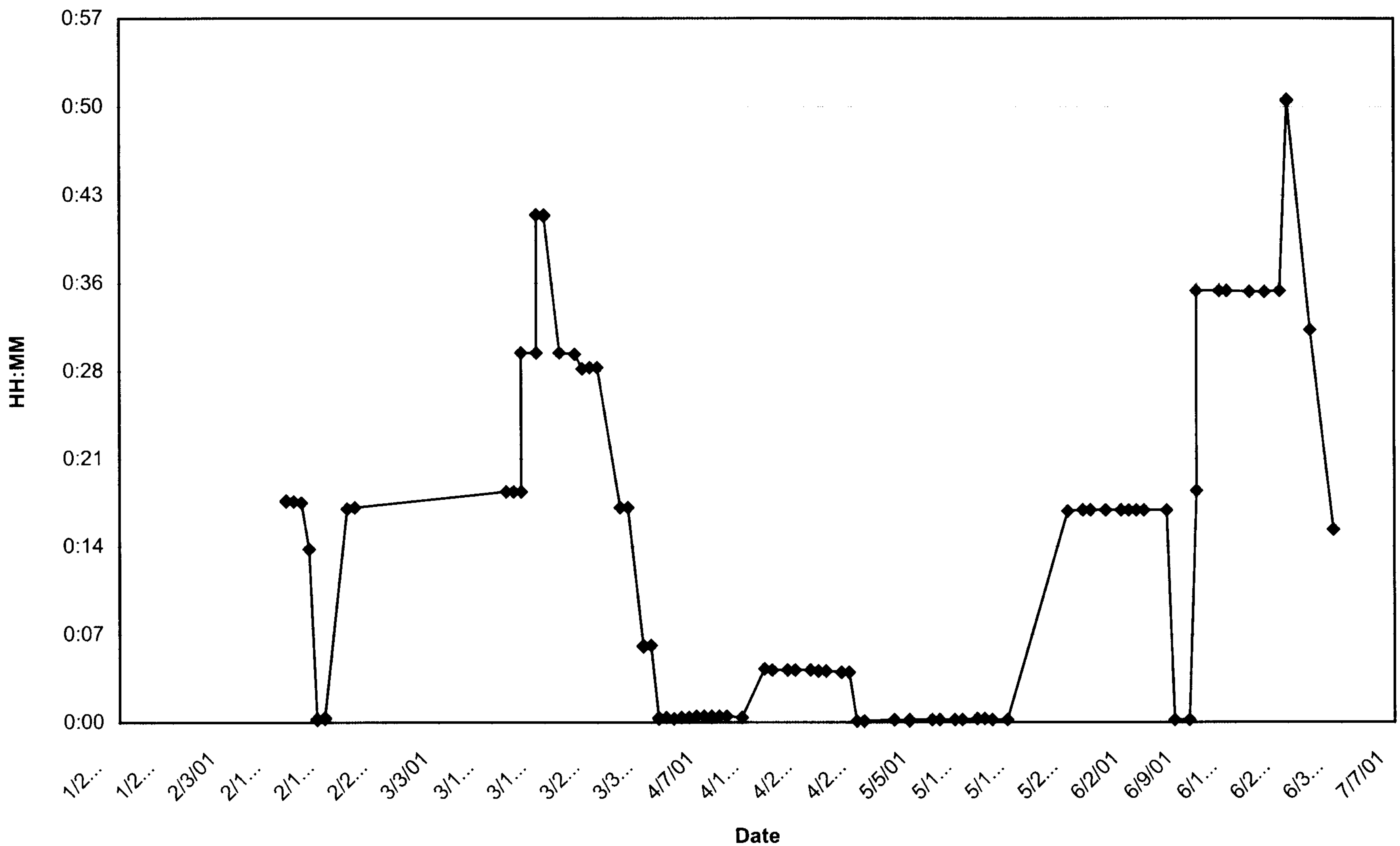
60 Day Average Charge Time - Vehicle BTE03



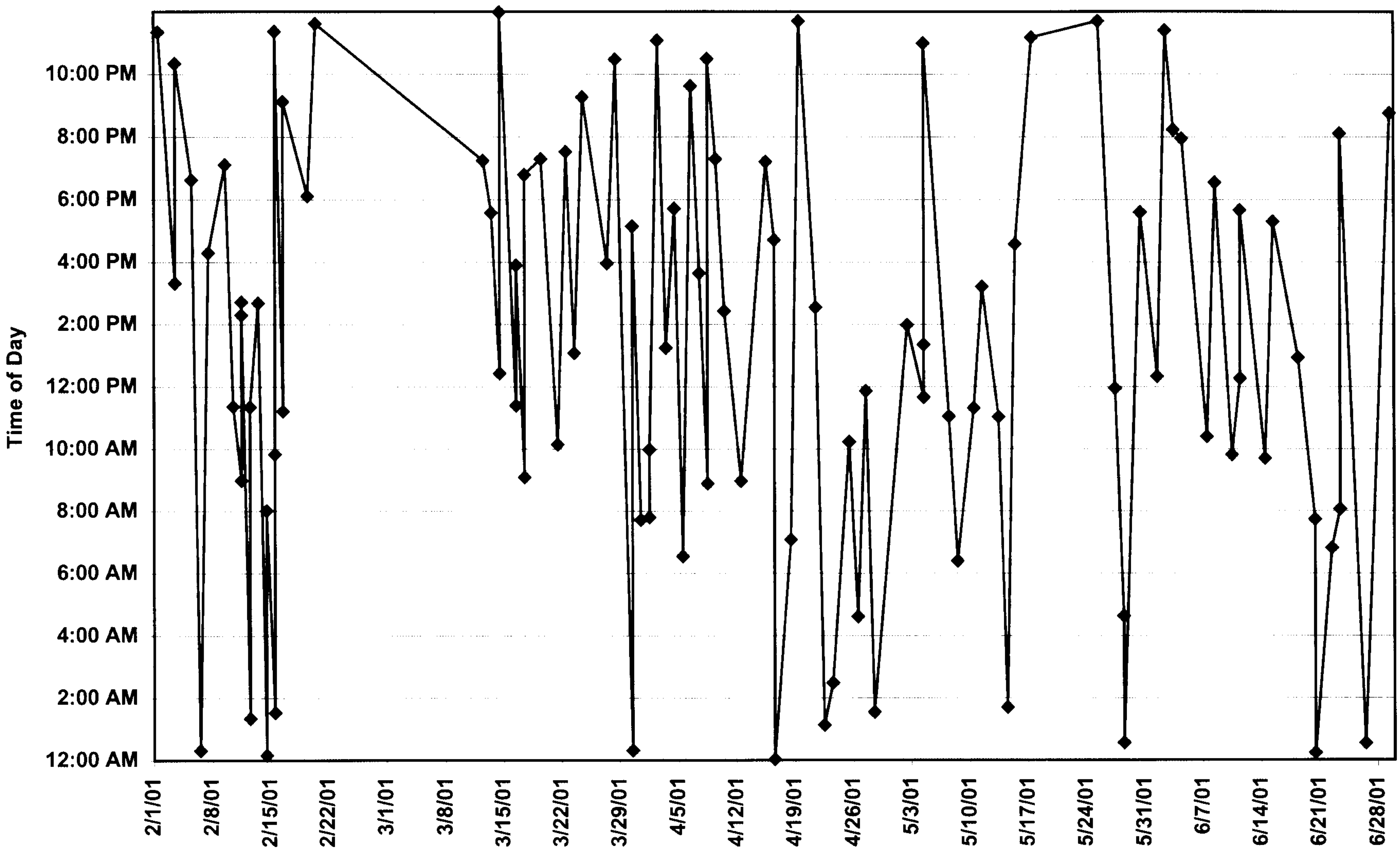
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-03



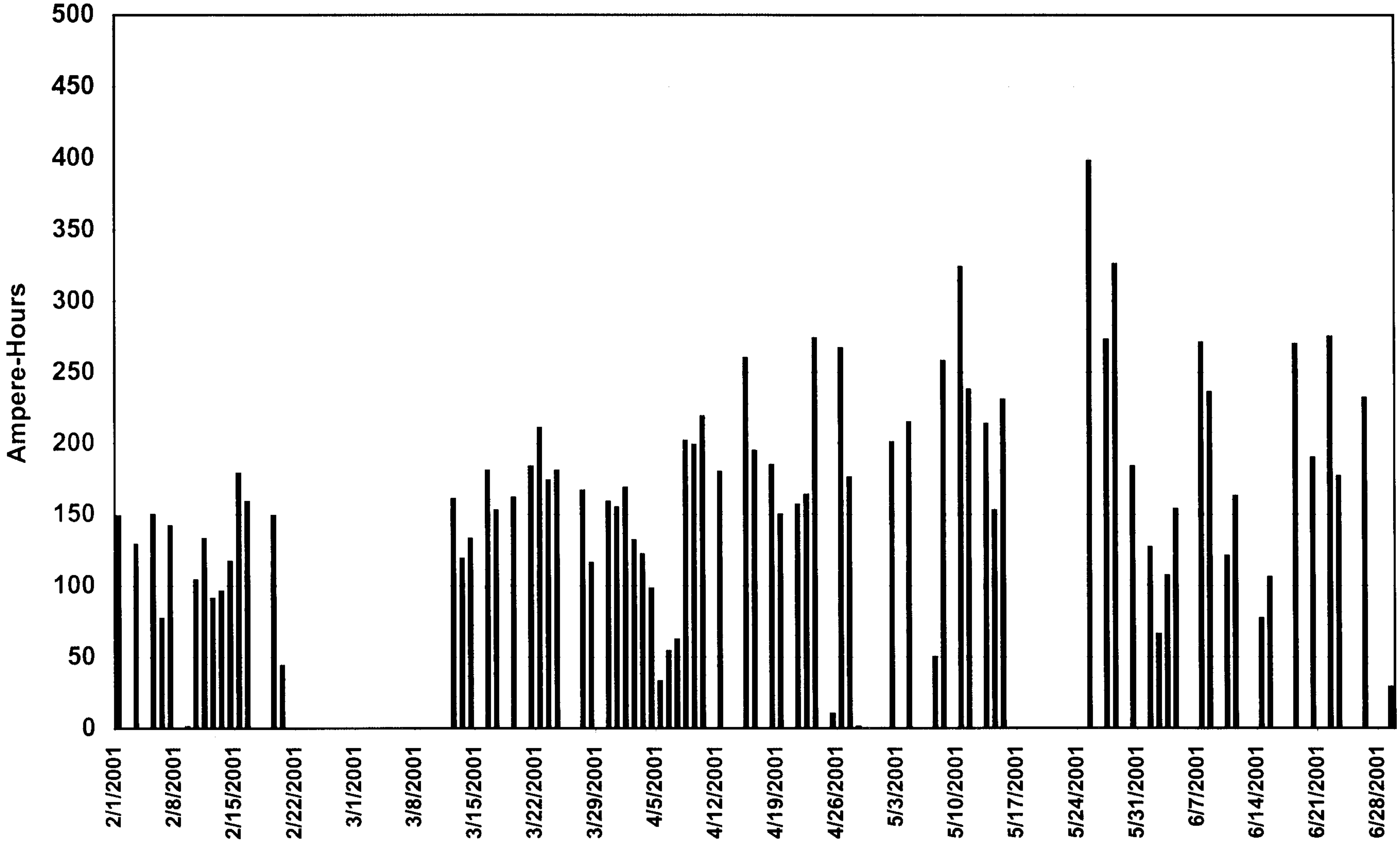
10-cycle Average Connect Standby Time - Vehicle BTE-03



Charge Start Time - Vehicle BTE-03

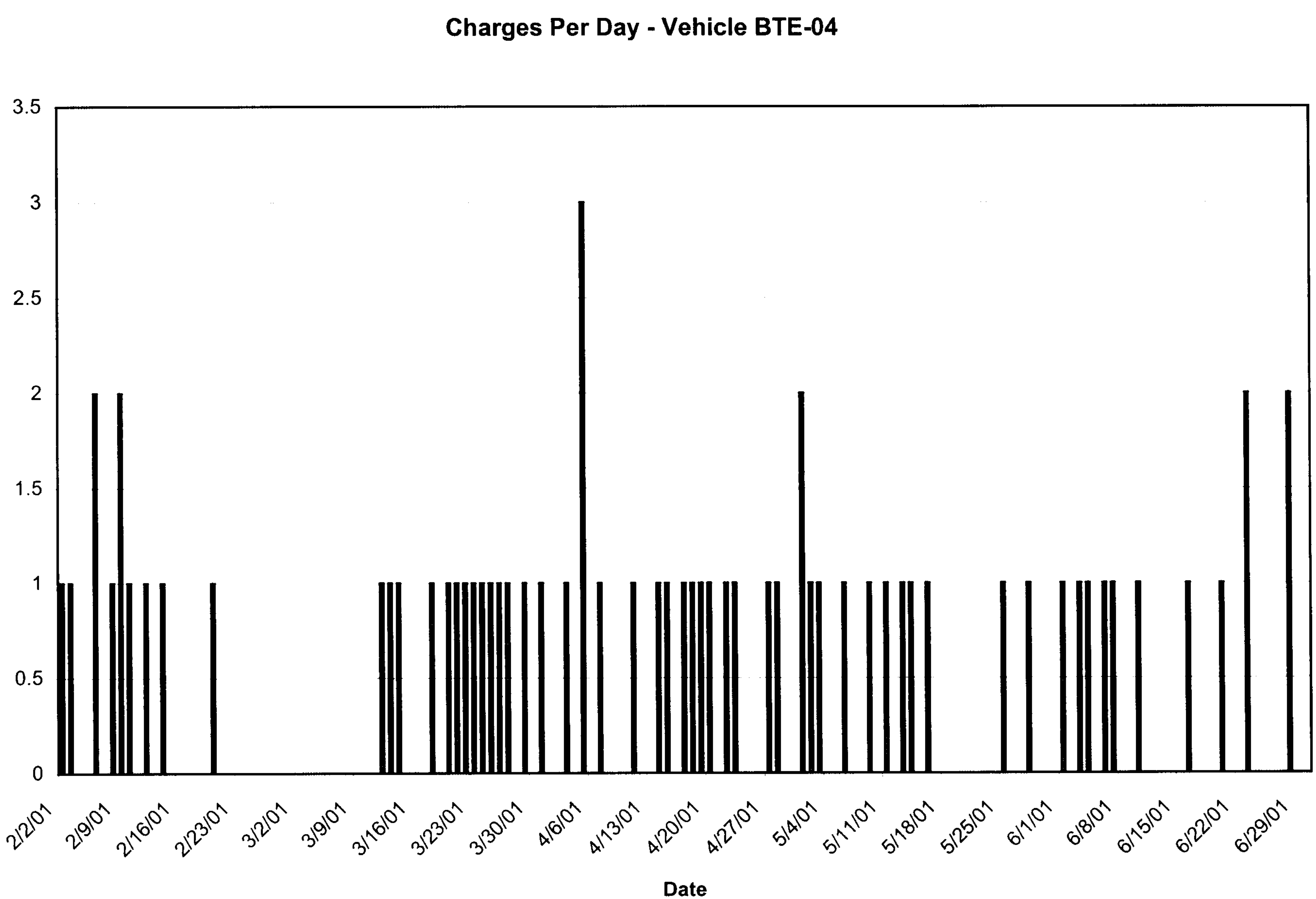


Ampere-Hours Returned per Charge - Vehicle BTE-03



DATA GRAPHS

TRACTOR
BTE-04



Charges Per Day - Vehicle BTE-04
3.5
3
2.5
2
1.5
1
0.5
0
2/2/01
2/9/01
2/16/01
2/23/01
3/2/01
3/9/01
3/16/01
3/23/01
3/30/01
4/6/01
4/13/01
4/20/01
4/27/01
5/4/01
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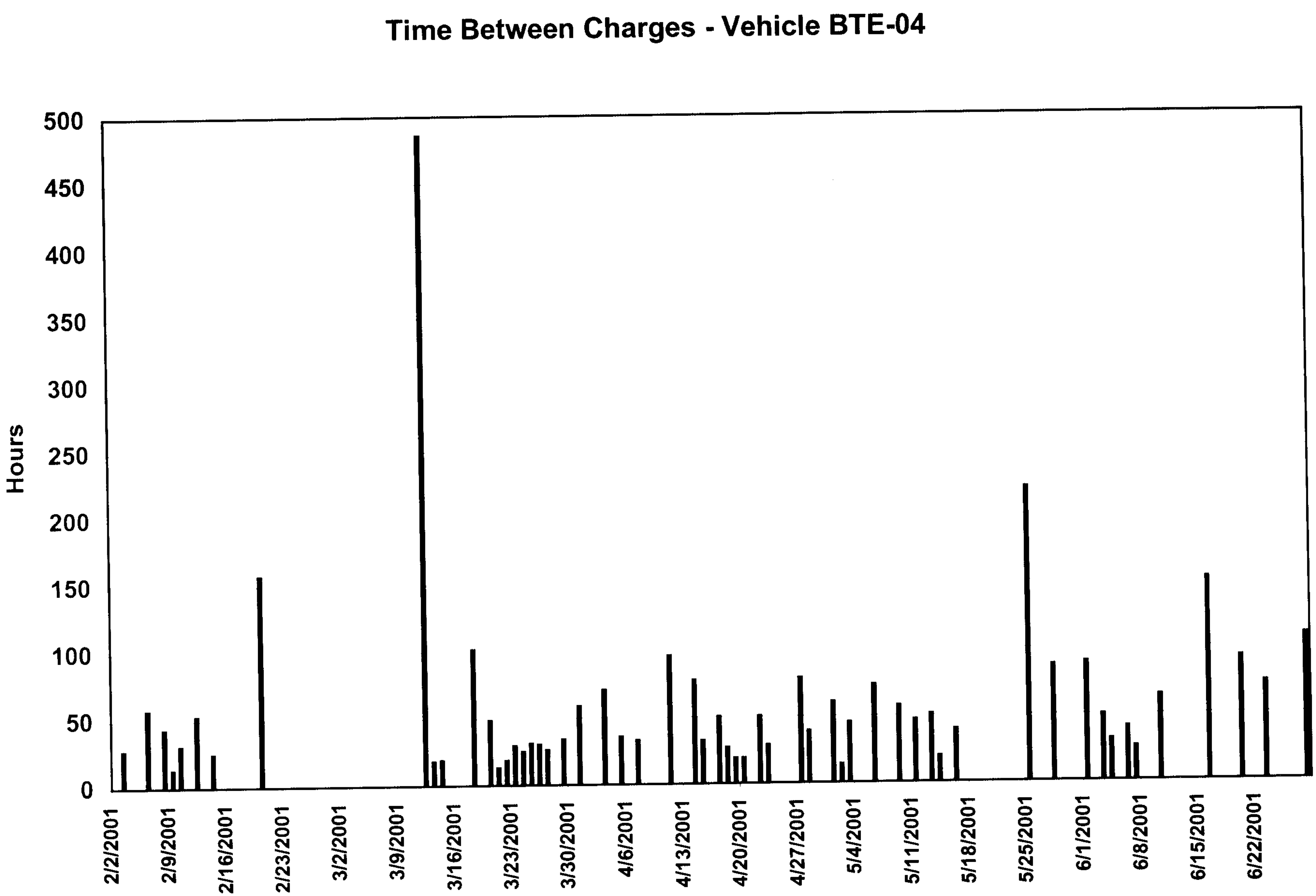
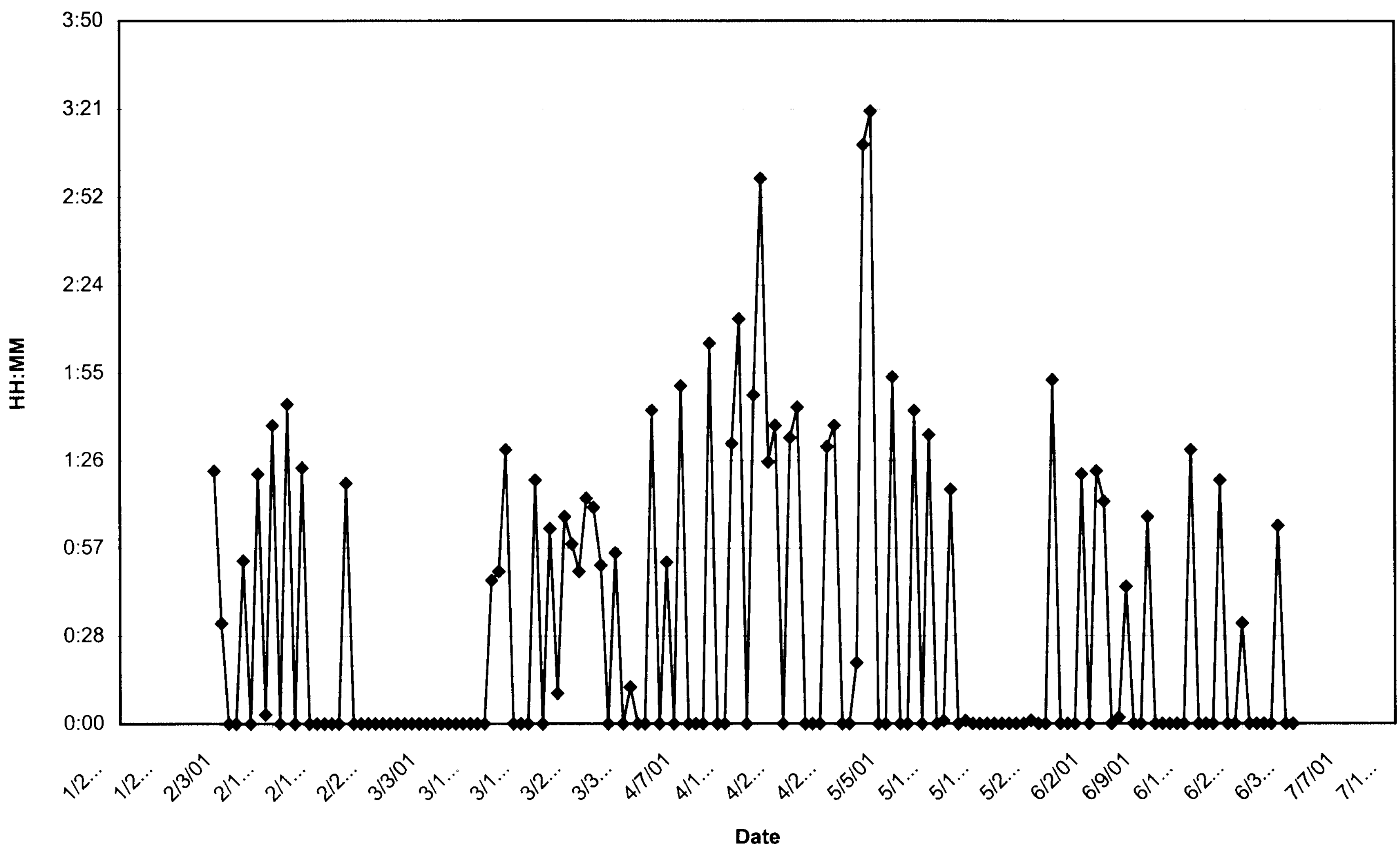
6/22/01
6/29/01
Date

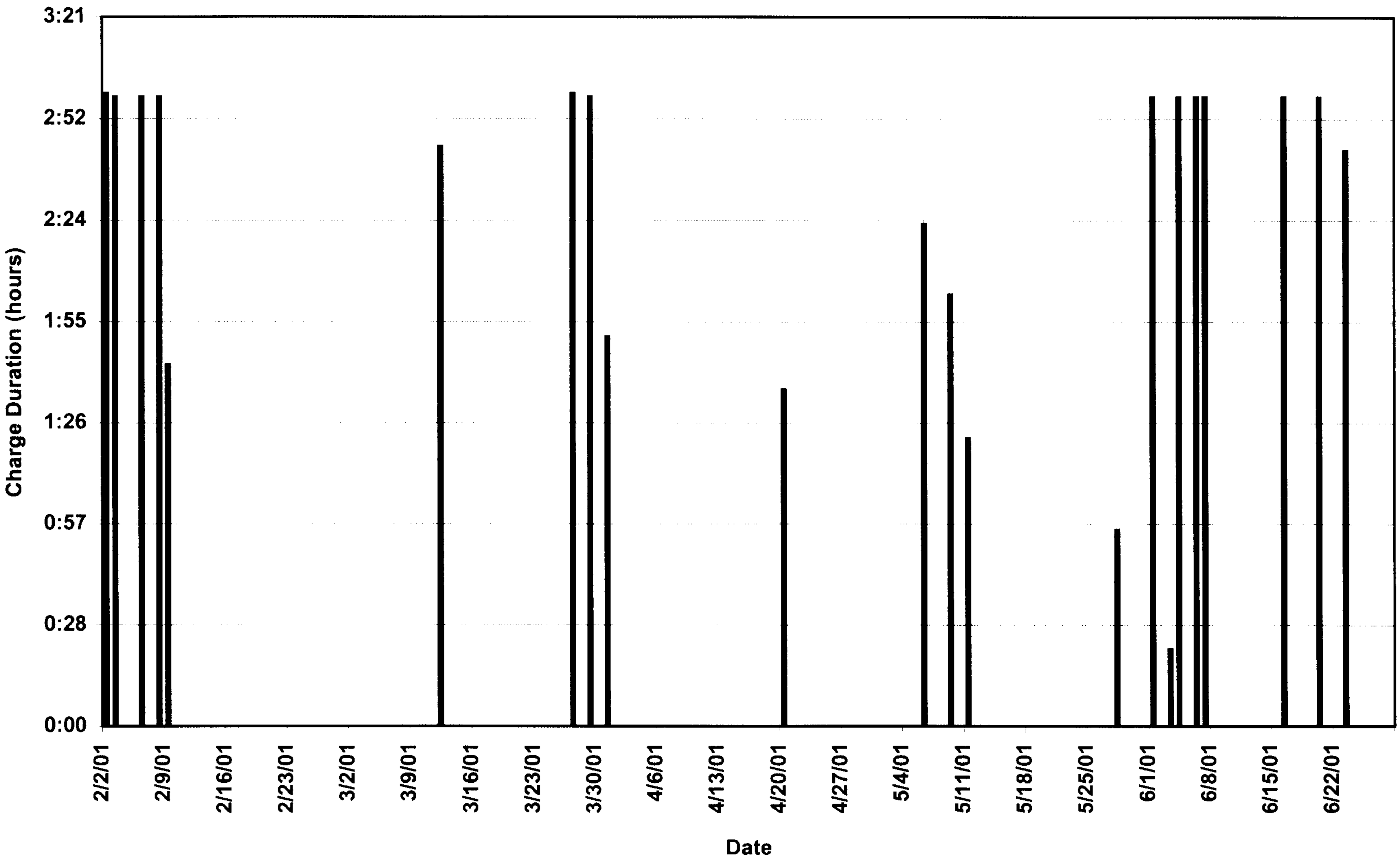


Time Between Charges - Vehicle BTE-04
Hours
500
450
400
350
300
250
200
150
100
50
0
2/2/2001
2/9/2001
2/16/2001
2/23/2001
3/2/2001
3/9/2001
3/16/2001
3/23/2001
3/30/2001
4/6/2001
4/13/2001
4/20/2001
4/27/2001
5/4/2001
5/11/2001
5/18/2001
5/25/2001
6/1/2001
6/8/2001
6/15/2001
6/22/2001

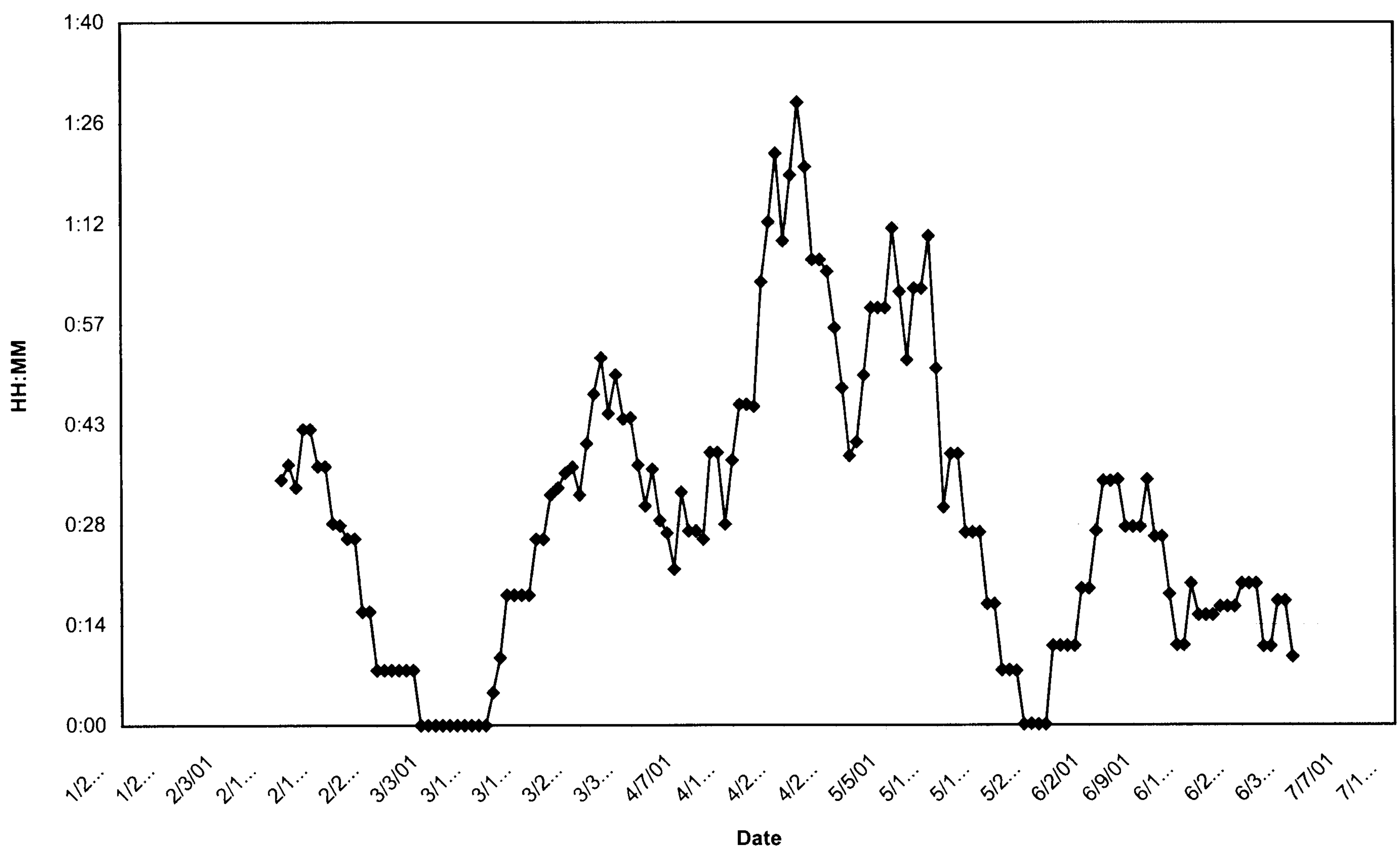
Average Charge Time - Vehicle BTE-04



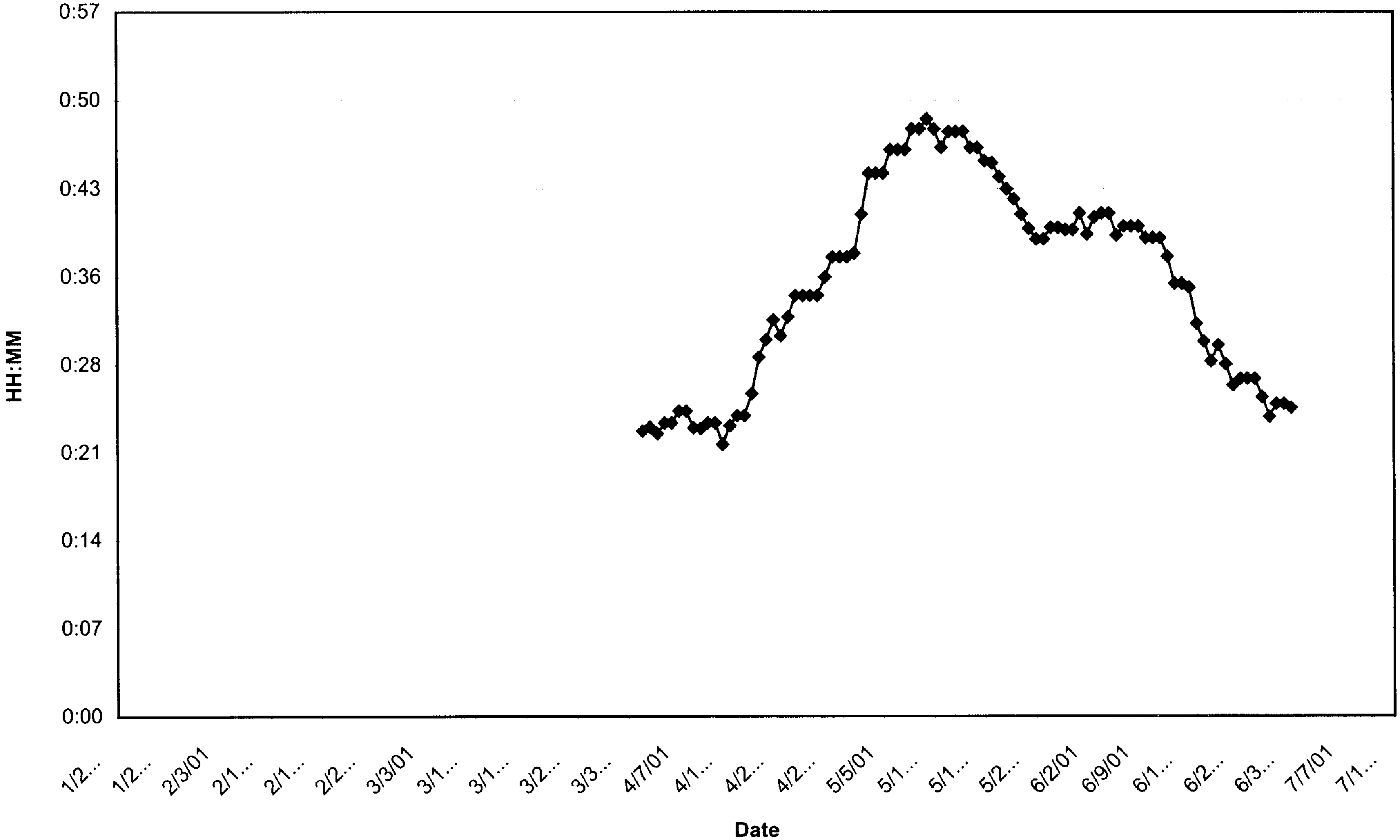
Time on Equalizing Charge - Vehicle BTE-04



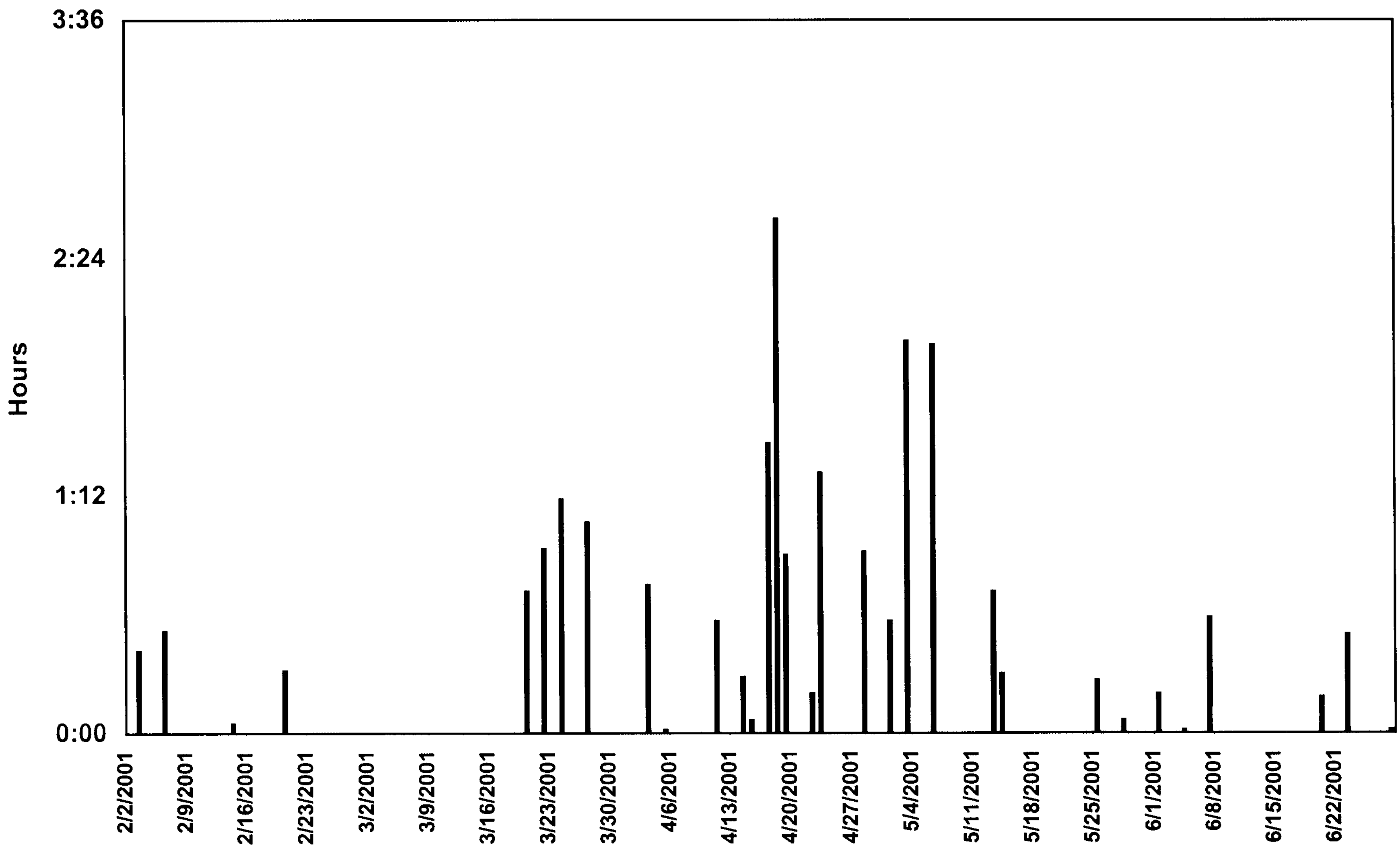
10-Day Average Charge Time - Vehicle BTE-04



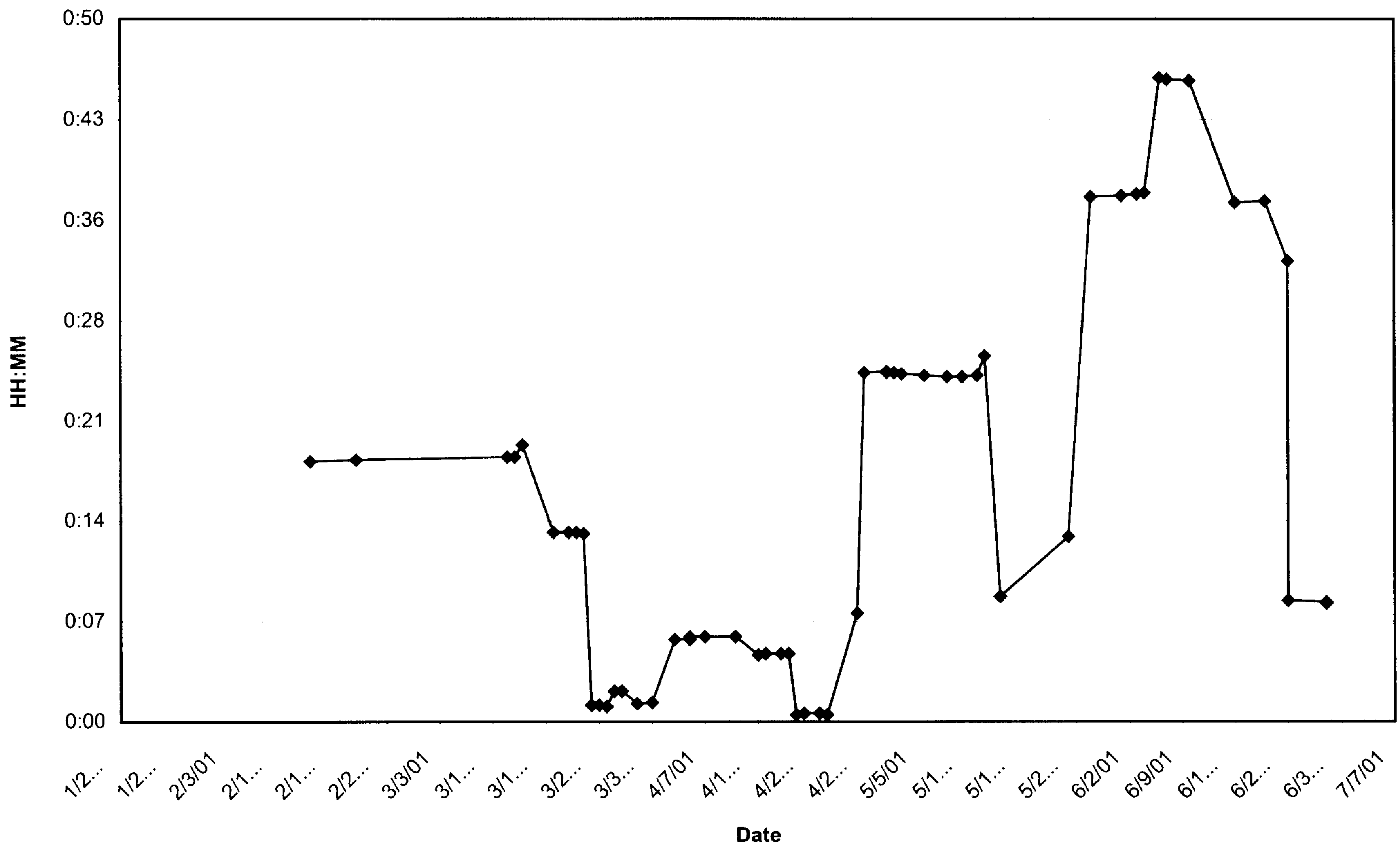
60-Day Average Charge Time - Vehicle BTE-04



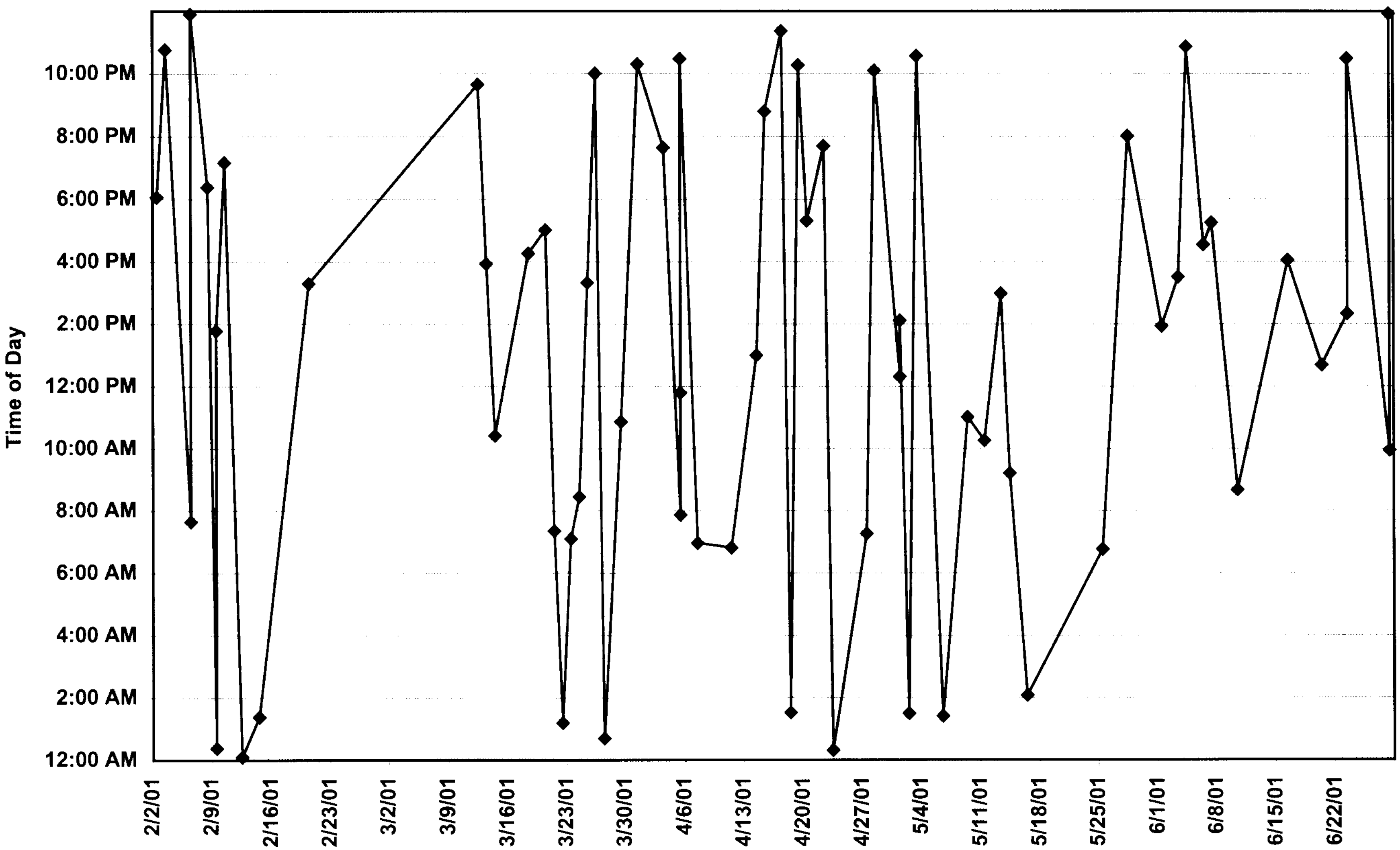
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-04



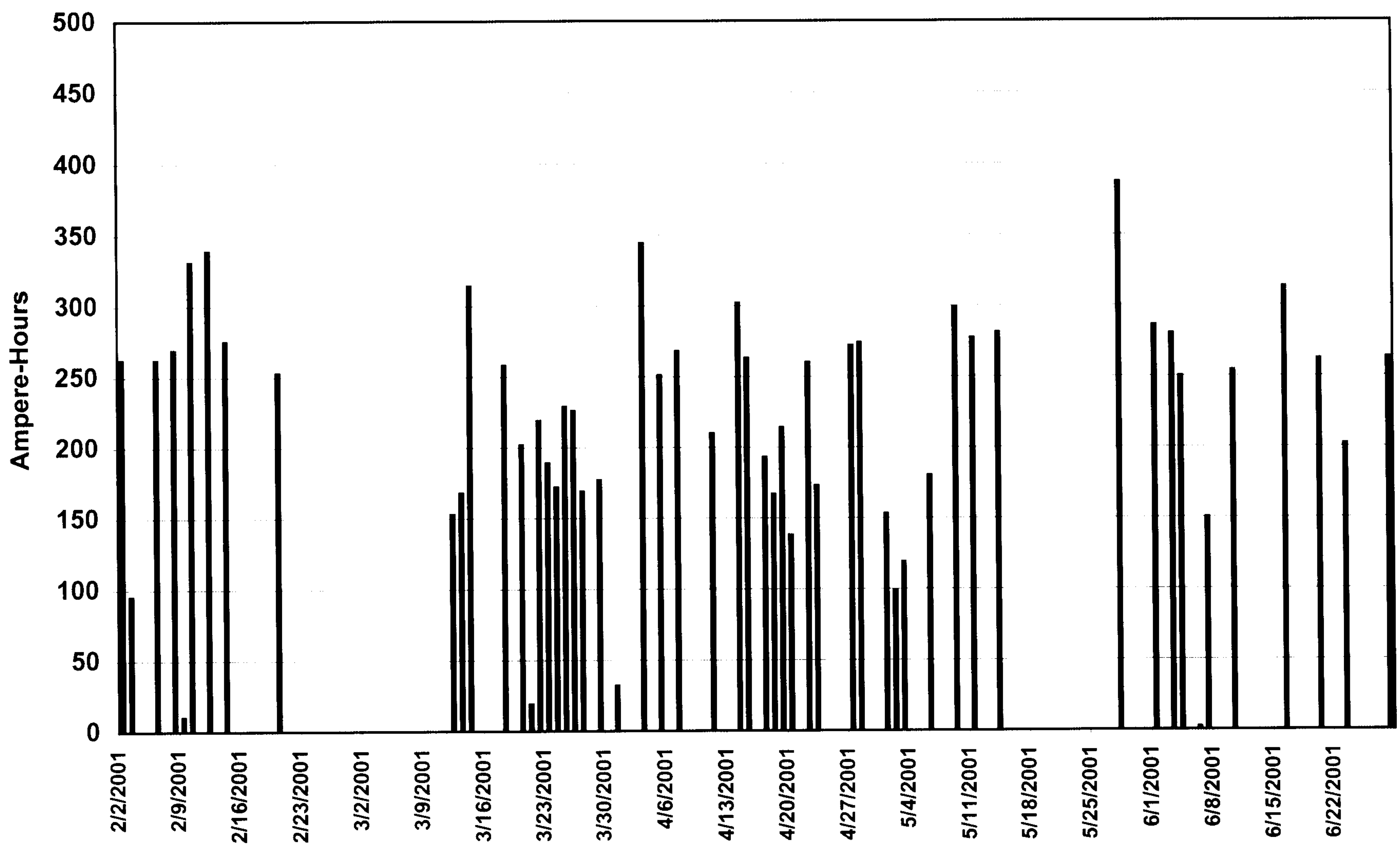
10-Cycle Average Connect Standby Time - Vehicle BTE-04



Charge Start Times - Vehicle BTE-04



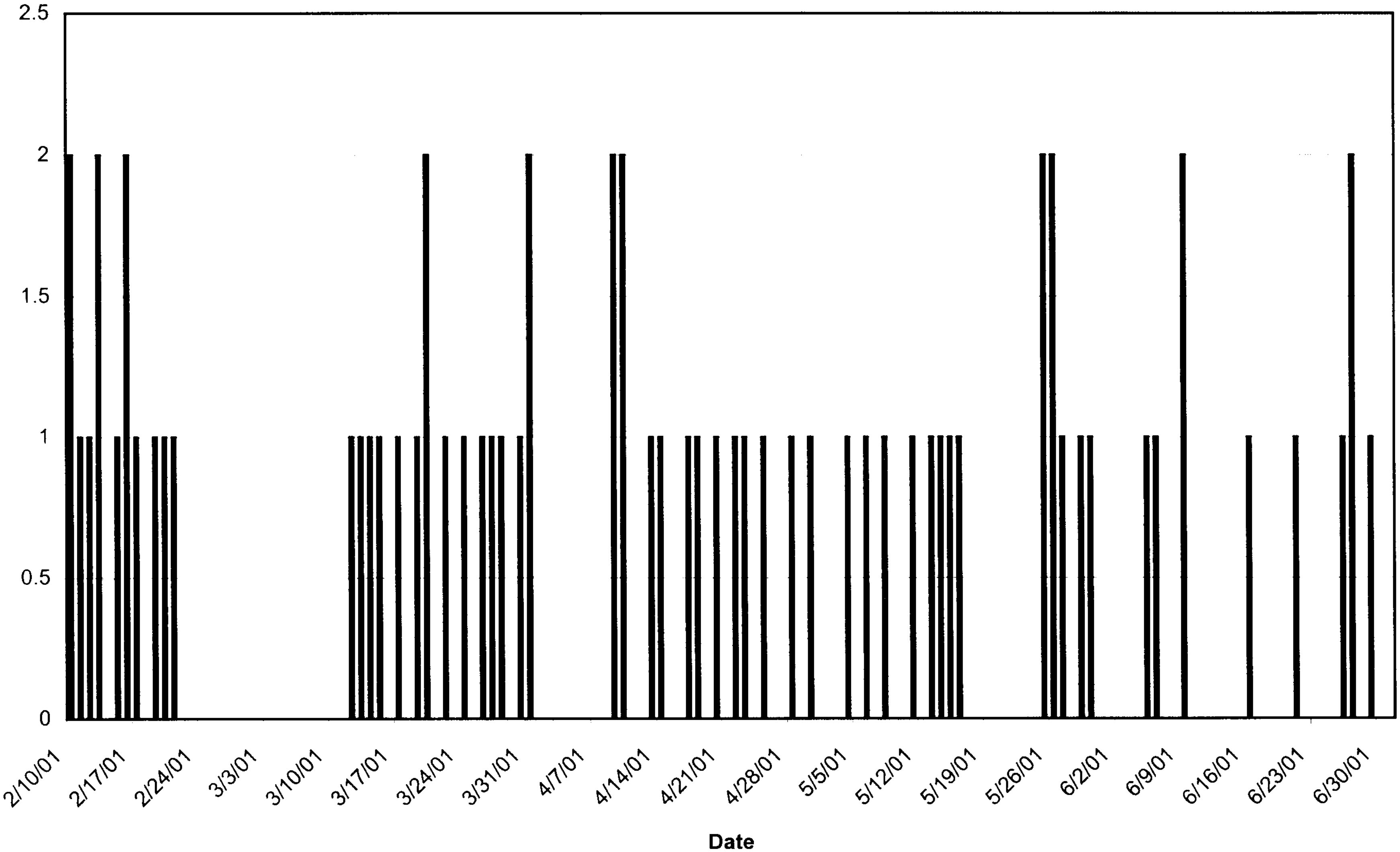
Ampere-Hours Returned per Charge - Vehicle BTE-04



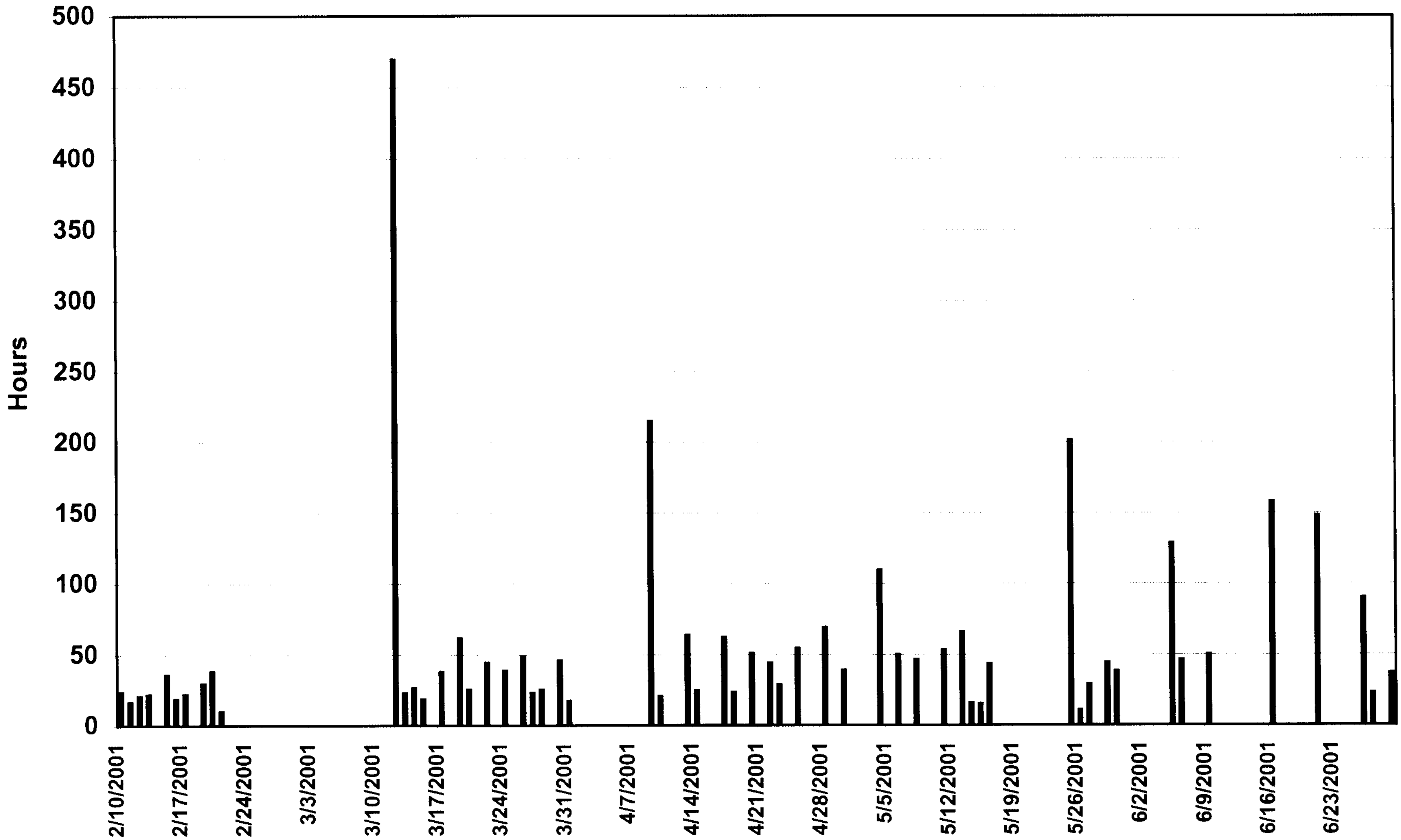
DATA GRAPHS

TRACTOR
BTE-05

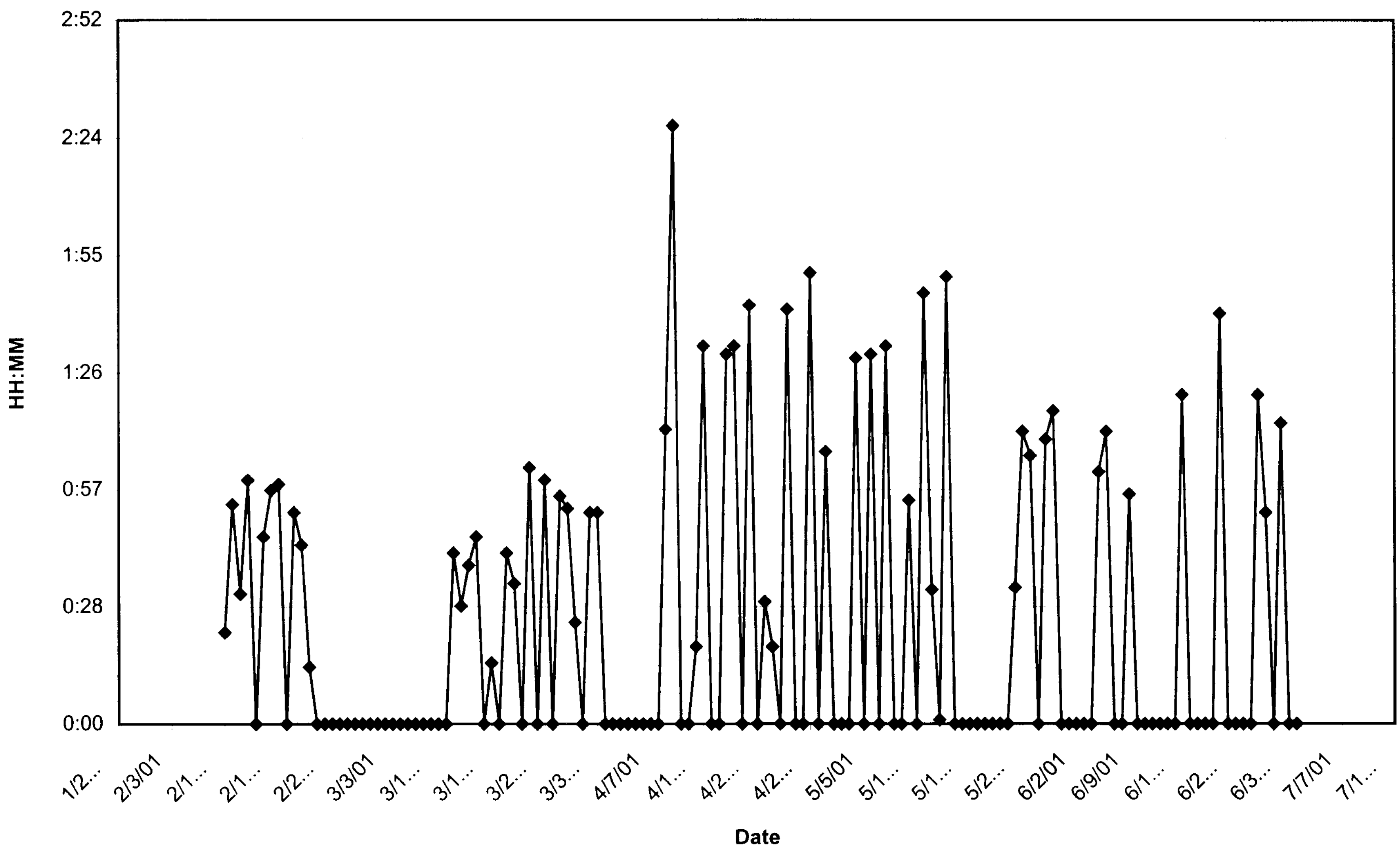
Charges Per Day - Vehicle BTE-05



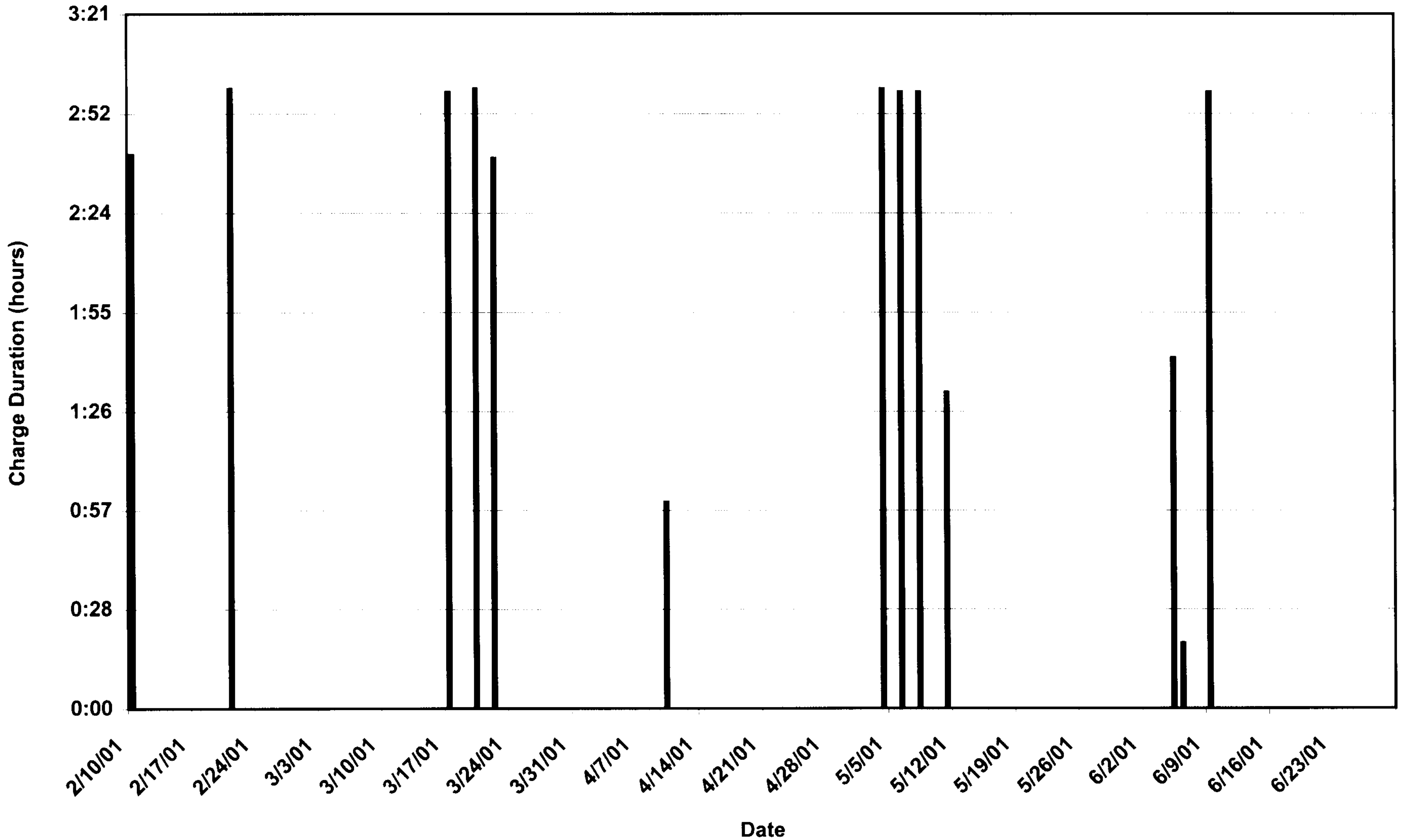
Time Between Charges - Vehicle BTE-05

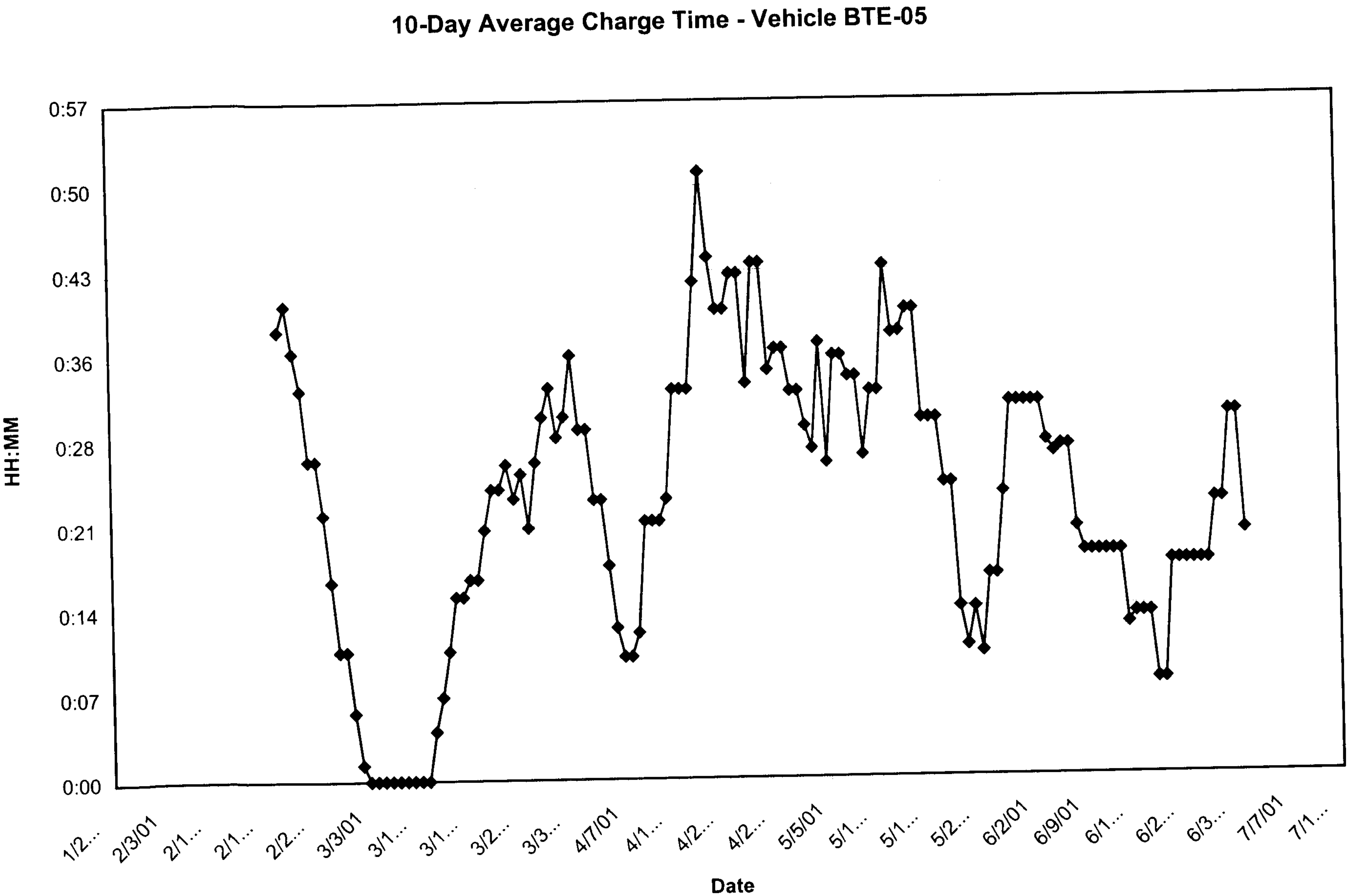


Average Charge Time - Vehicle BTE-05

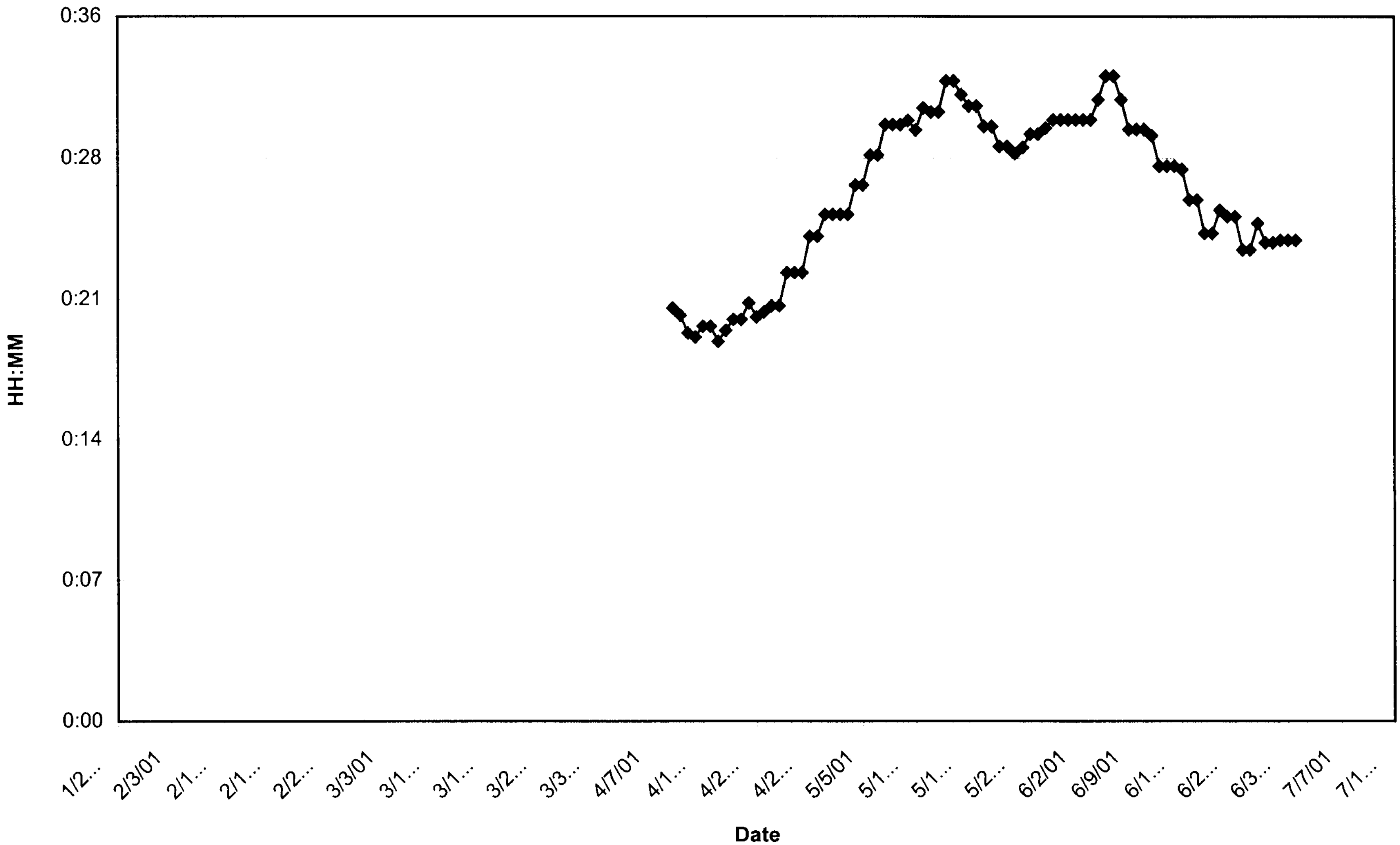


Time on Equalize Charge - Vehicle BTE-05

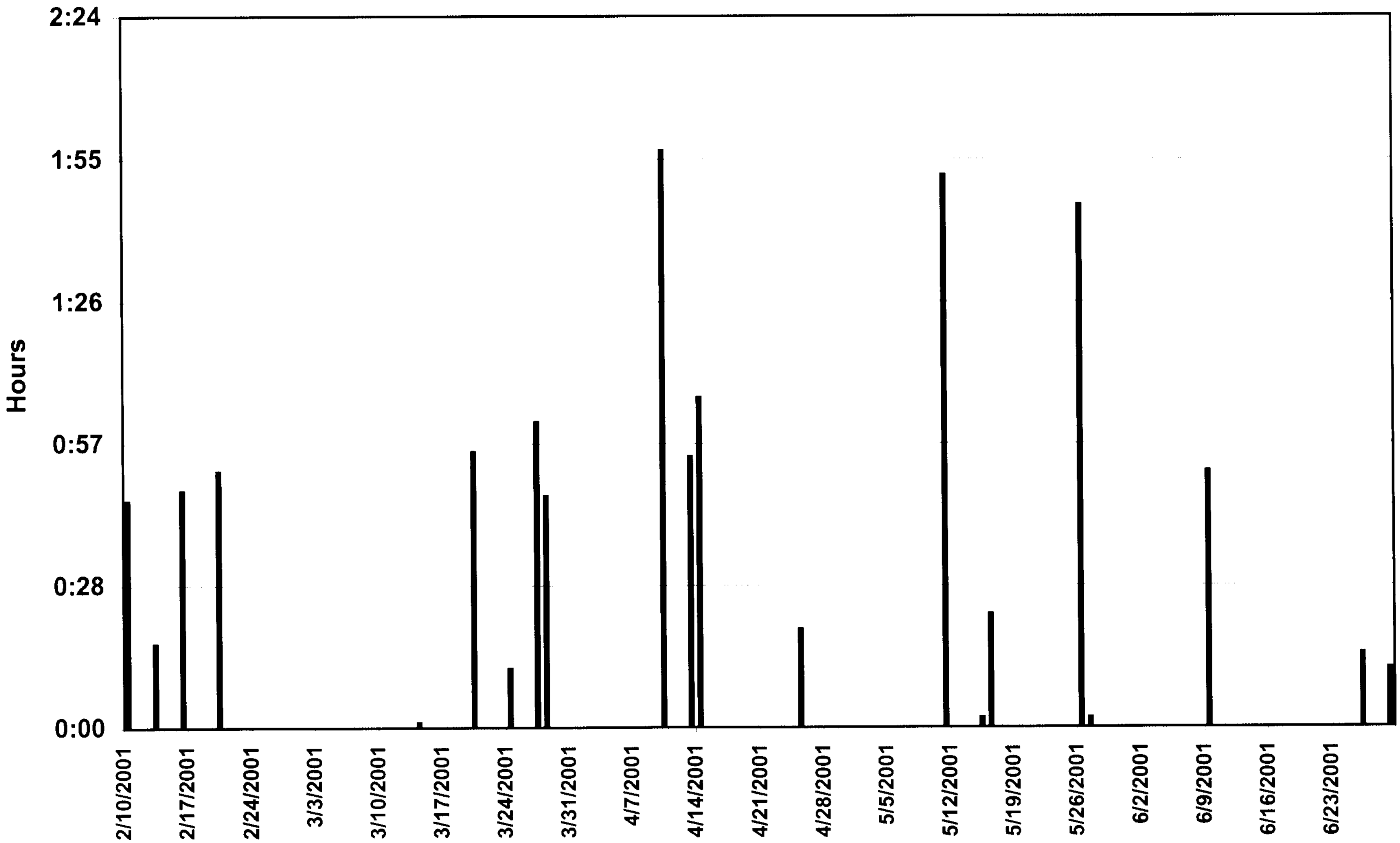



10-Day Average Charge Time - Vehicle BTE-05
HH:MM
0:57
0:50
0:43
0:36
0:28
0:21
0:14
0:07
0:00
1/2...
2/3/01
2/1...
2/1...
2/2...
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
7/1...
Date

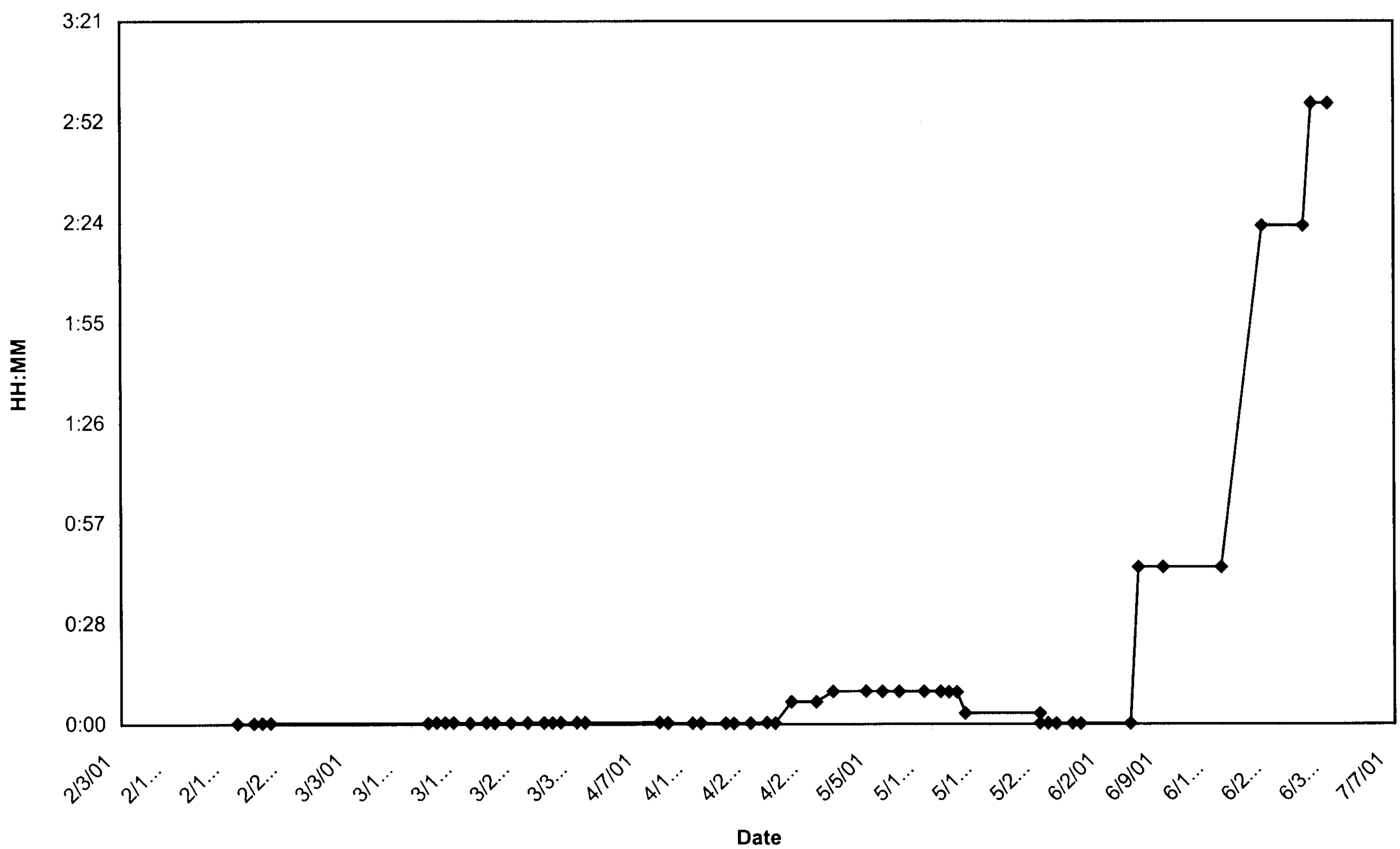
60-Day Average Charge Time - Vehicle BTE-05



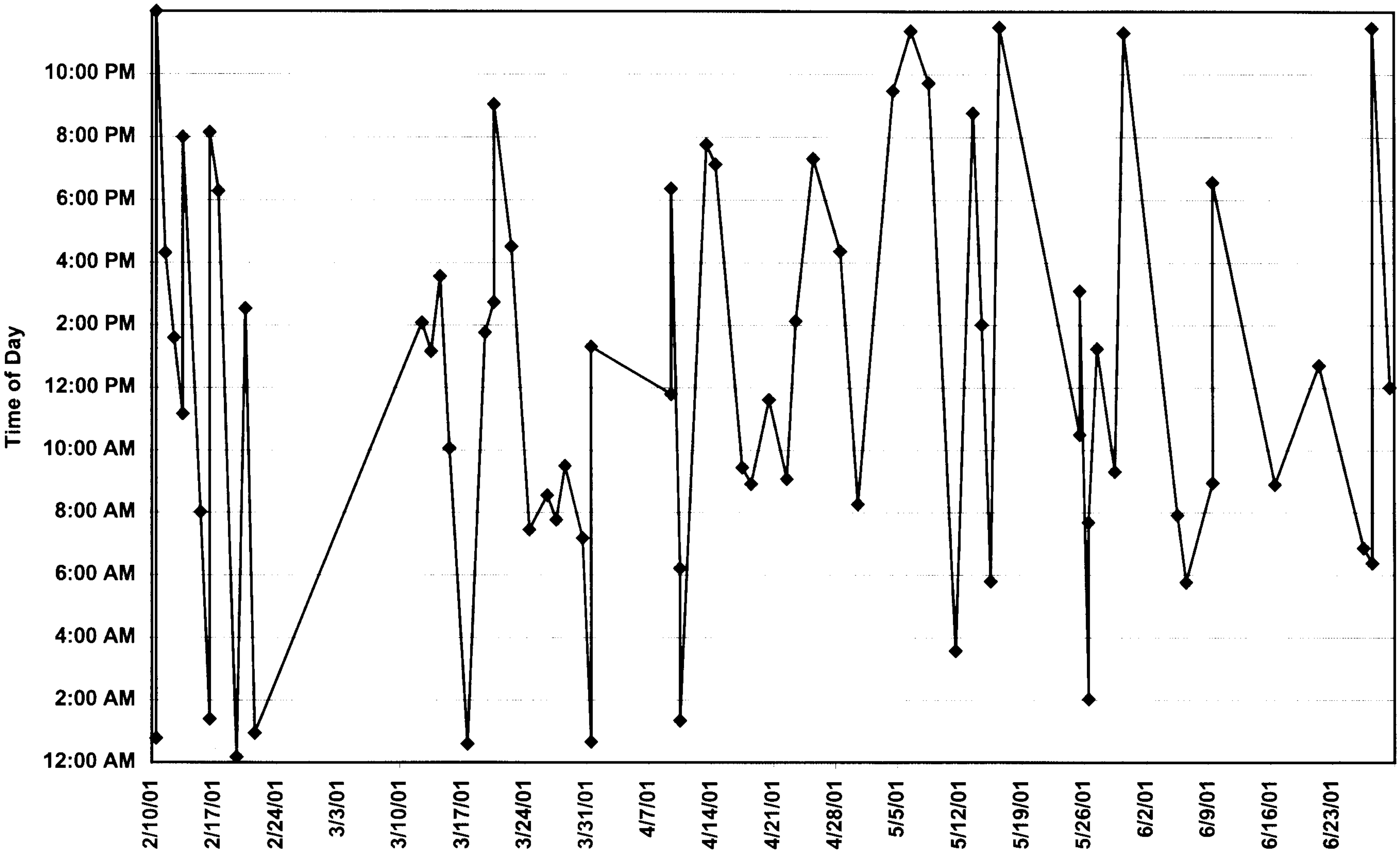
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-05



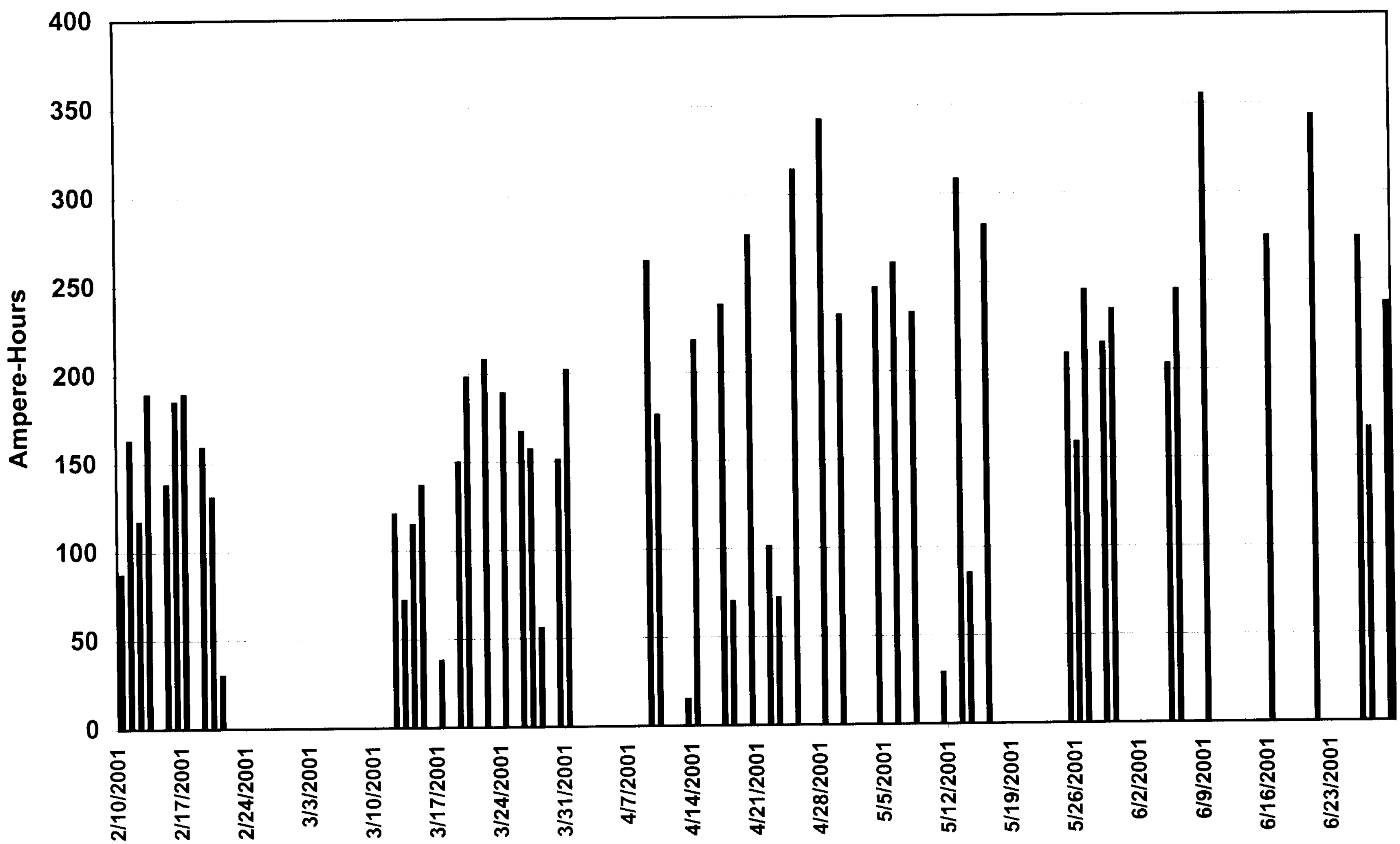
10-Cycle Average Connect Standby Time - Vehicle BTE-05



Charge Start Times - Vehicle BTE-05



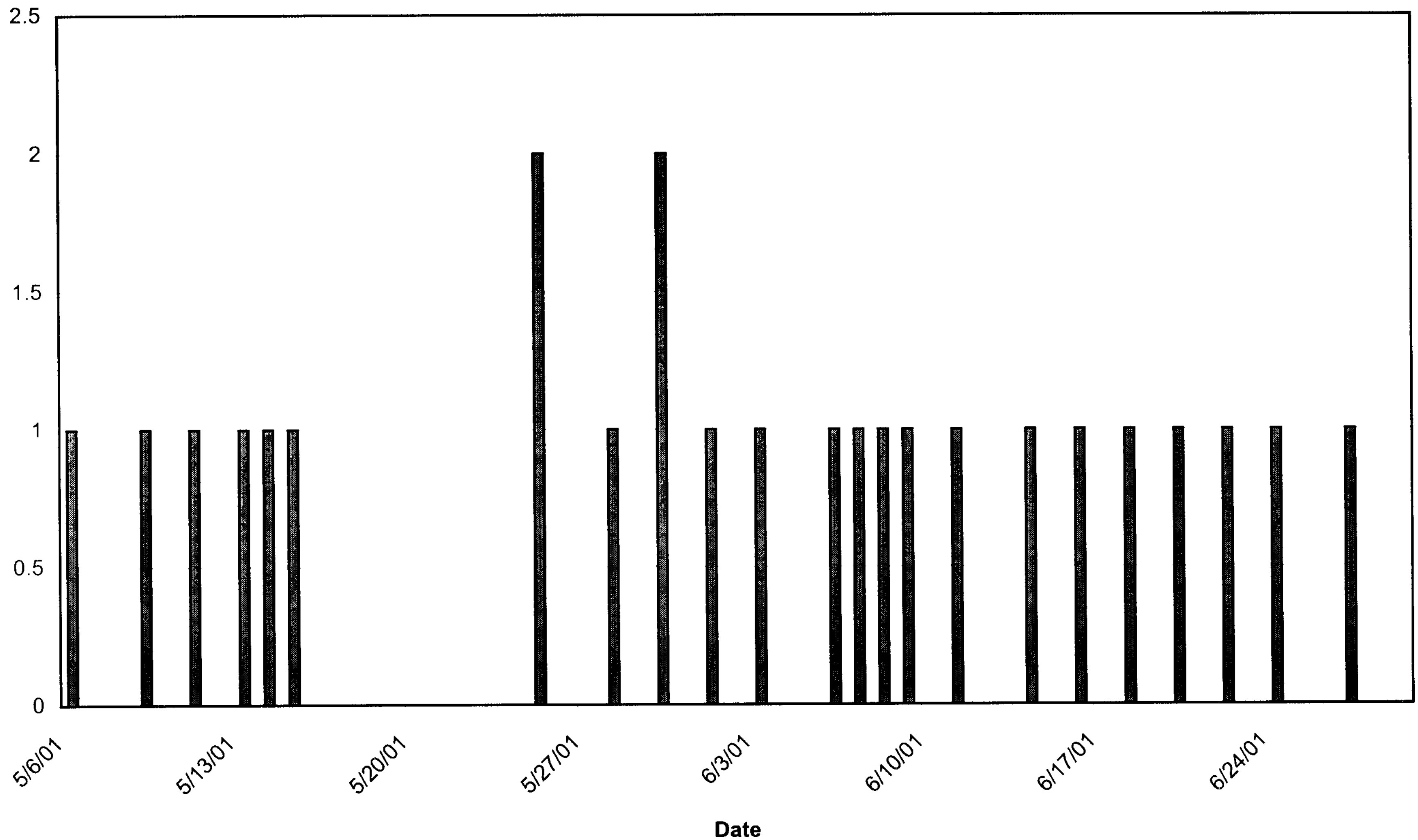
Ampere-Hours Returned per Charge - Vehicle BTE-05

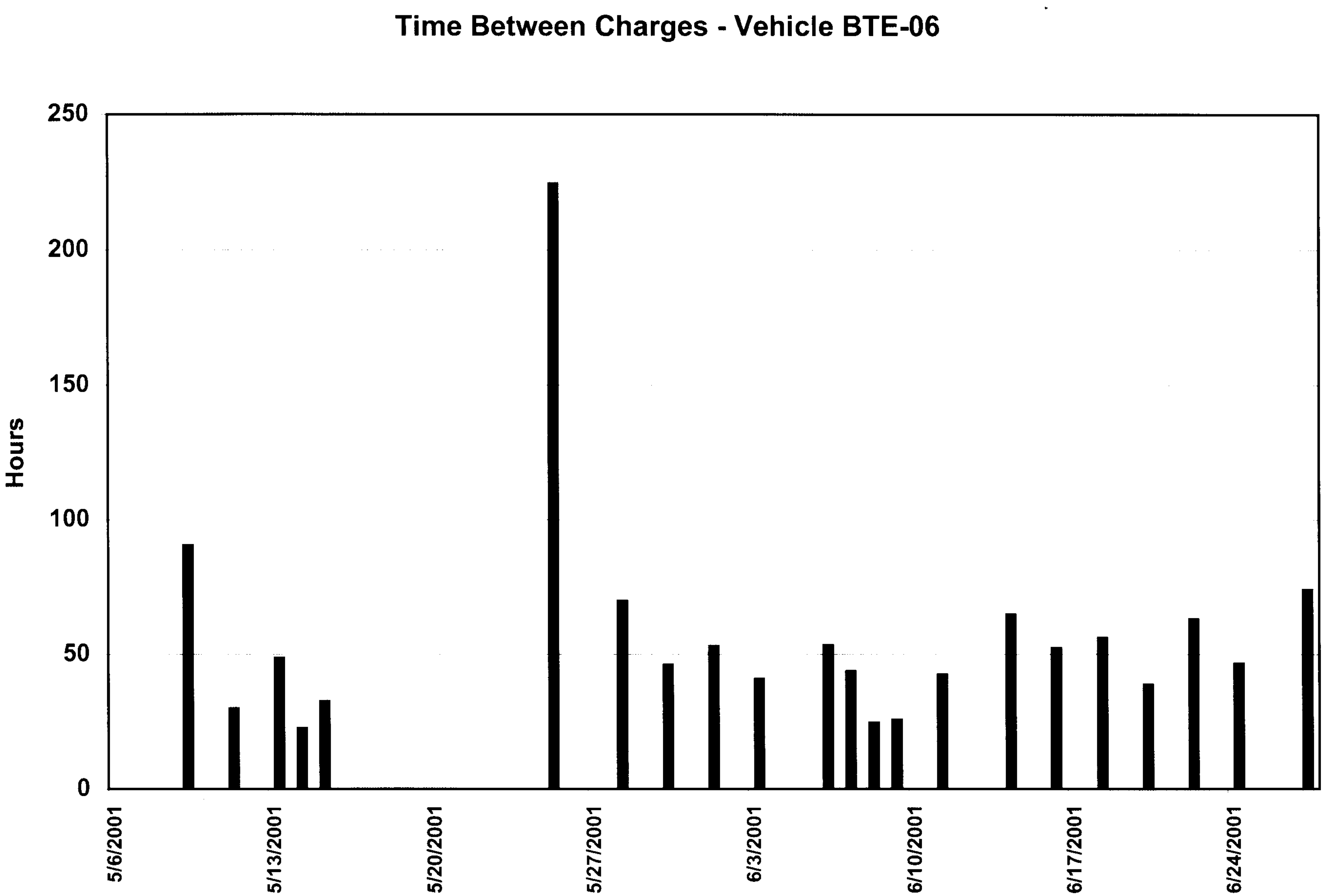


DATA GRAPHS

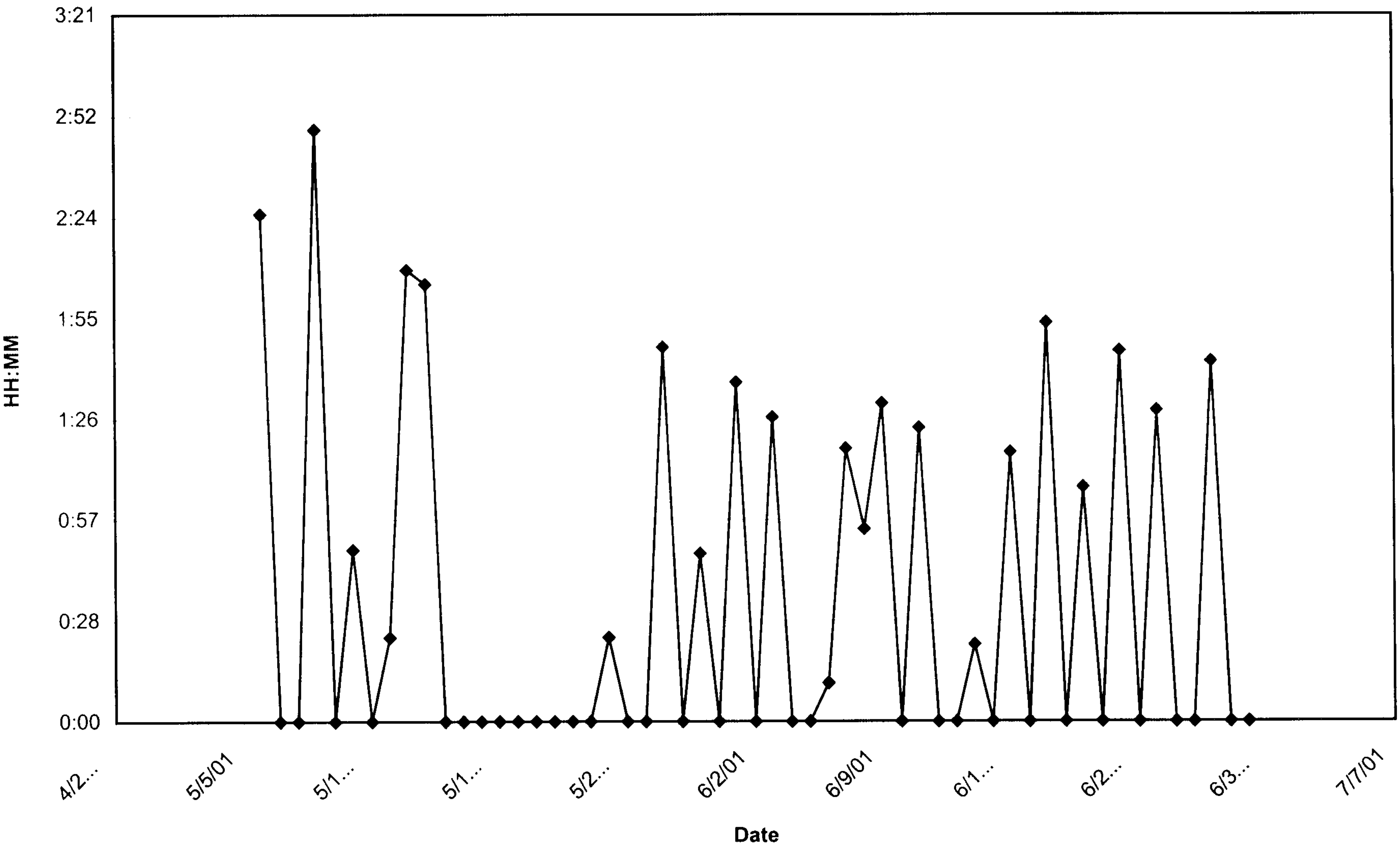
TRACTOR
BTE-06

Charges Per Day - Vehicle BTE-06

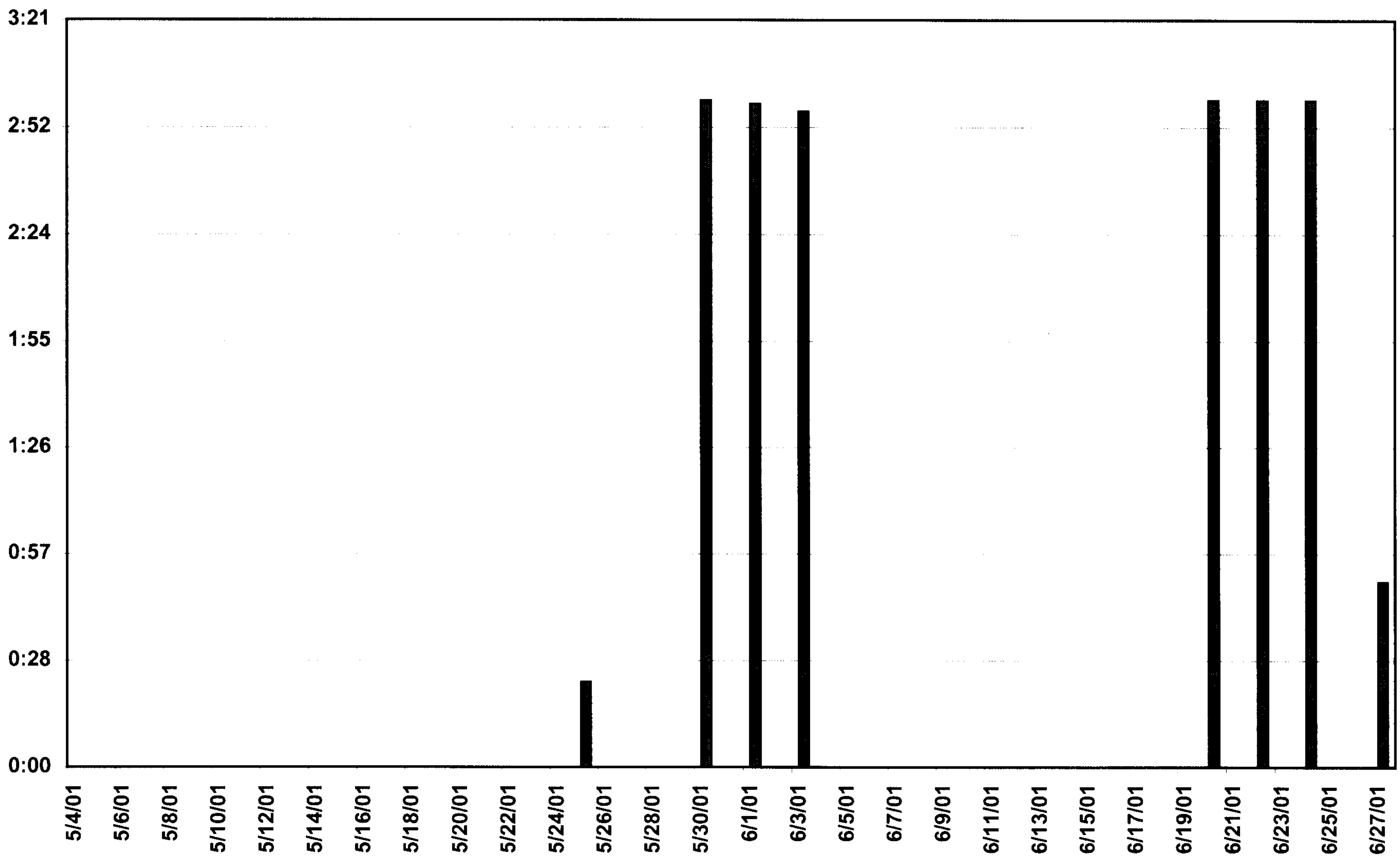



Time Between Charges - Vehicle BTE-06
Hours
250
200
150
100
50
0
5/6/2001
5/13/2001
5/20/2001
5/27/2001
6/3/2001
6/10/2001
6/17/2001
6/24/2001

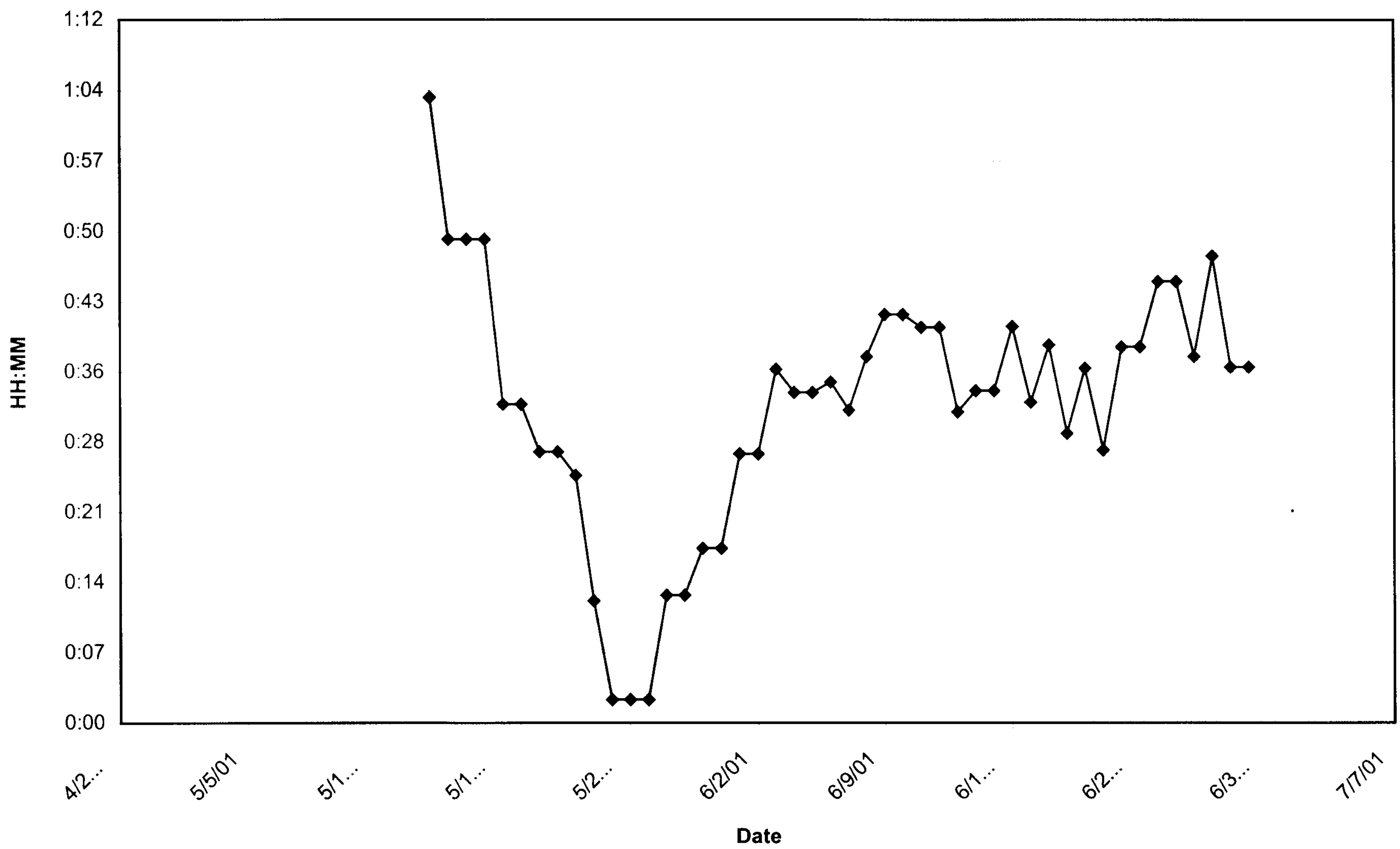
Average Charge Time - Vehicle BTE-06



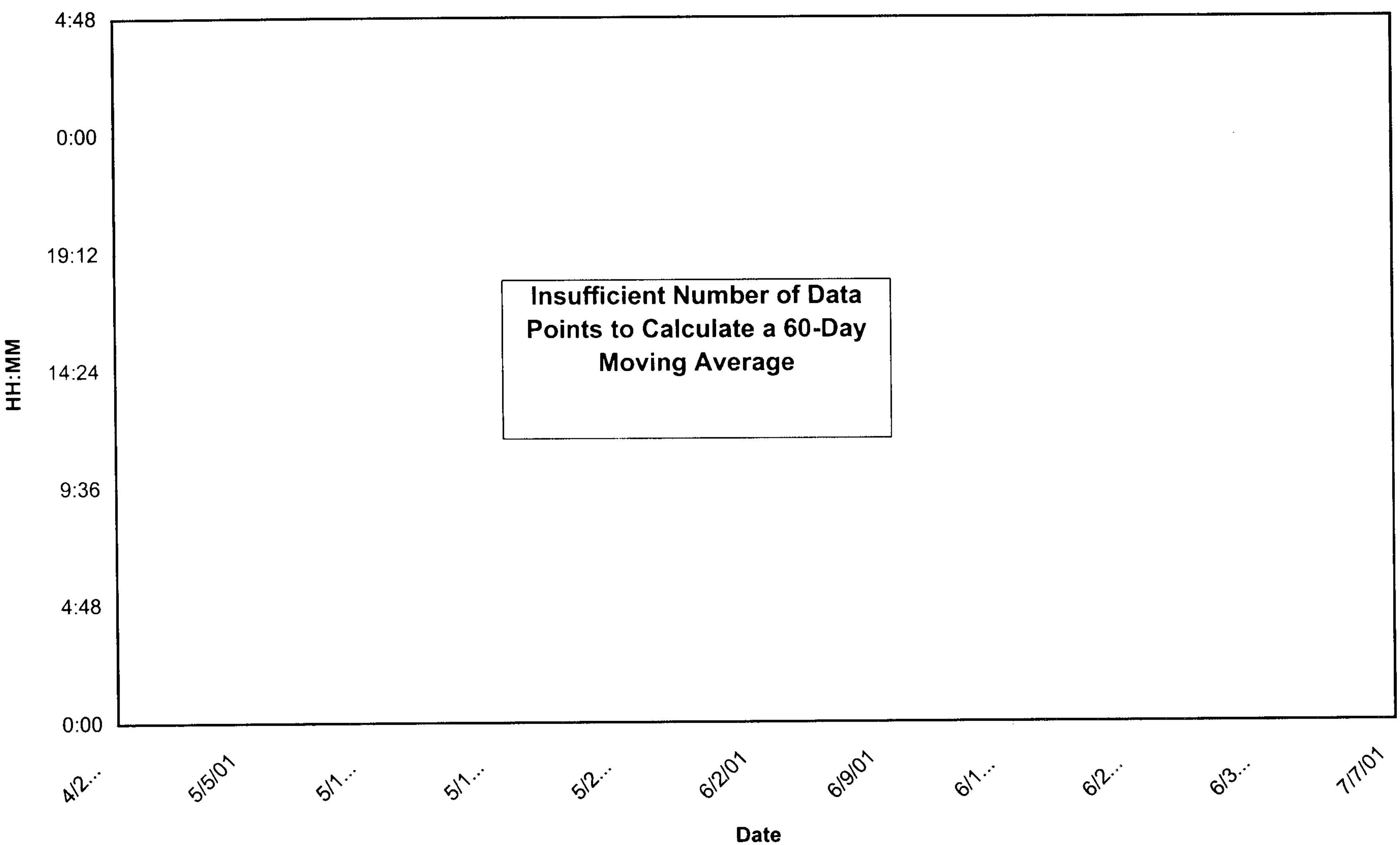
Time on Equalize Charge - Vehicle BTE-06



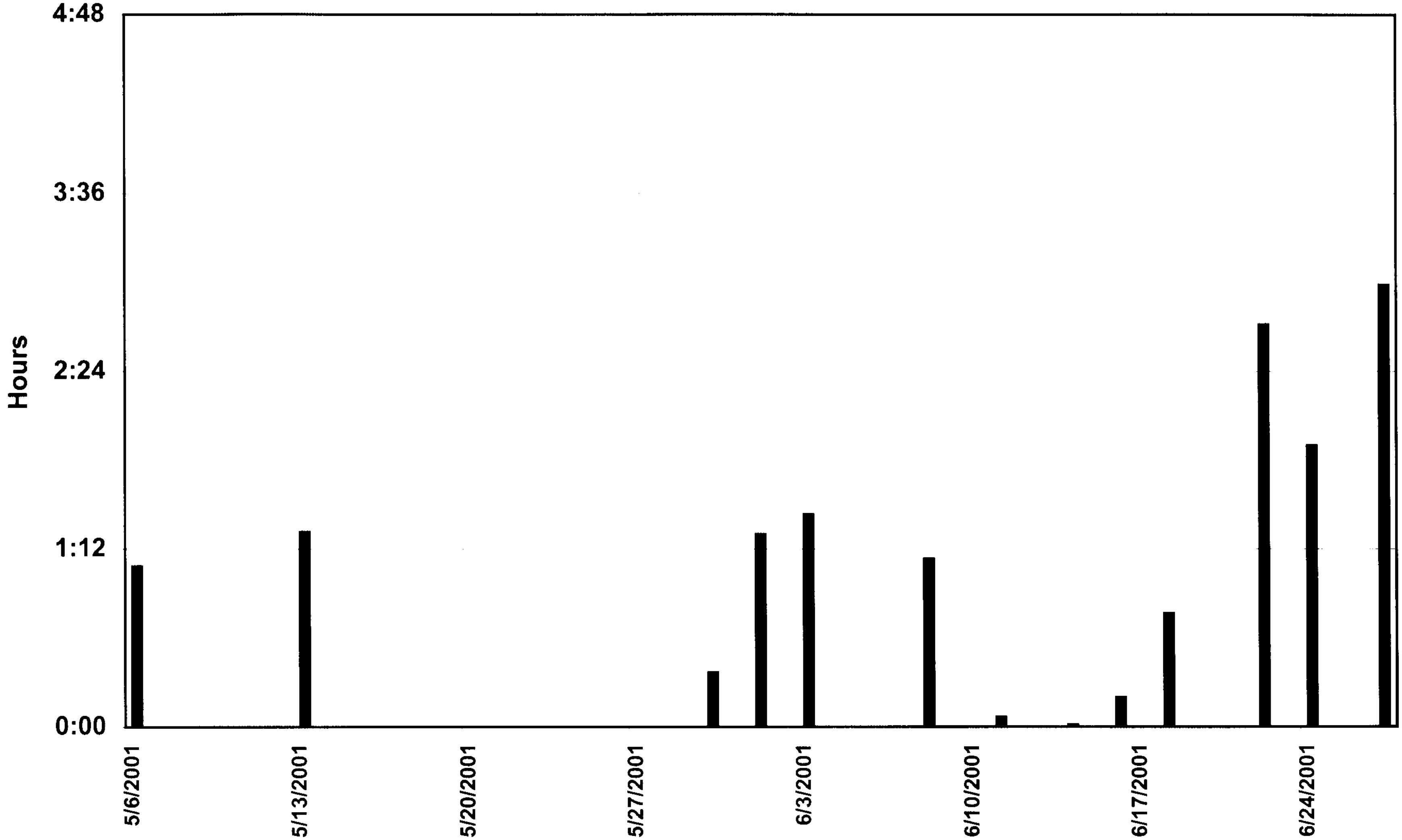
10-Day Average Charge Time - Vehicle BTE-06



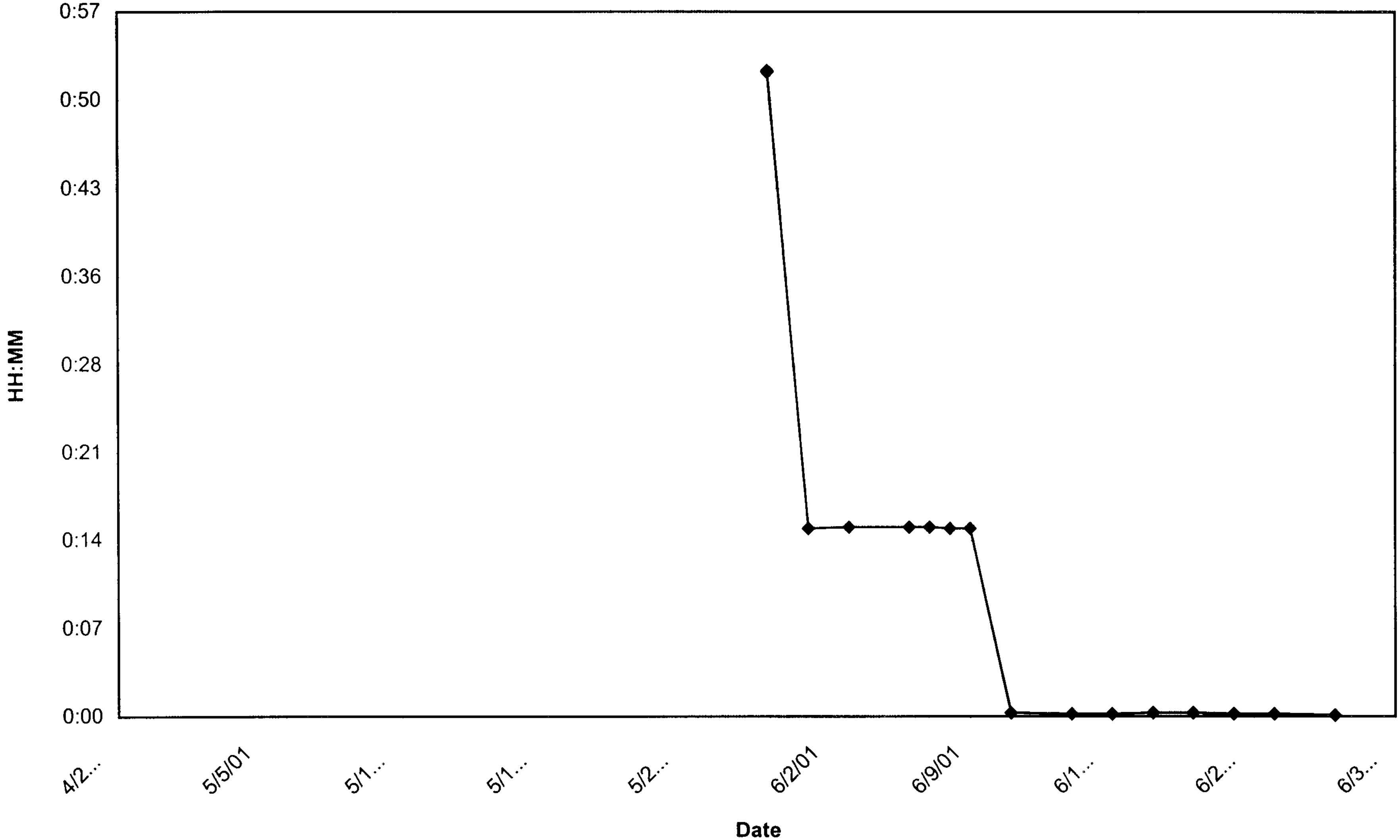
60-Day Average Charge Time - Vehicle BTE-06



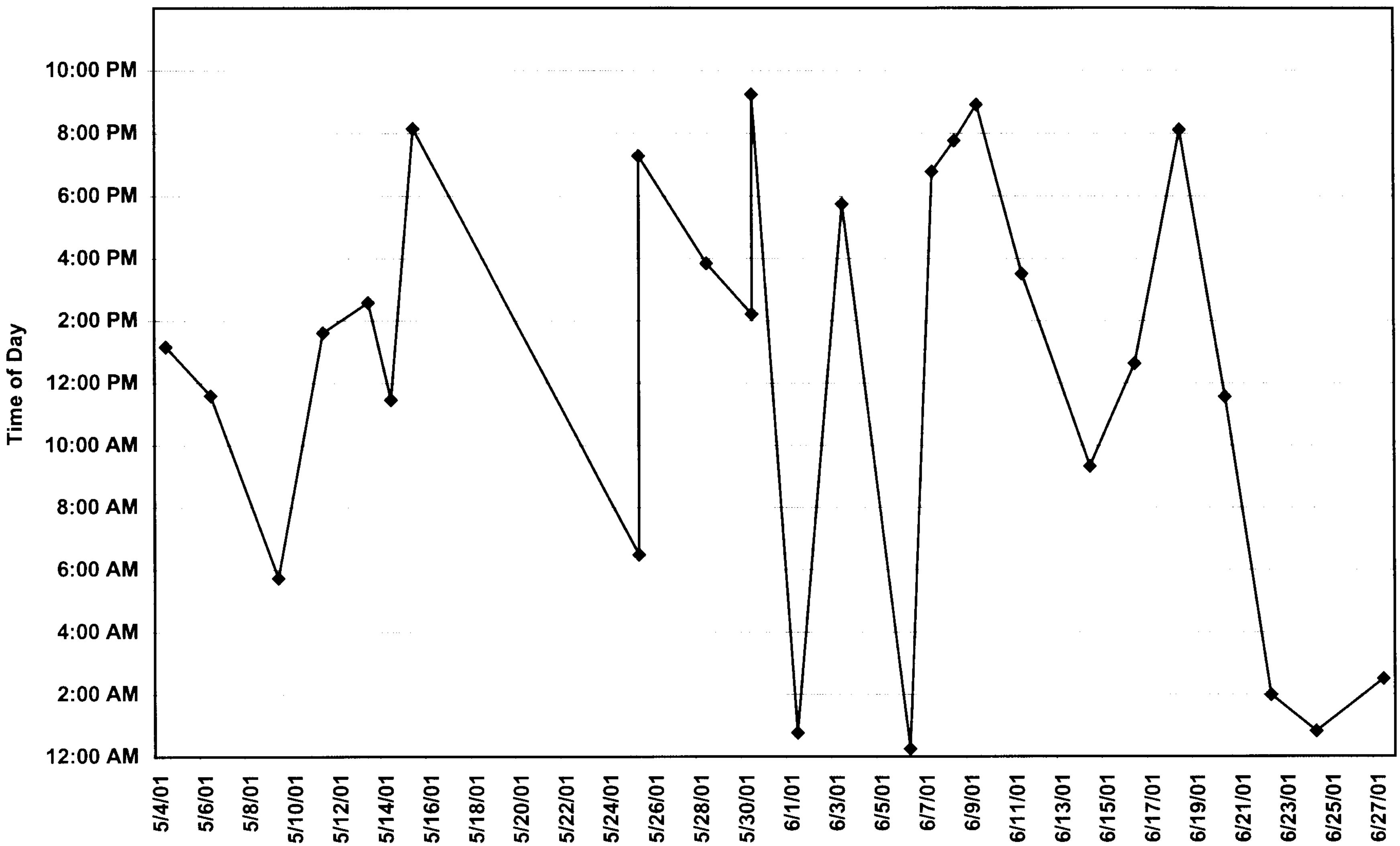
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-06



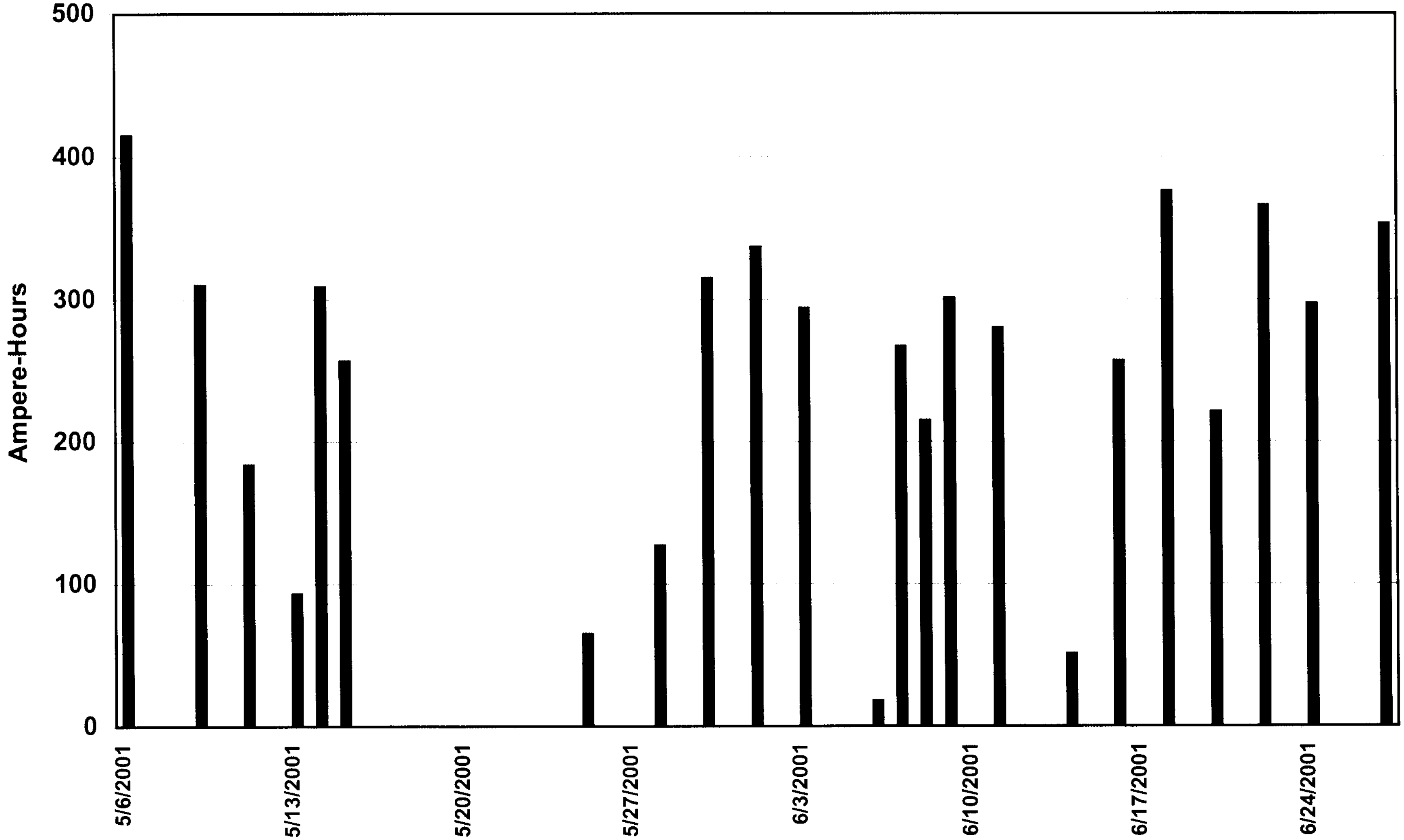
10-Cycle Average Connect Standby Time - Vehicle BTE-06



Charge Start Times - Vehicle BTE-06



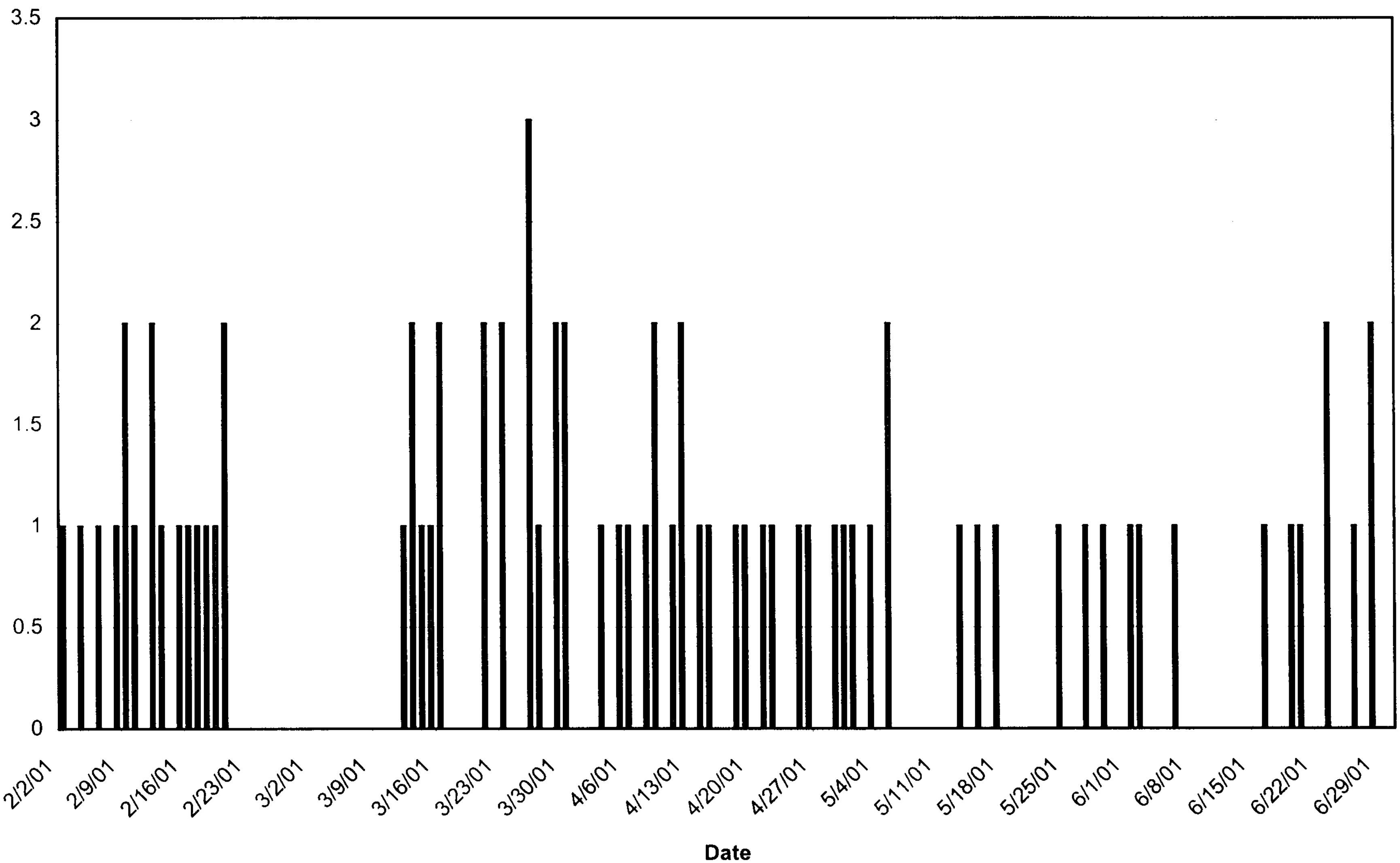
Ampere-Hours Returned per Charge - Vehicle BTE-06



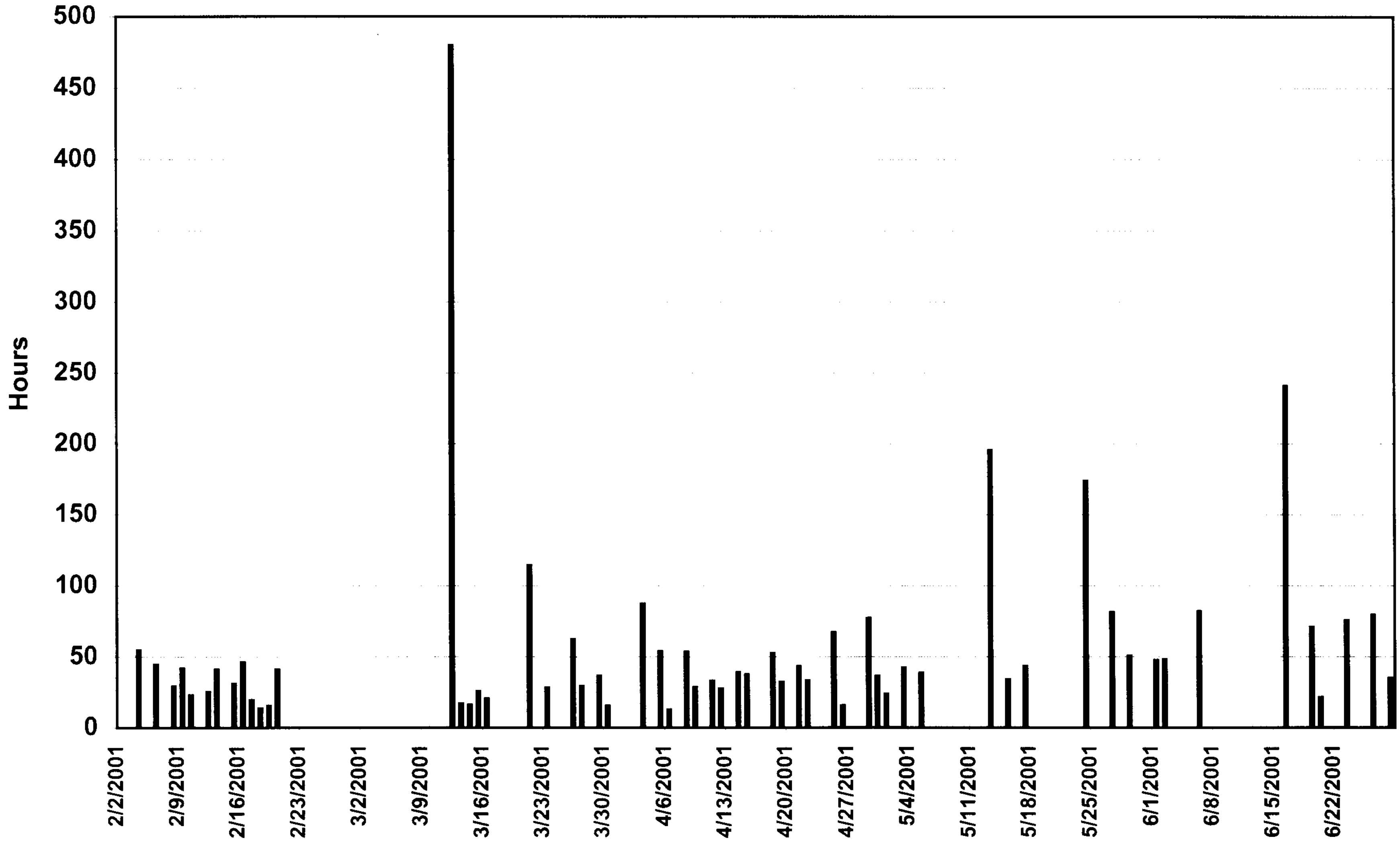
DATA GRAPHS

TRACTOR
BTE-07

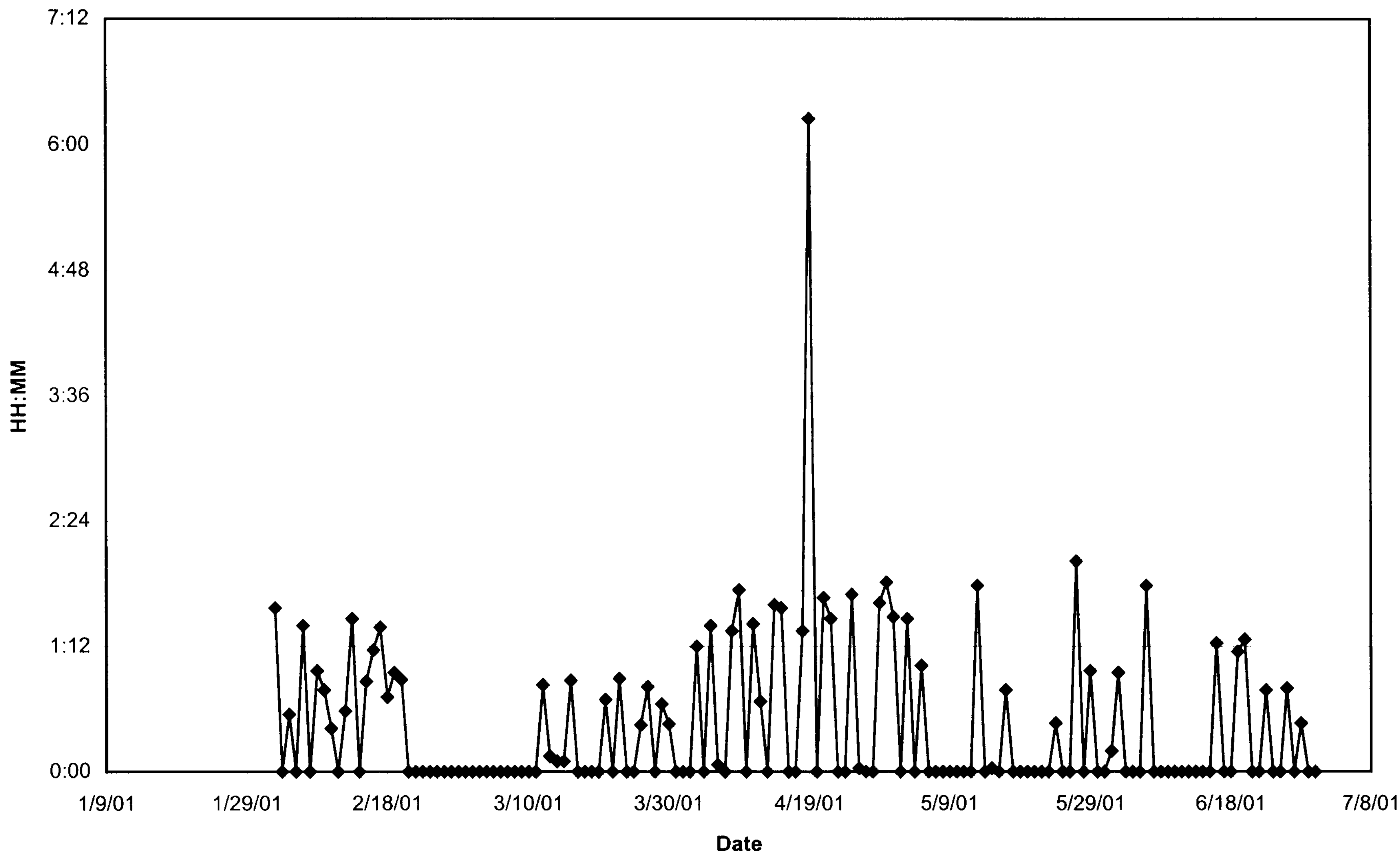
Charges Per Day - Vehicle BTE-07



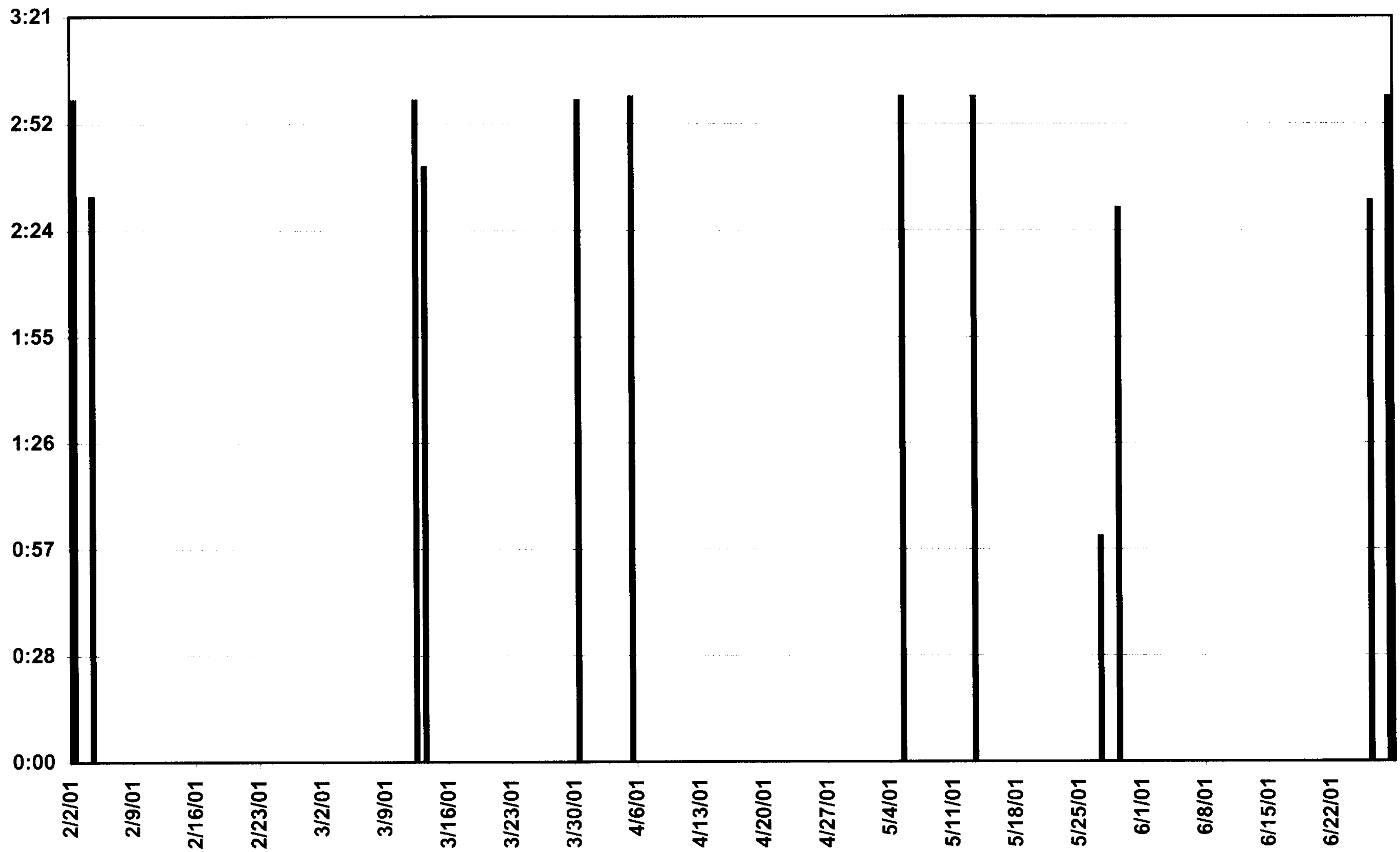
Time Between Charges - Vehicle BTE-07



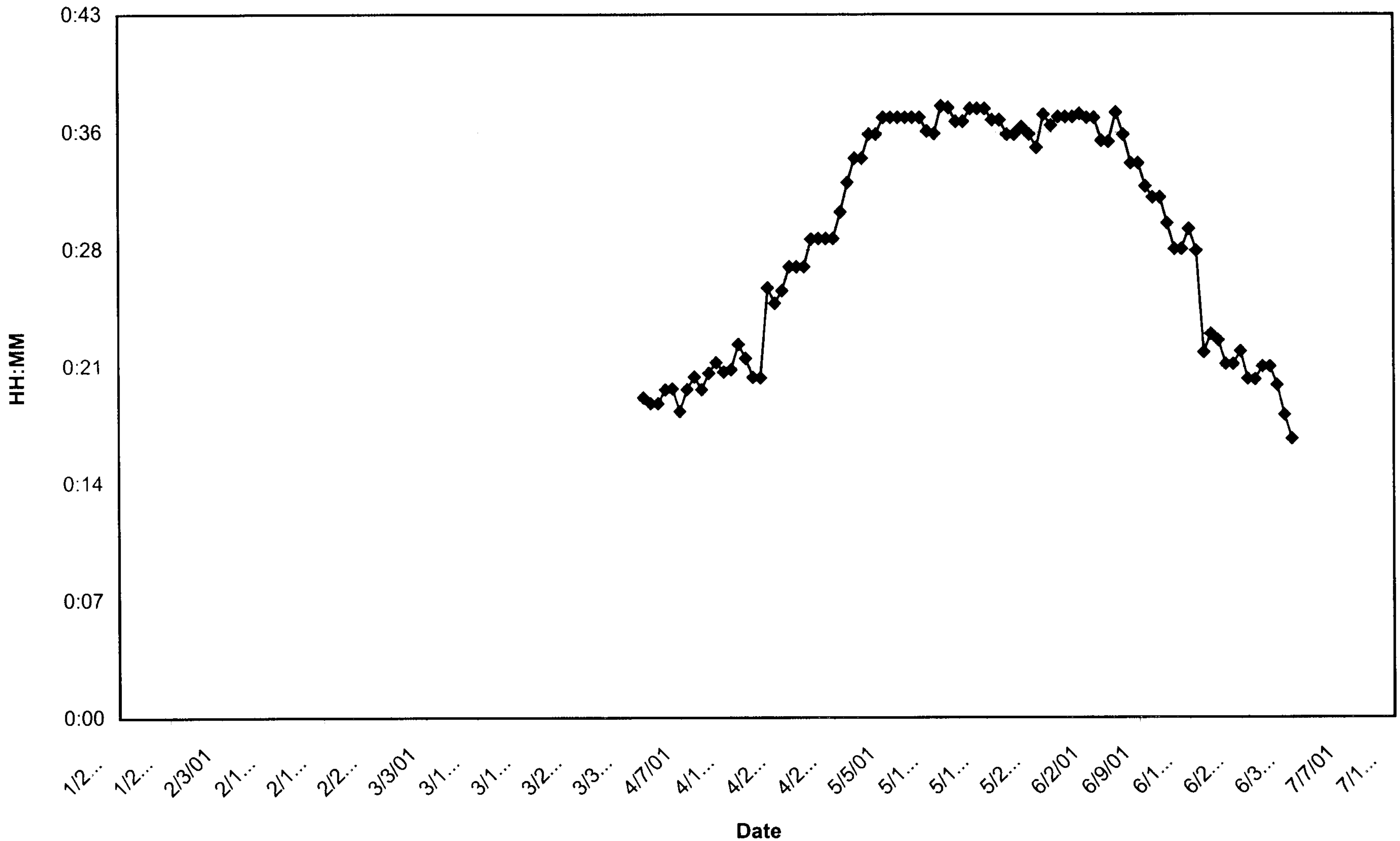
Average Charge Time - Vehicle BTE-07



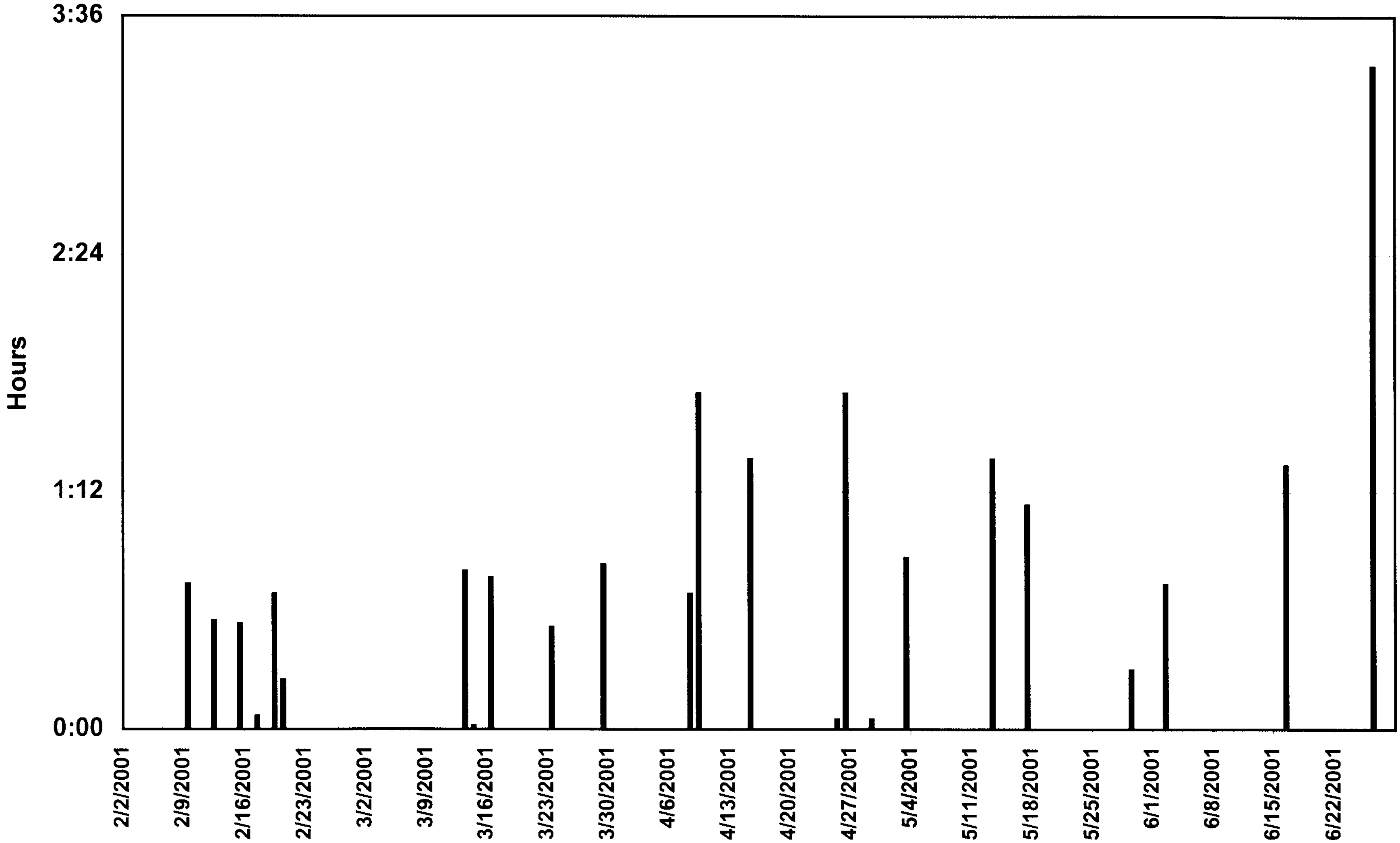
Time on Equalize Charge - Vehicle BTE-07



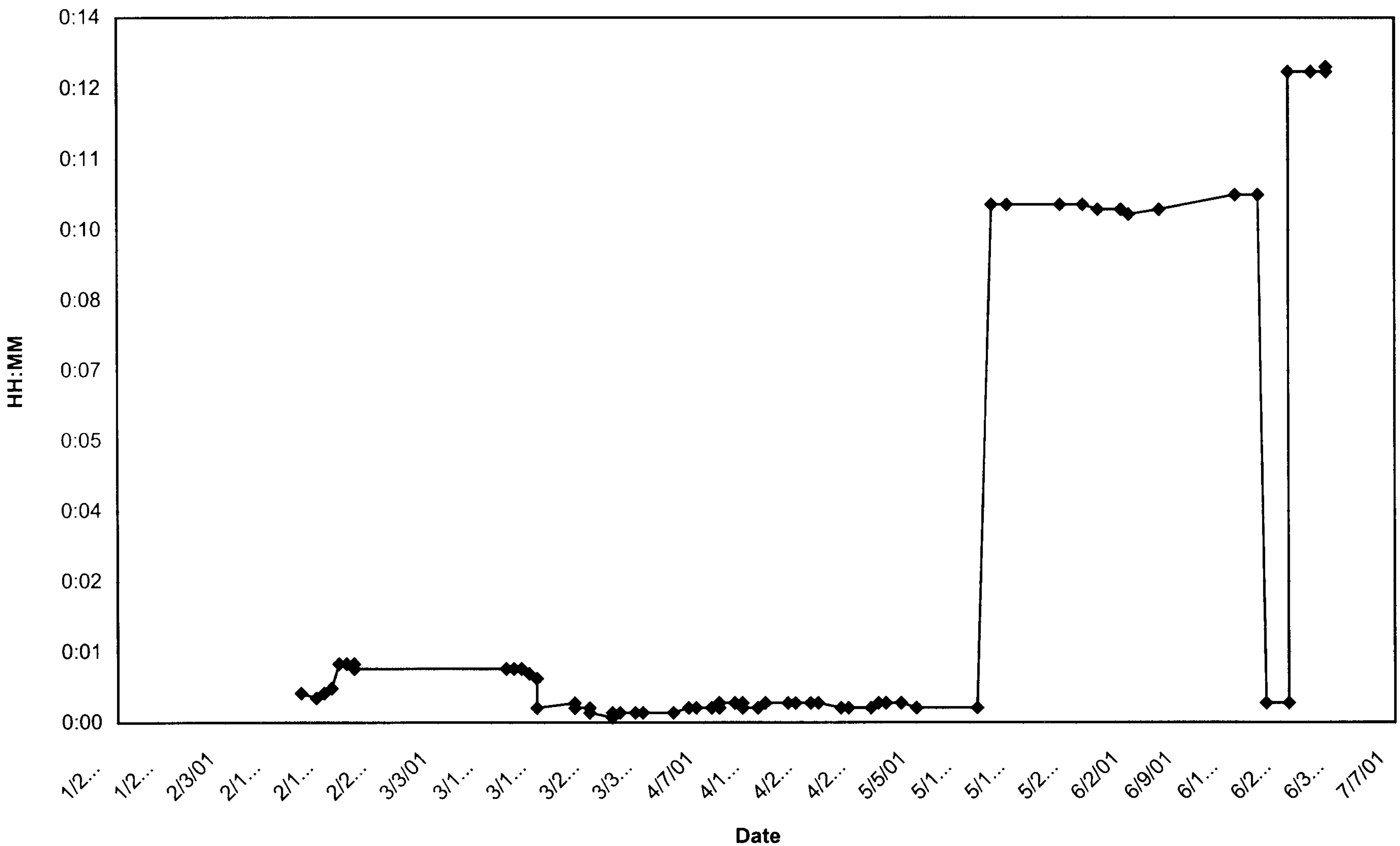
60-Day Average Charge Time - Vehicle BTE-07

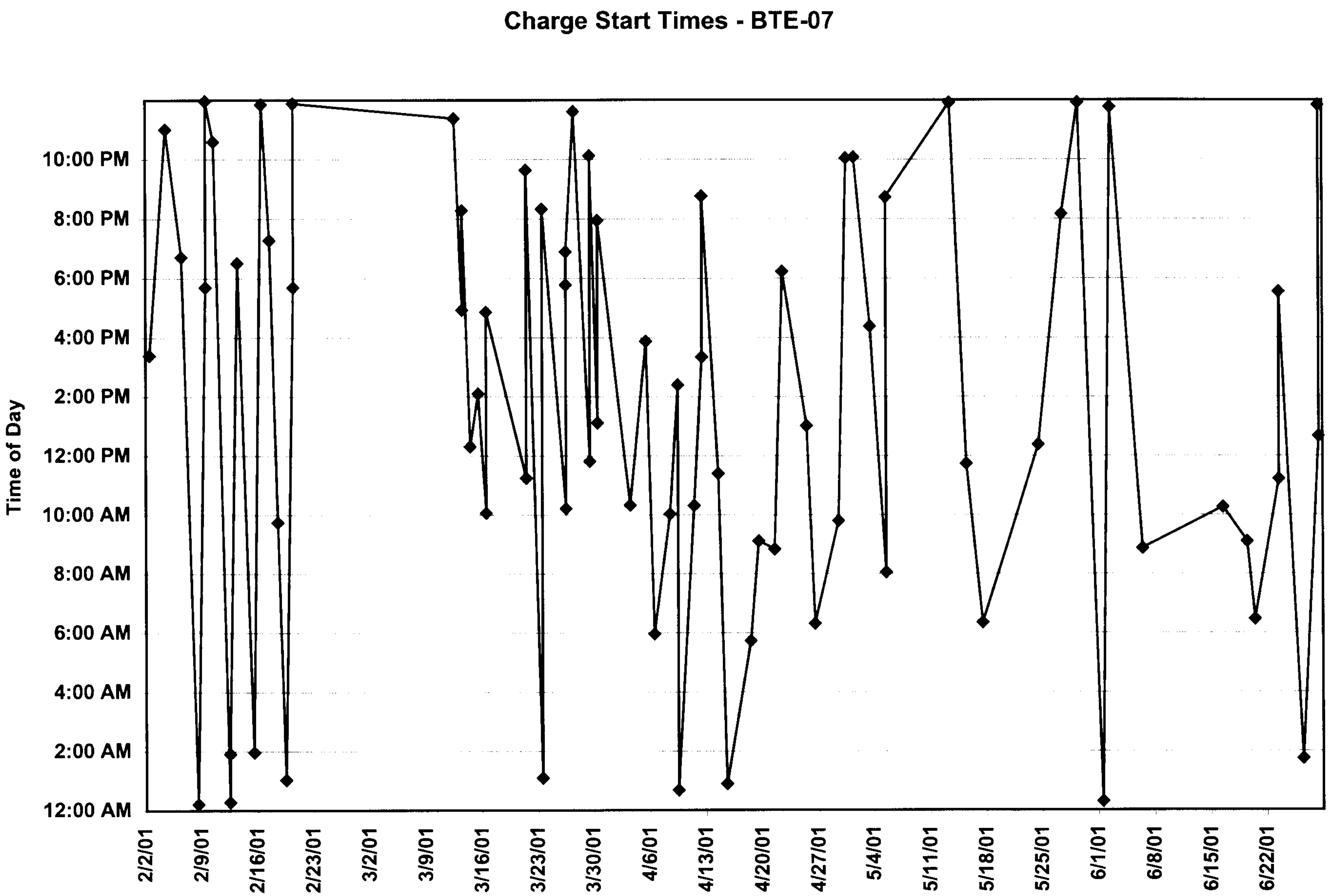


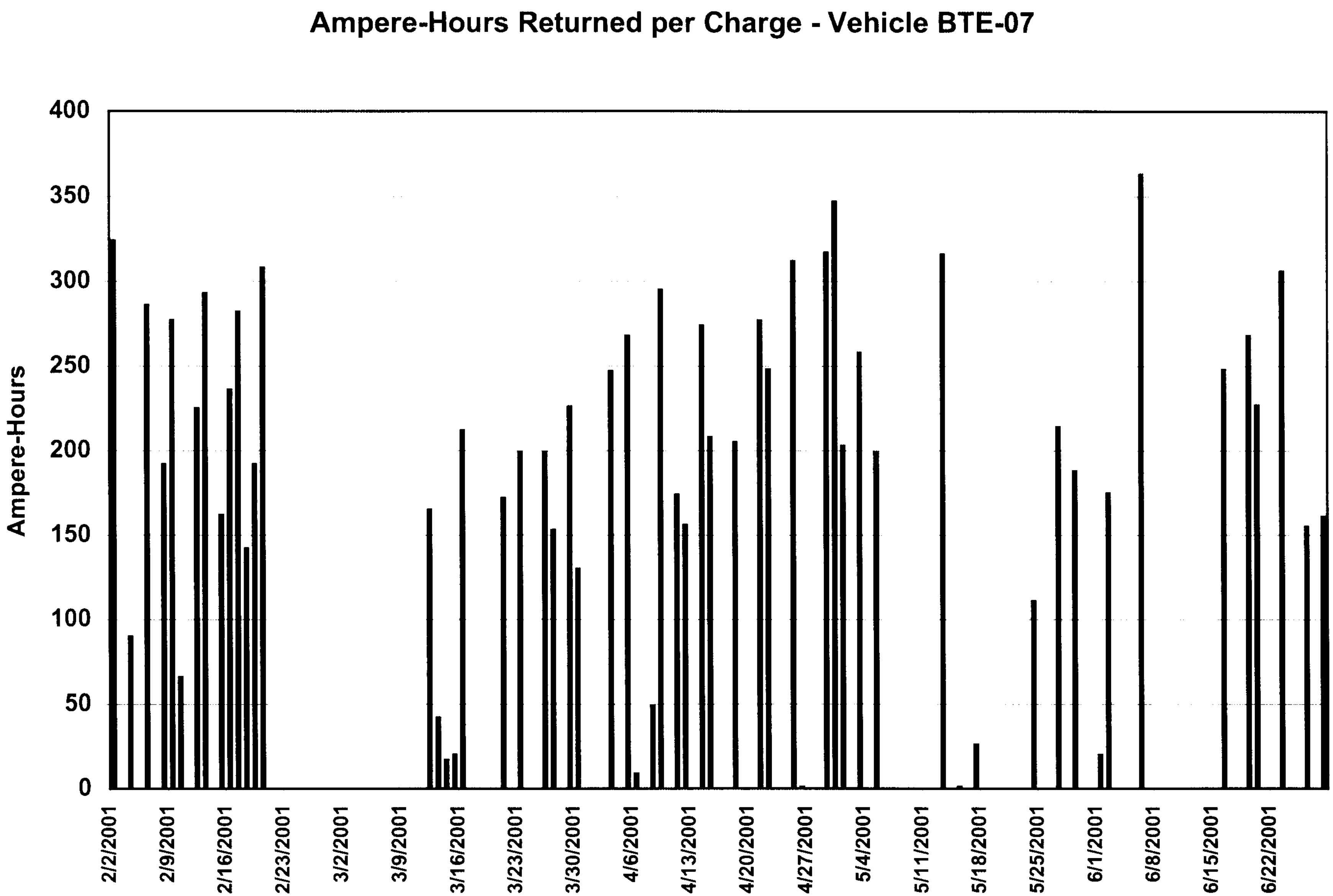
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-07



10-Cycle Average Standby Time - Vehicle BTE-07




Charge Start Times - BTE-07
Time of Day
10:00 PM
8:00 PM
6:00 PM
4:00 PM
2:00 PM
12:00 PM
10:00 AM
8:00 AM
6:00 AM
4:00 AM
2:00 AM
12:00 AM
2/2/01
2/9/01
2/16/01
2/23/01
3/2/01
3/9/01
3/16/01
3/23/01
3/30/01
4/6/01
4/13/01
4/20/01
4/27/01
5/4/01
5/11/01
5/18/01
5/25/01
6/1/01
6/8/01
6/15/01
6/22/01

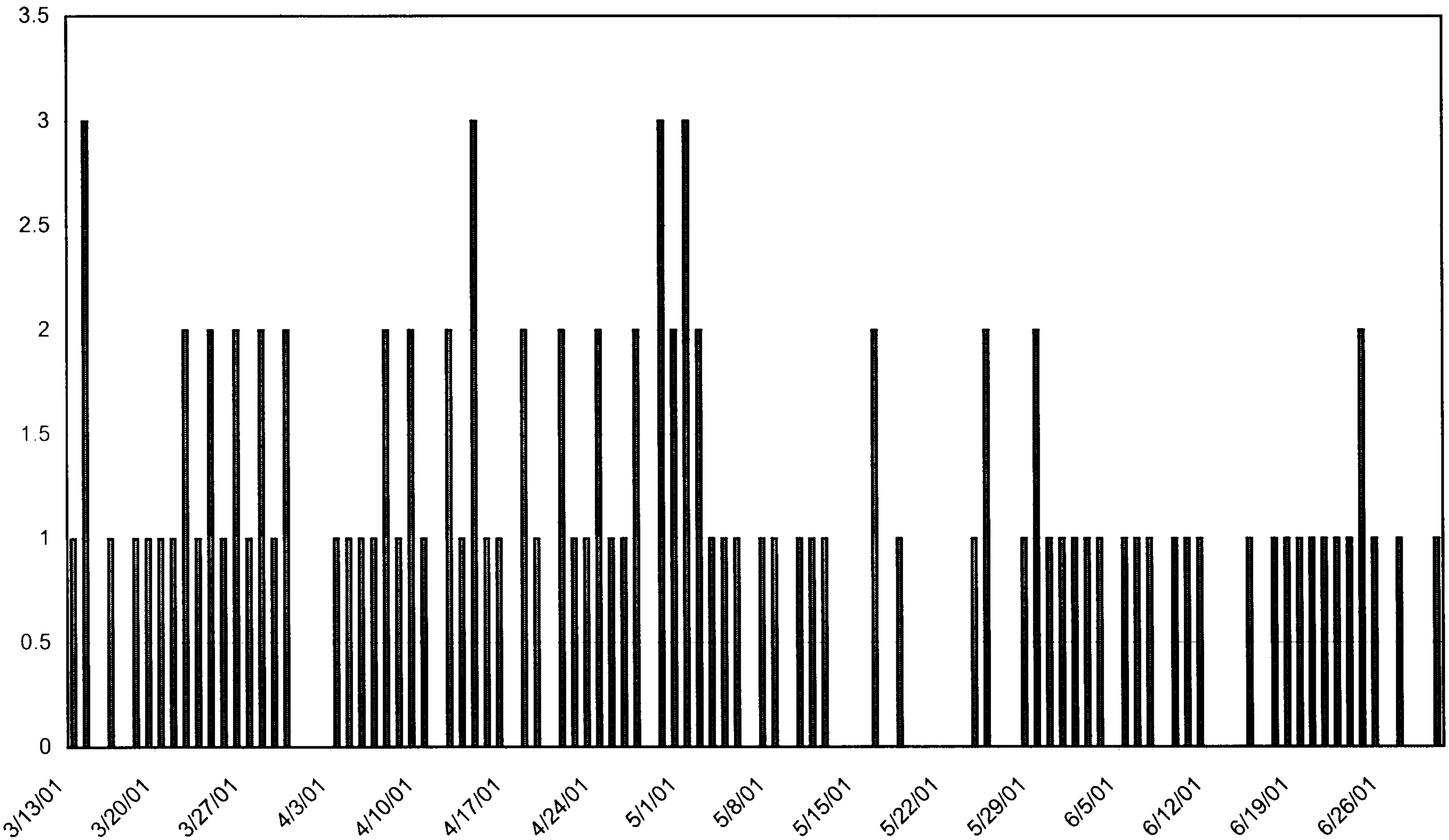


Ampere-Hours Returned per Charge - Vehicle BTE-07
Ampere-Hours
400
350
300
250
200
150
100
50
0
2/2/2001
2/9/2001
2/16/2001
2/23/2001
3/2/2001
3/9/2001
3/16/2001
3/23/2001
3/30/2001
4/6/2001
4/13/2001
4/20/2001
4/27/2001
5/4/2001
5/11/2001
5/18/2001
5/25/2001
6/1/2001
6/8/2001
6/15/2001
6/22/2001

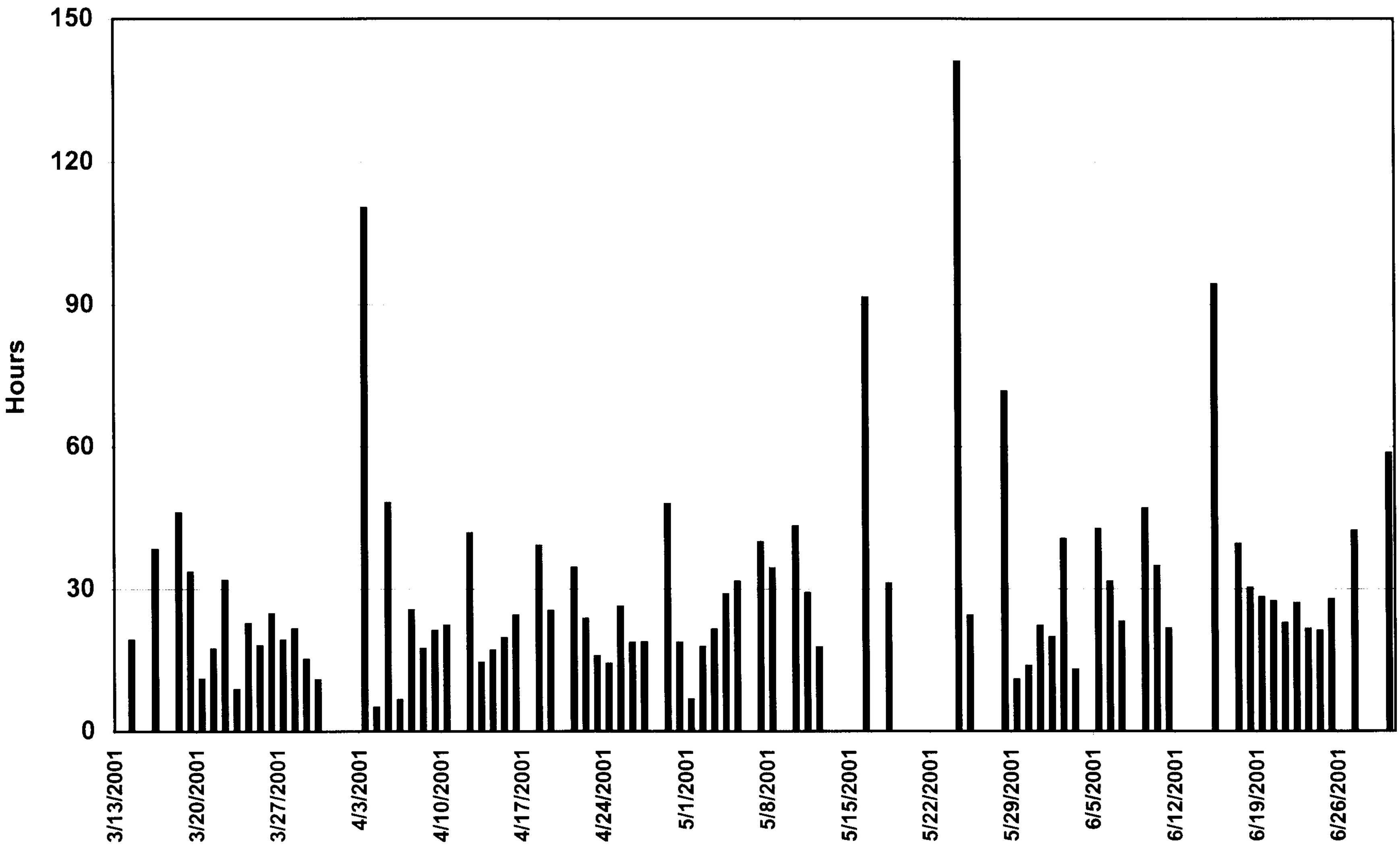
DATA GRAPHS

TRACTOR
BTE-08

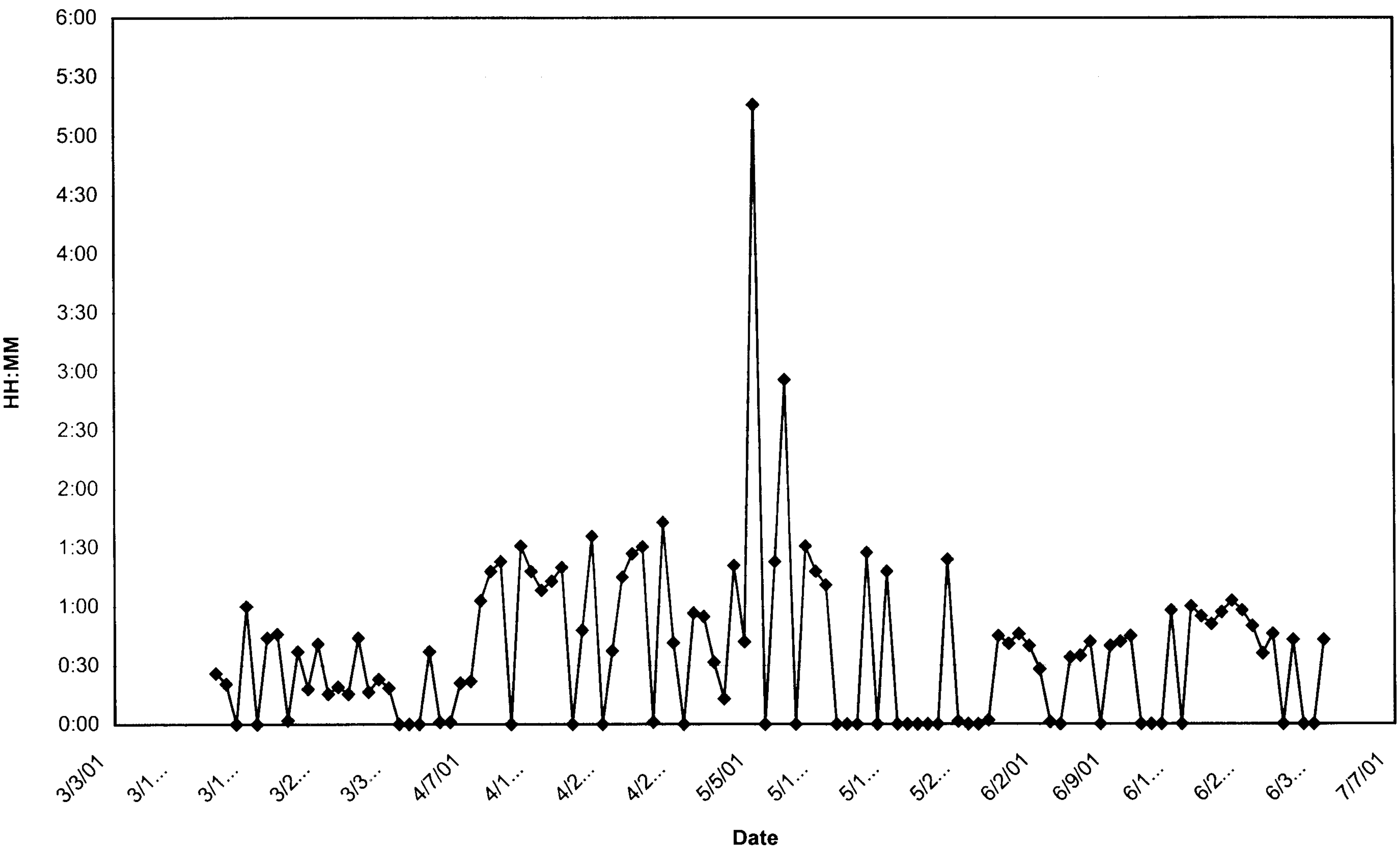
Charges Per Day - Vehicle BTE-08



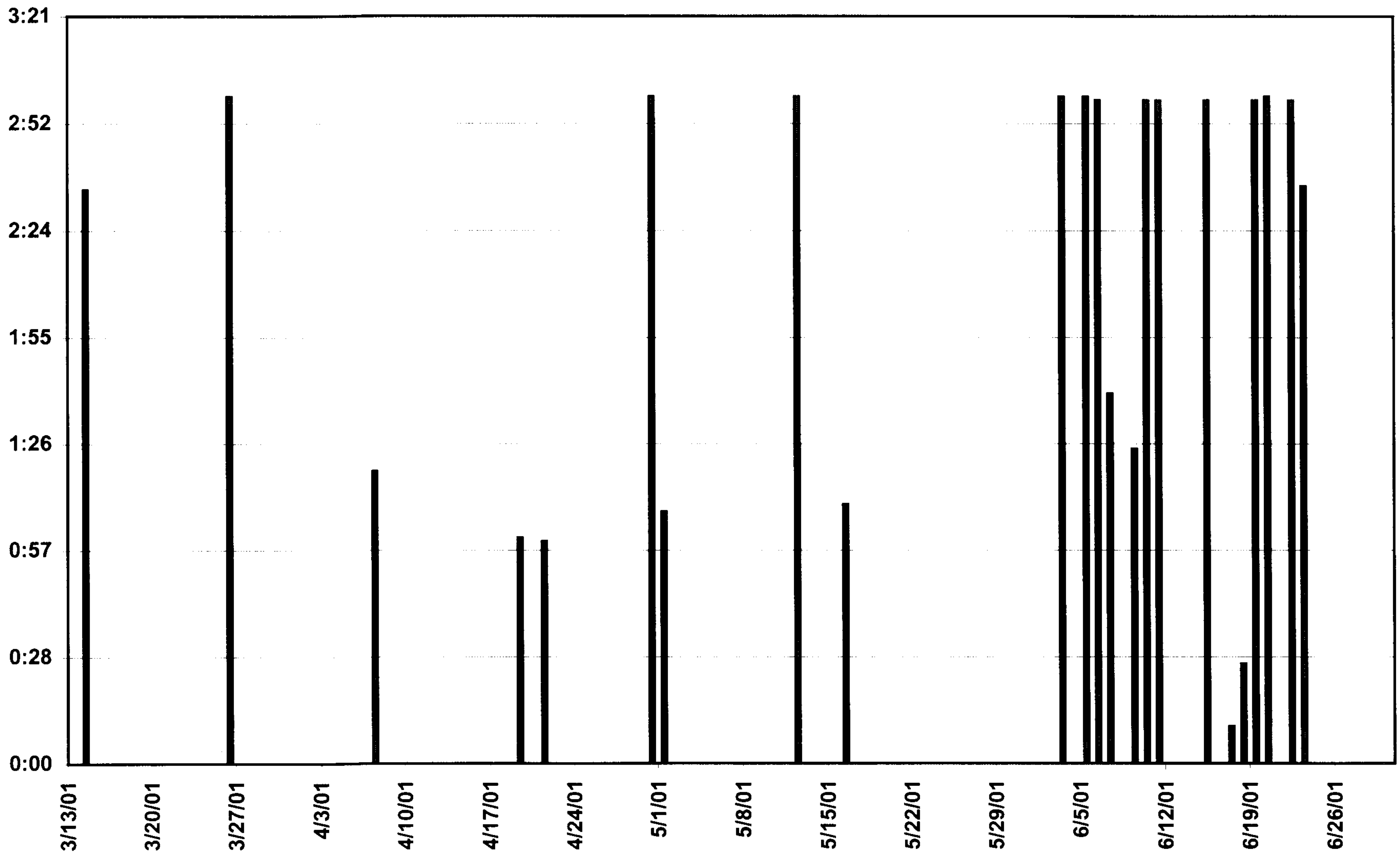
Time Between Charges - Vehicle BTE-08



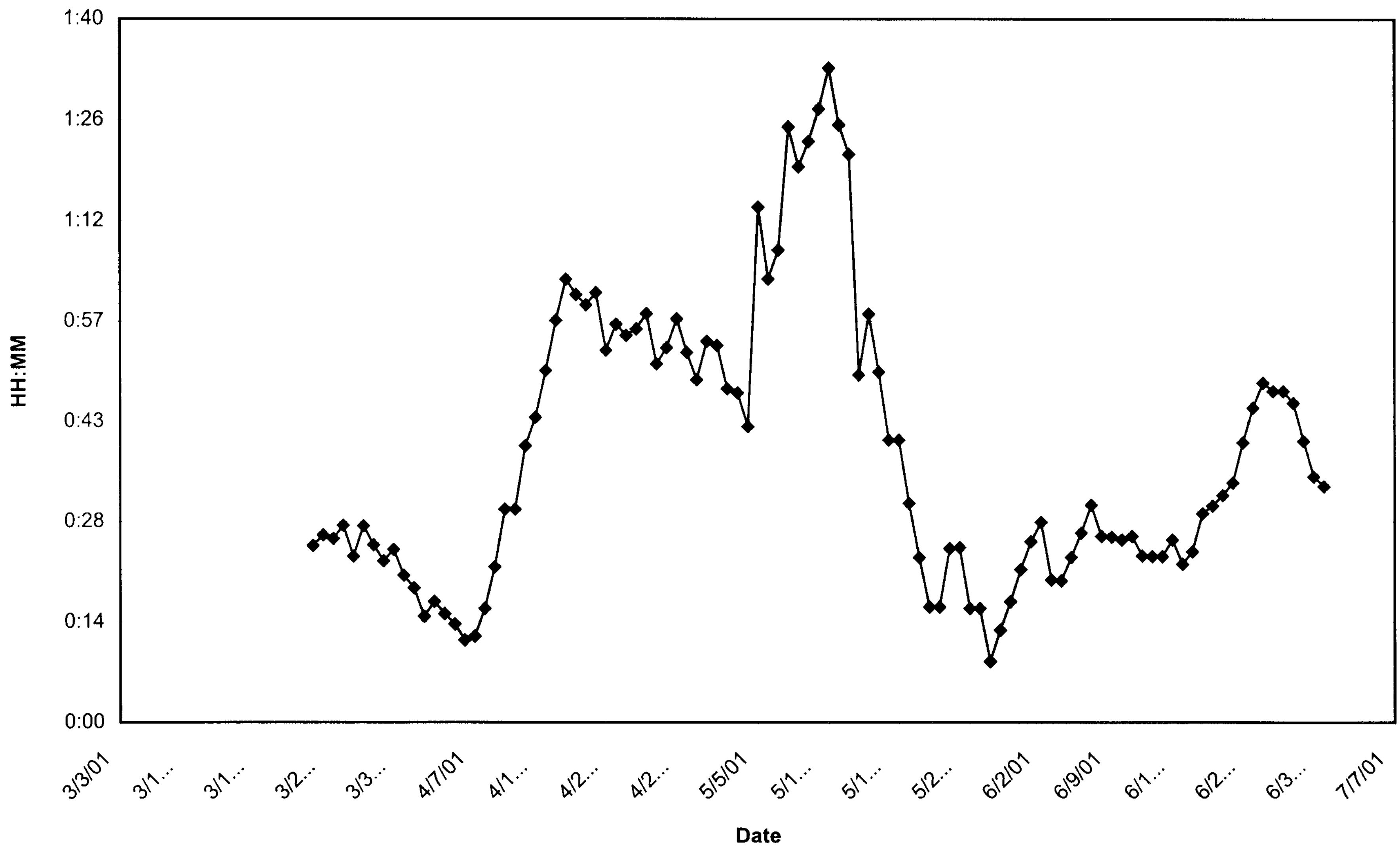
Average Charge Time - Vehicle BTE-08



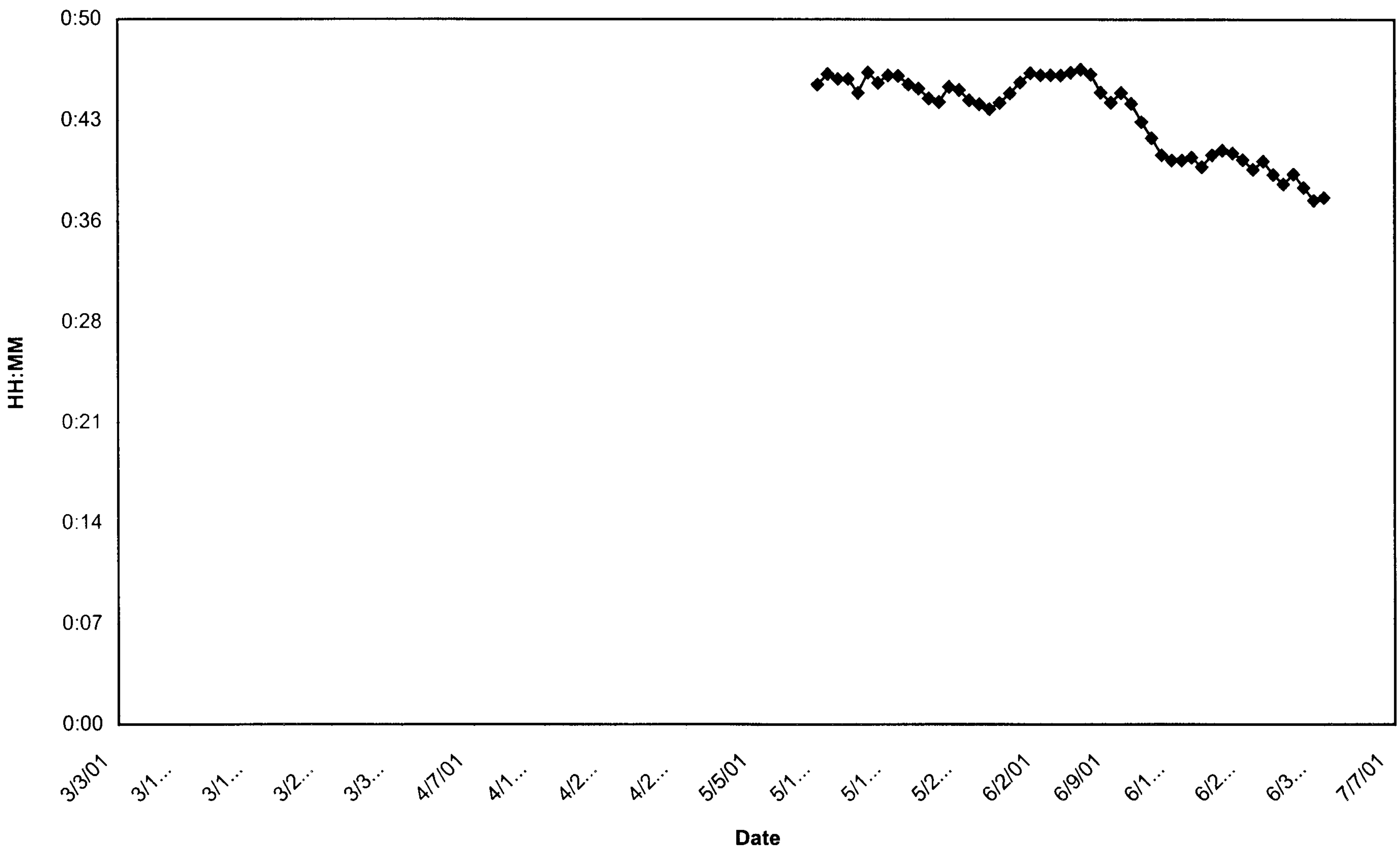
Time on Equalize - Vehicle BTE-08



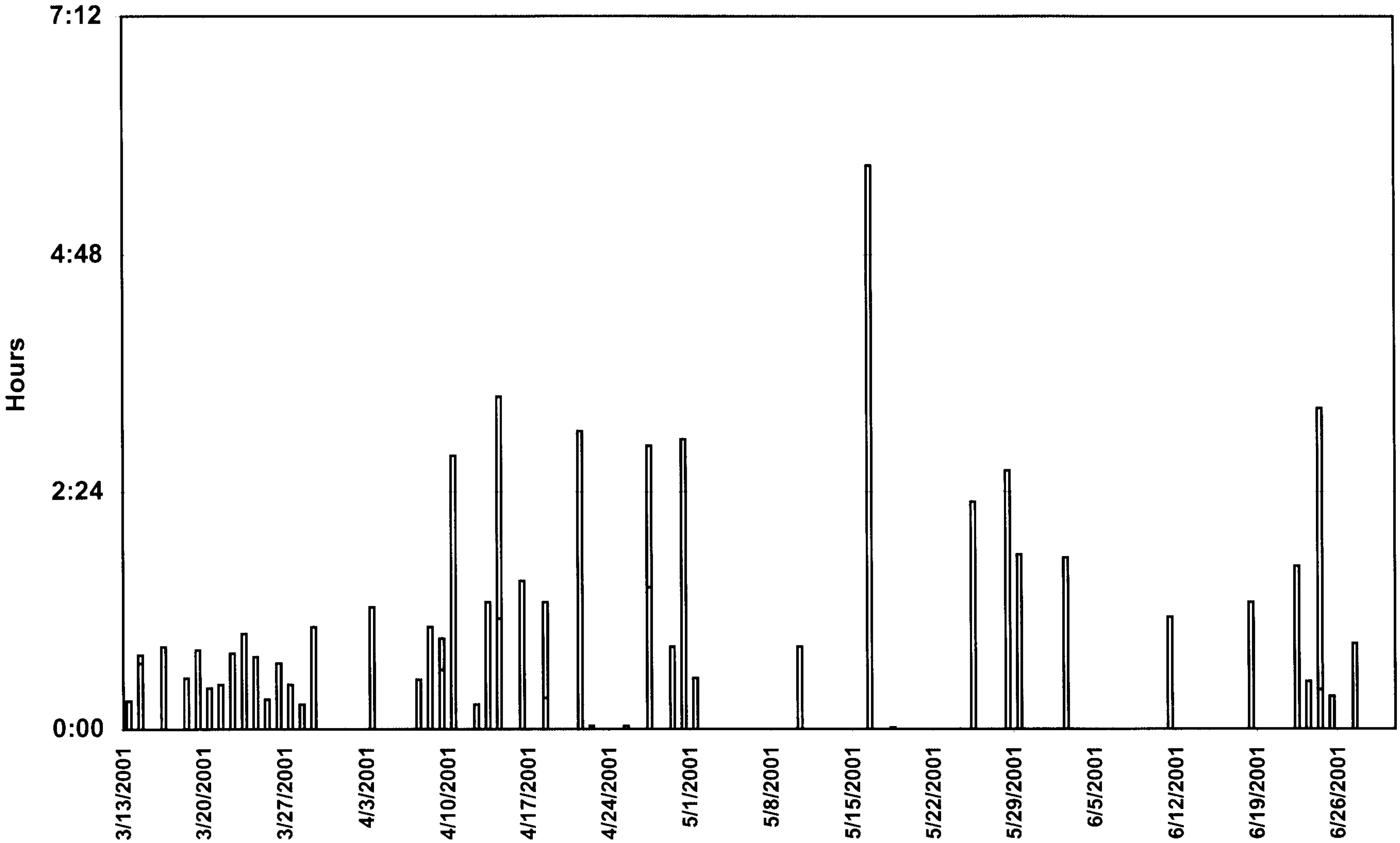
10-Day Average Charge Time - Vehicle BTE-08



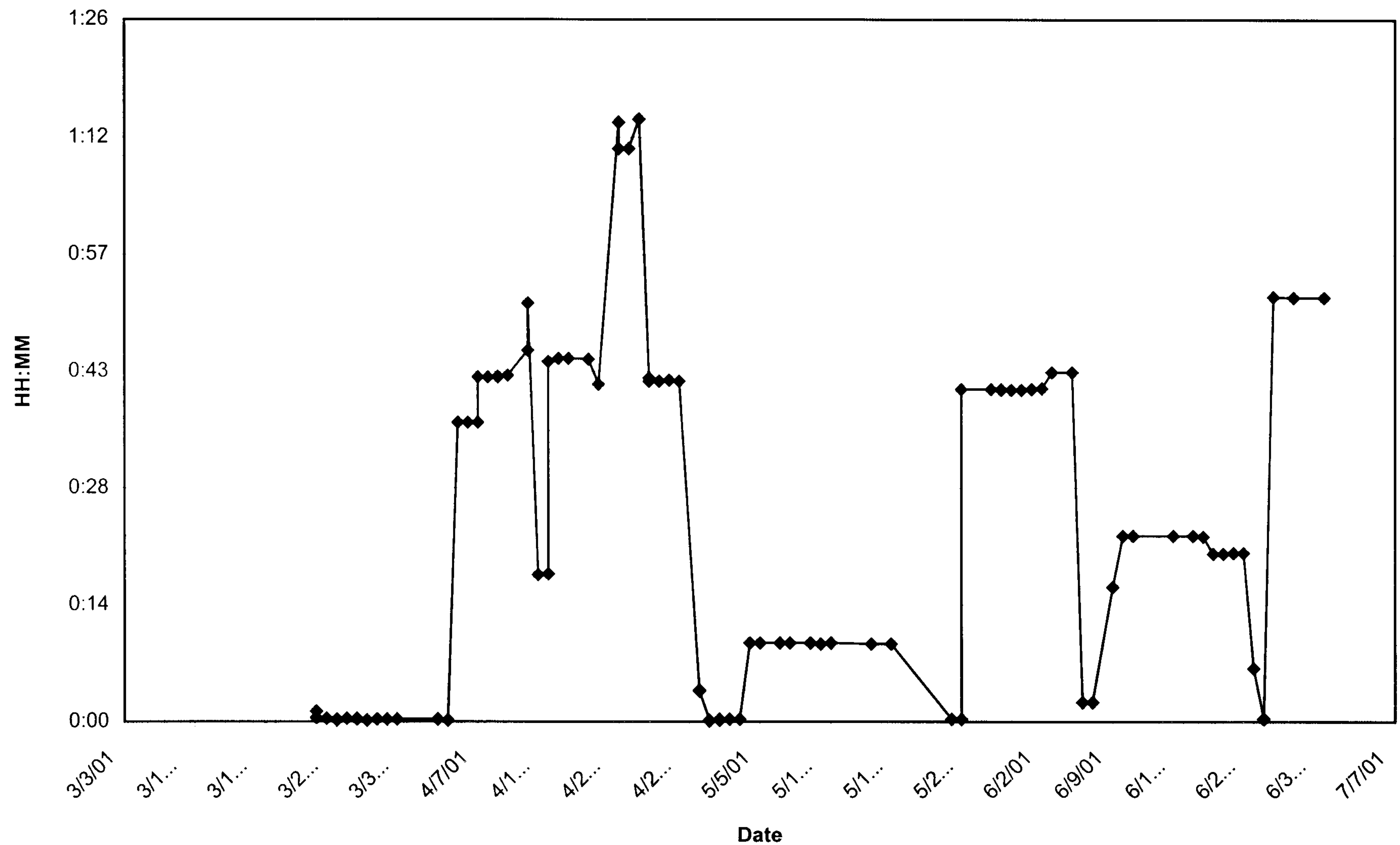
60-Day Average Charge Time - Vehicle BTE-08



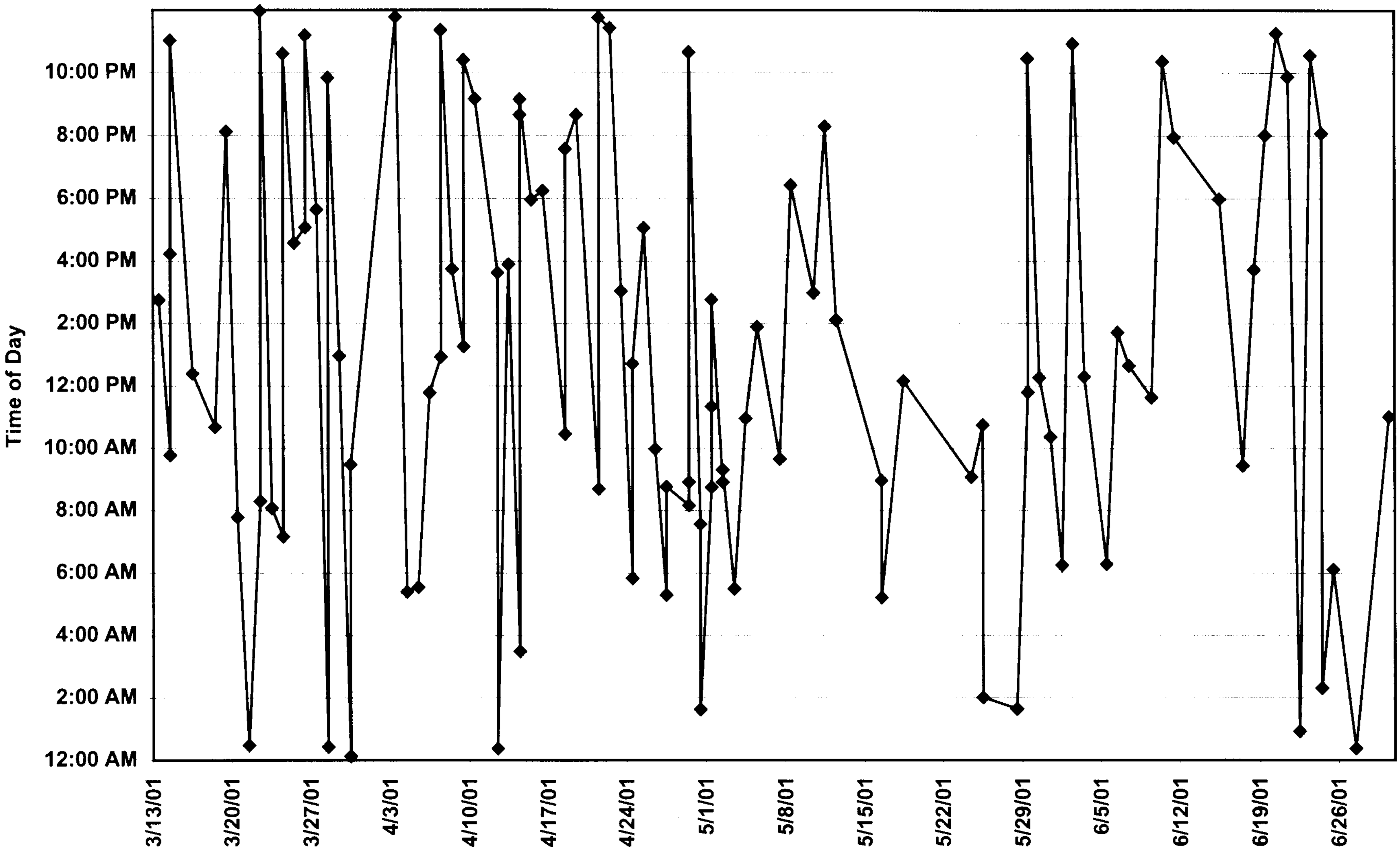
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-08



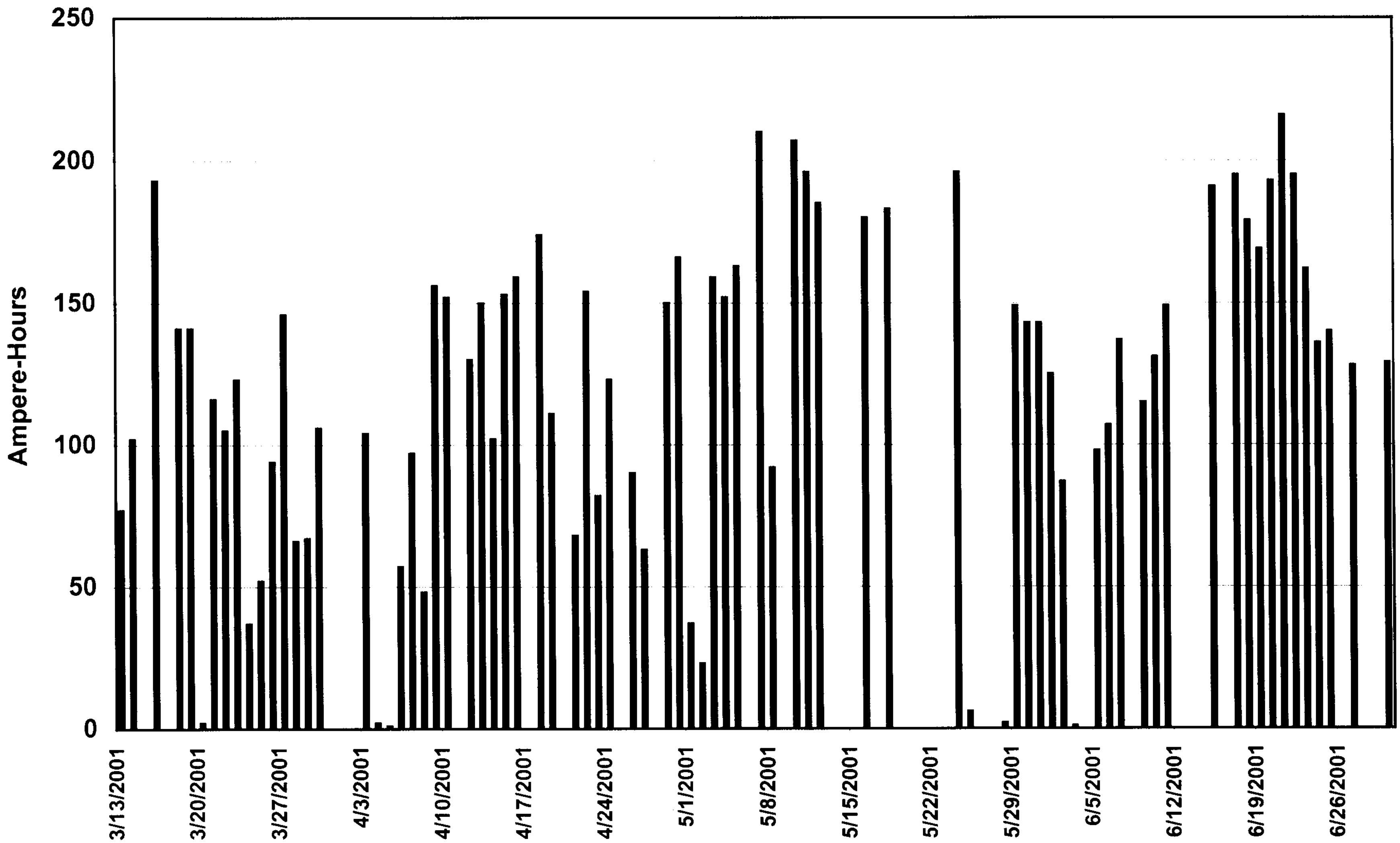
10-Cycle Average Connect Standby Time - Vehicle BTE-08



Charge Start Times - Vehicle BTE-08



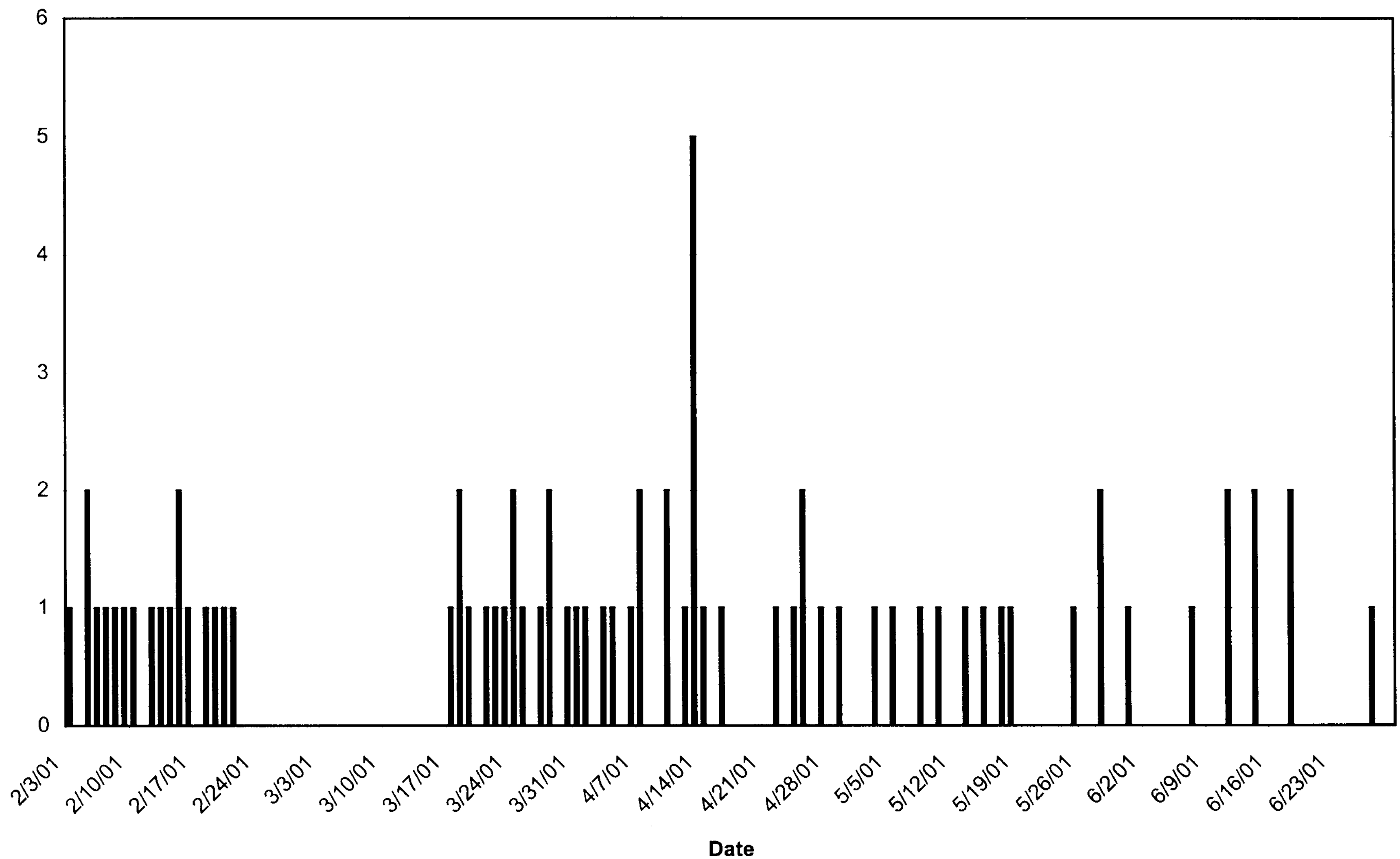
Ampere-Hours Returned per Charge - Vehicle BTE-08



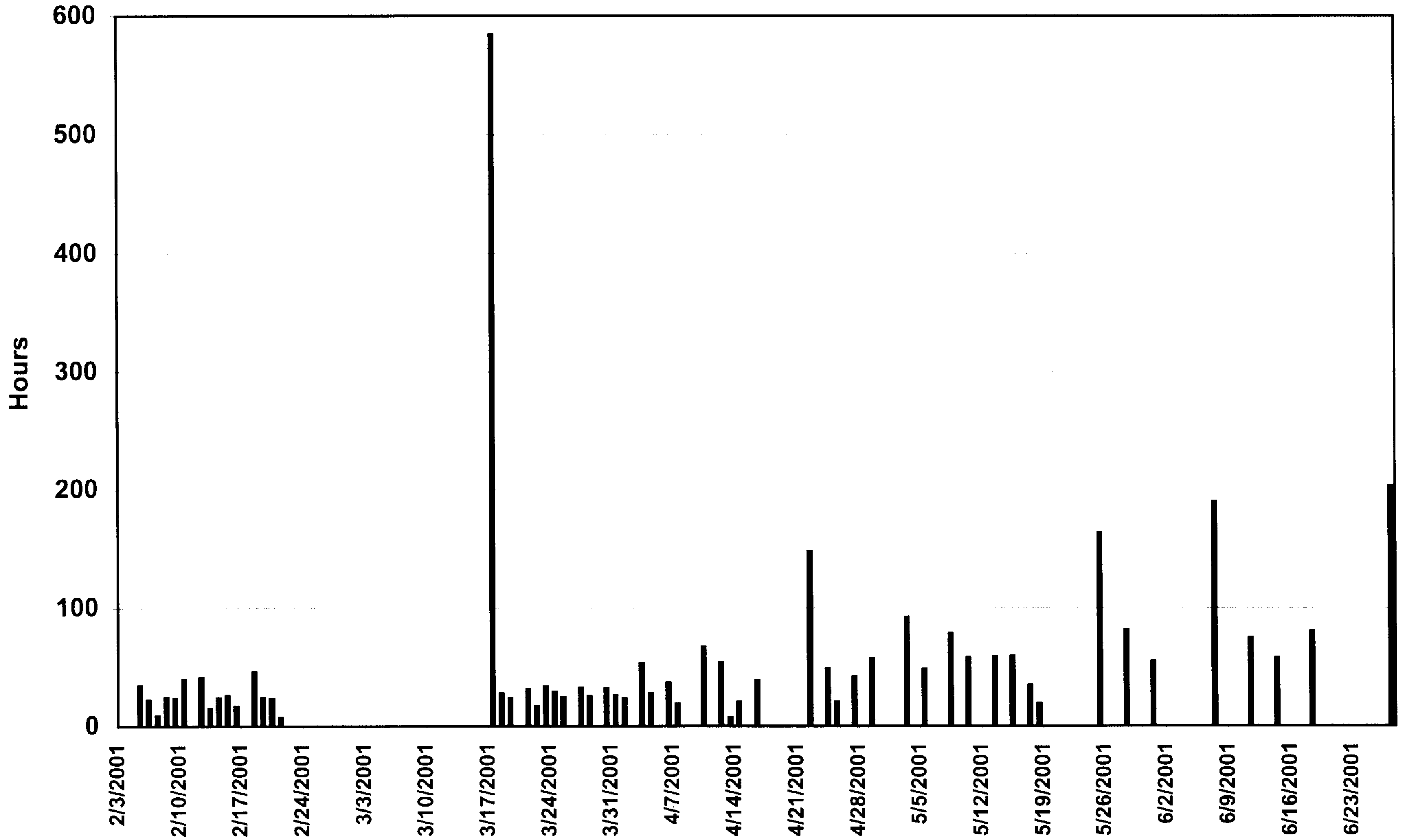
DATA GRAPHS

TRACTOR
BTE-09

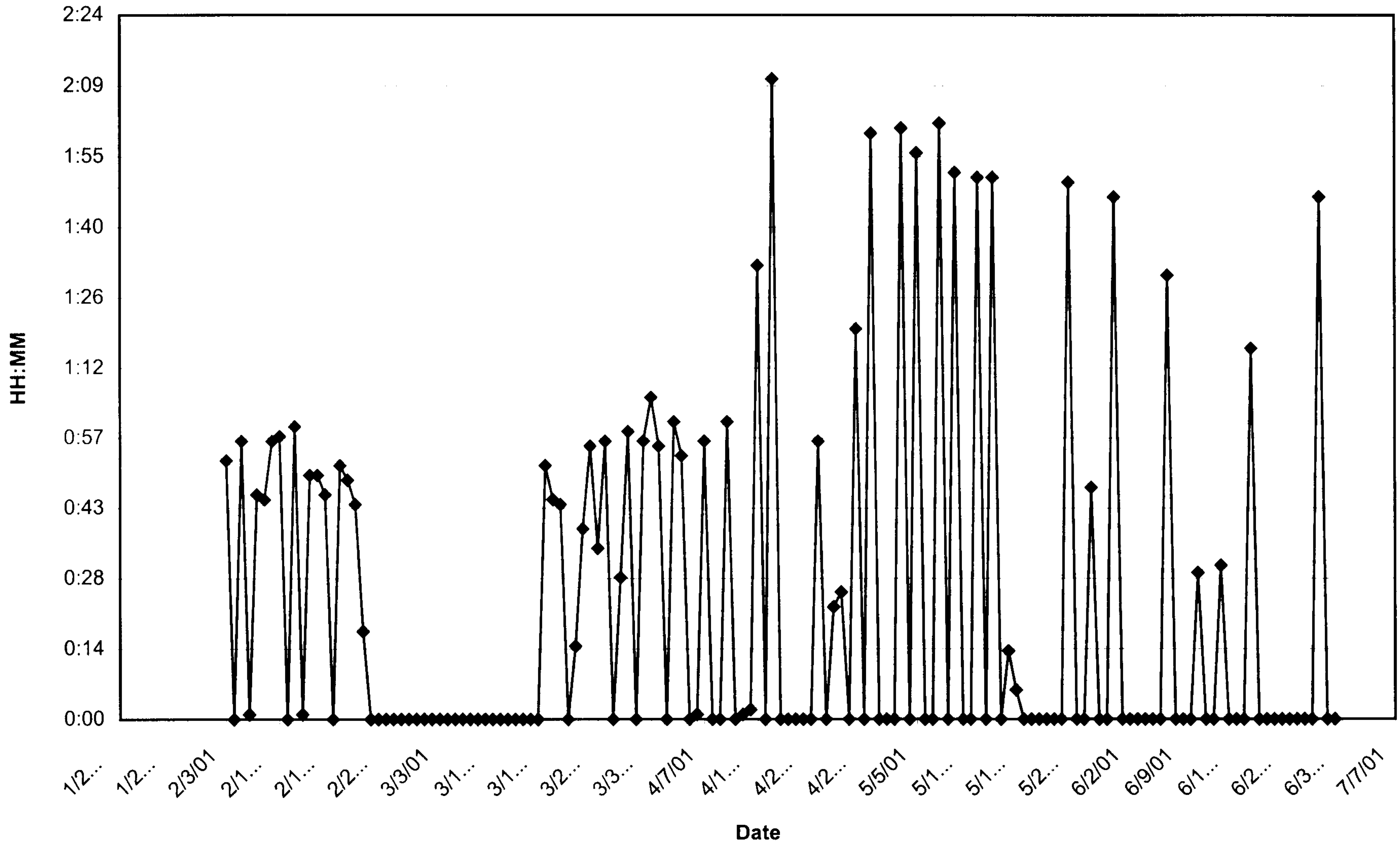
Charges Per Day - Vehicle BTE-09



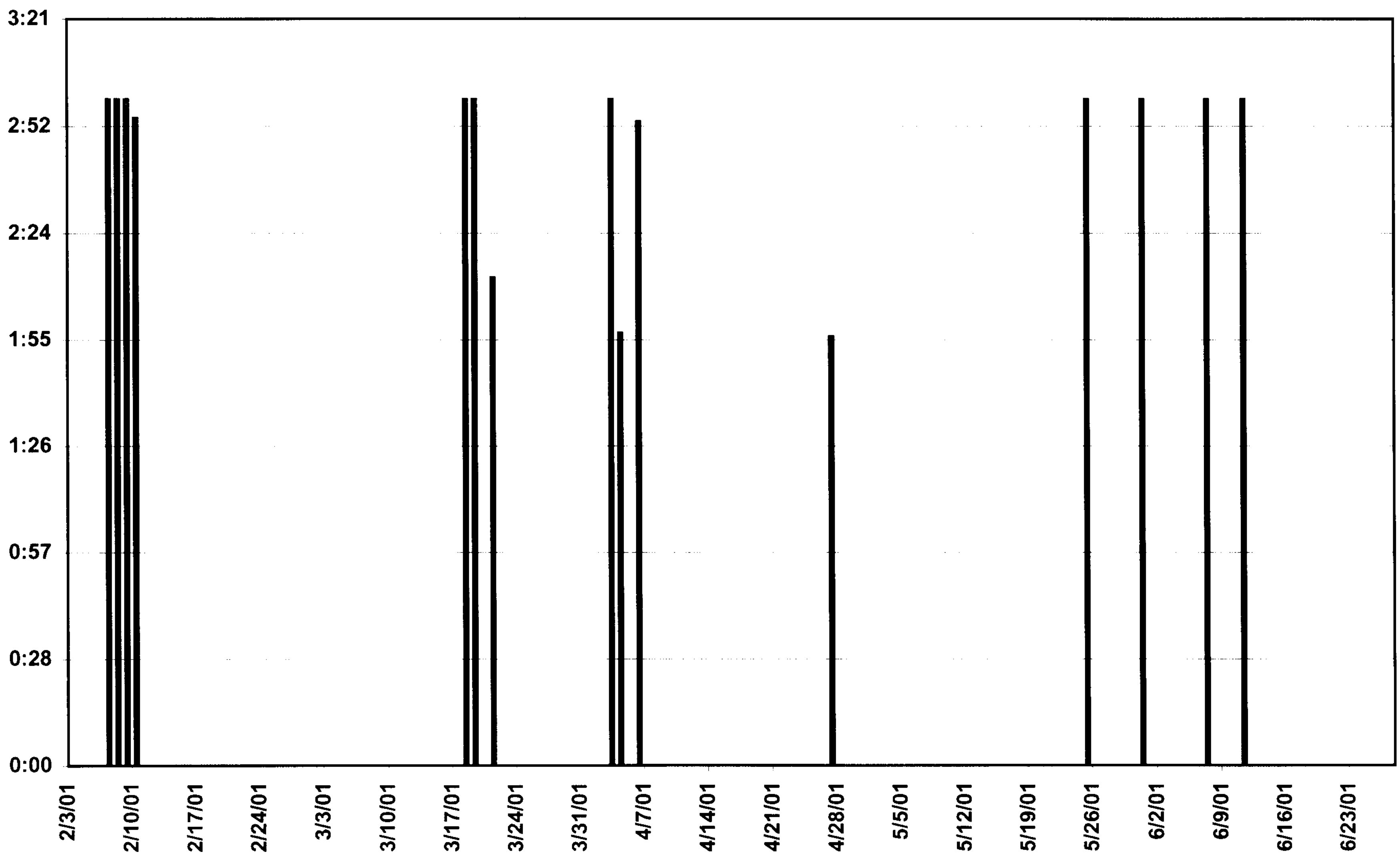
Time Between Charges - Vehicle BTE-09



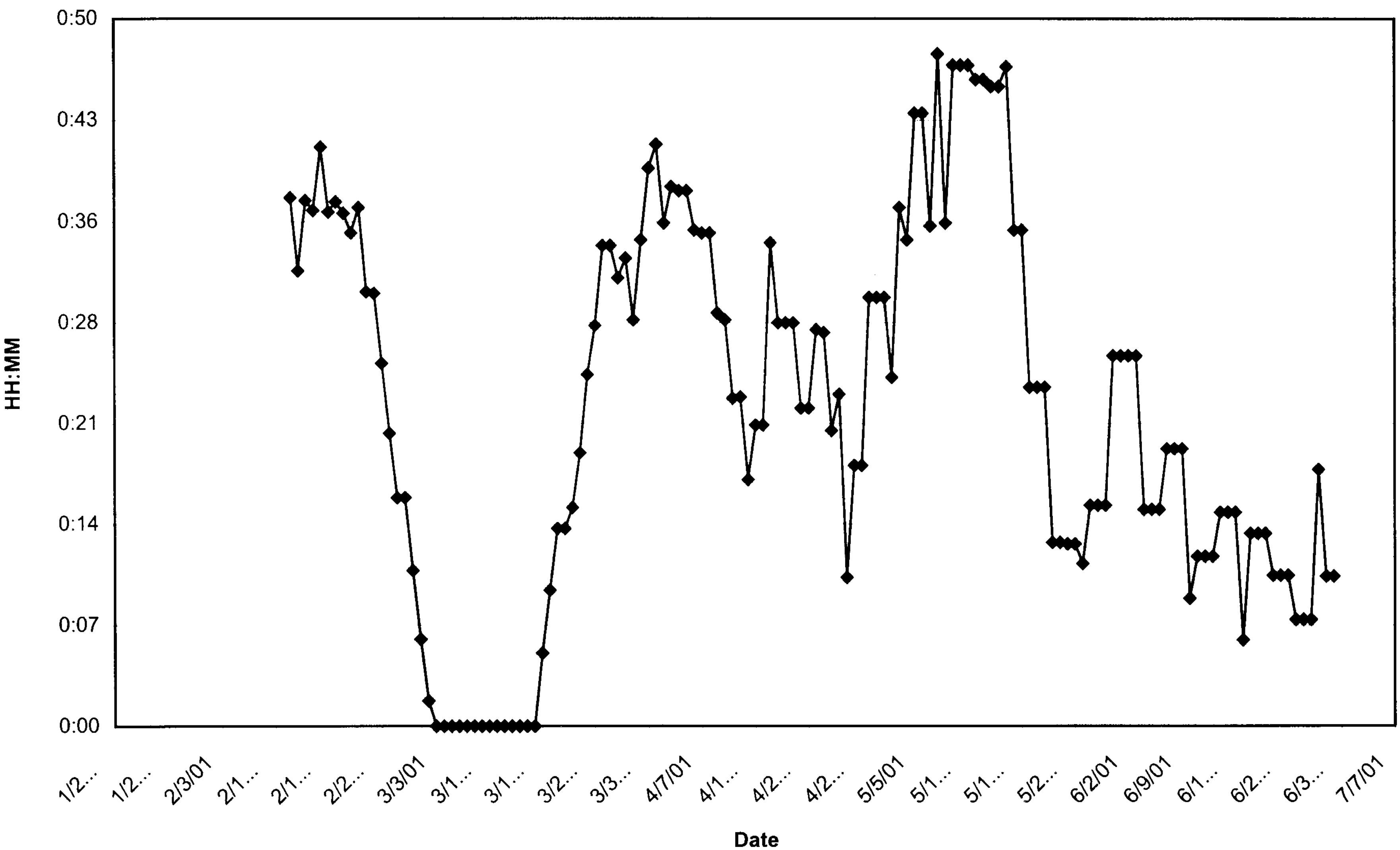
Average Charge Time - Vehicle BTE-09



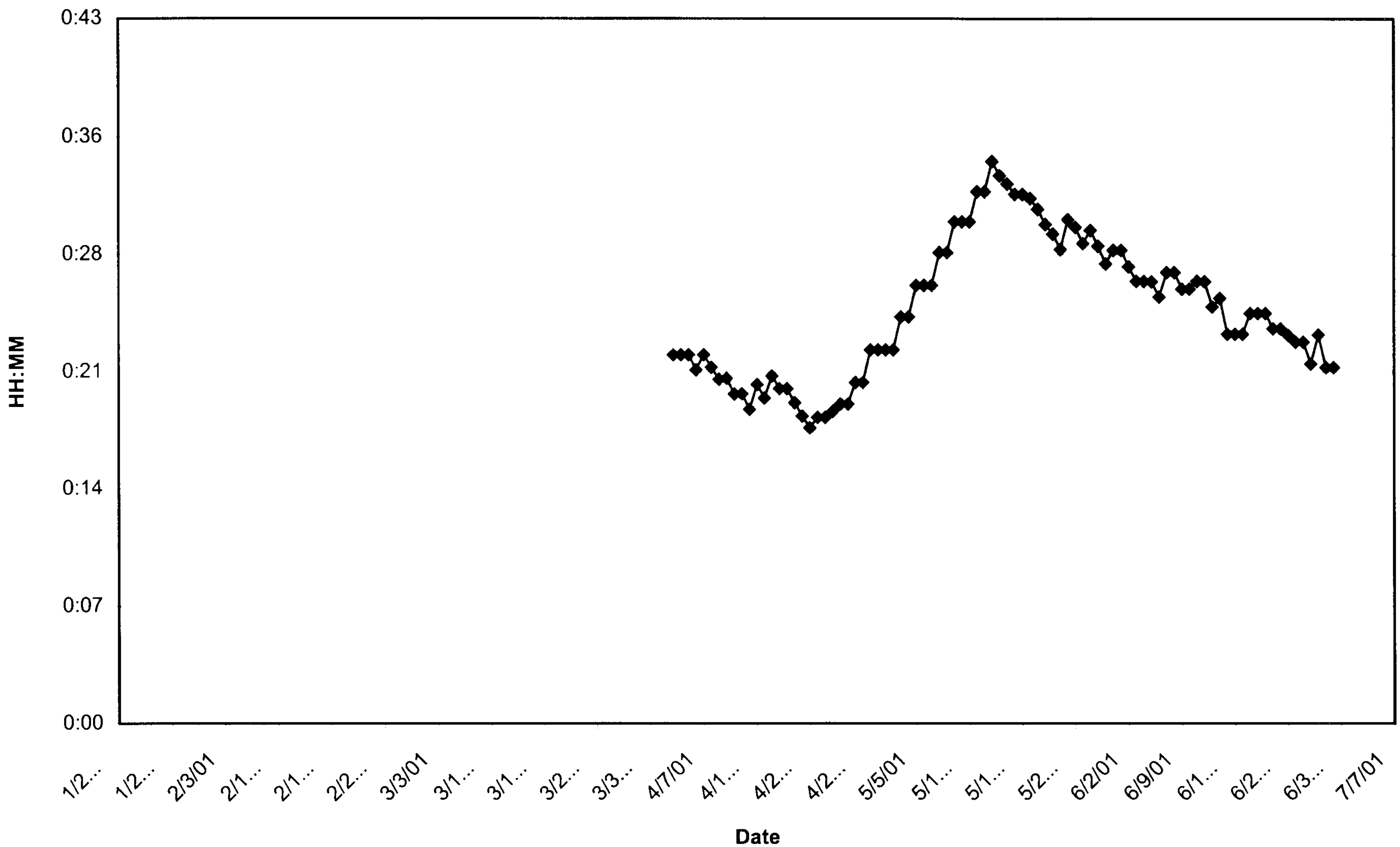
Time on Equalize Charge - Vehicle BTE-09



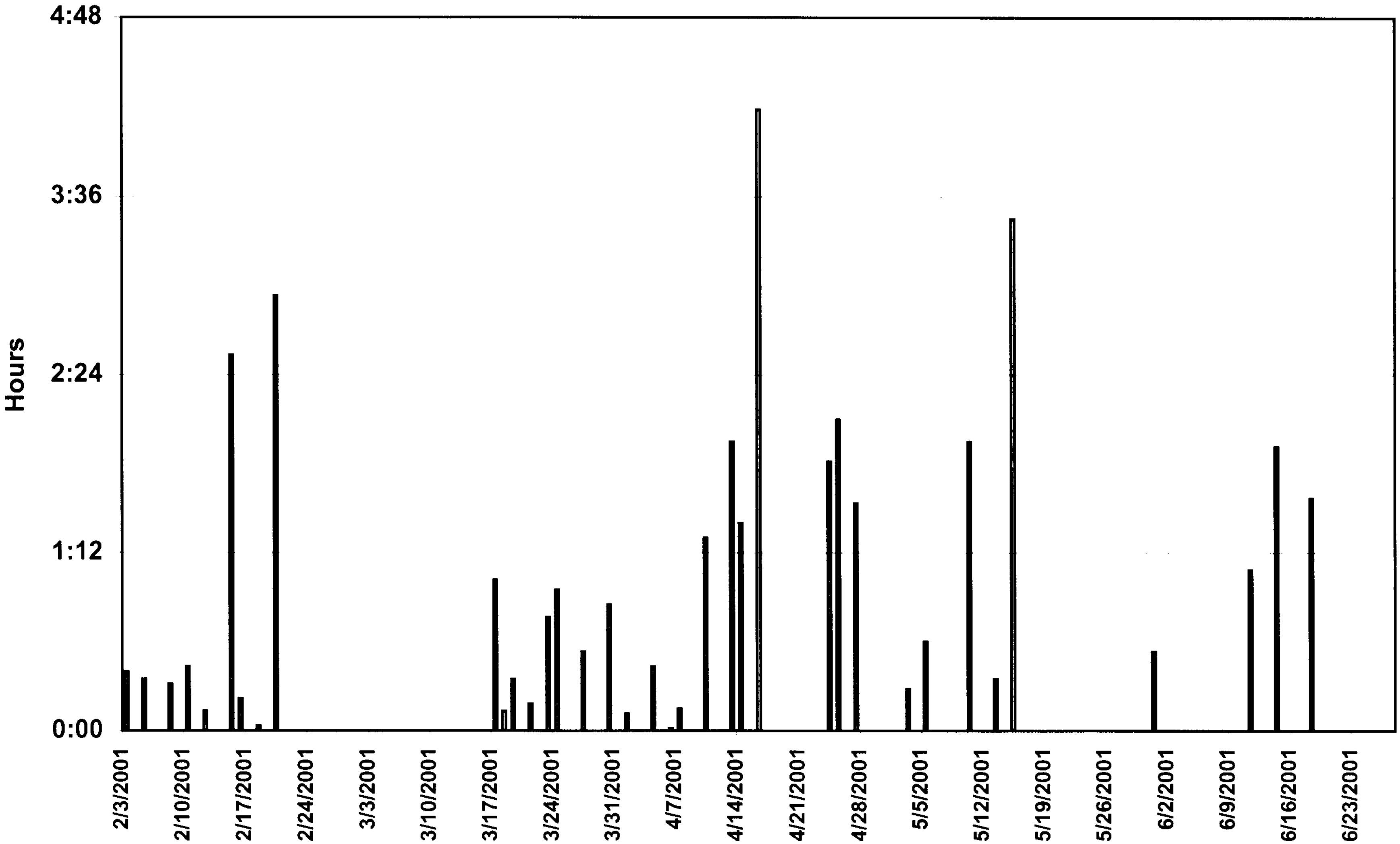
10-Day Average Charge Time - Vehicle BTE-09



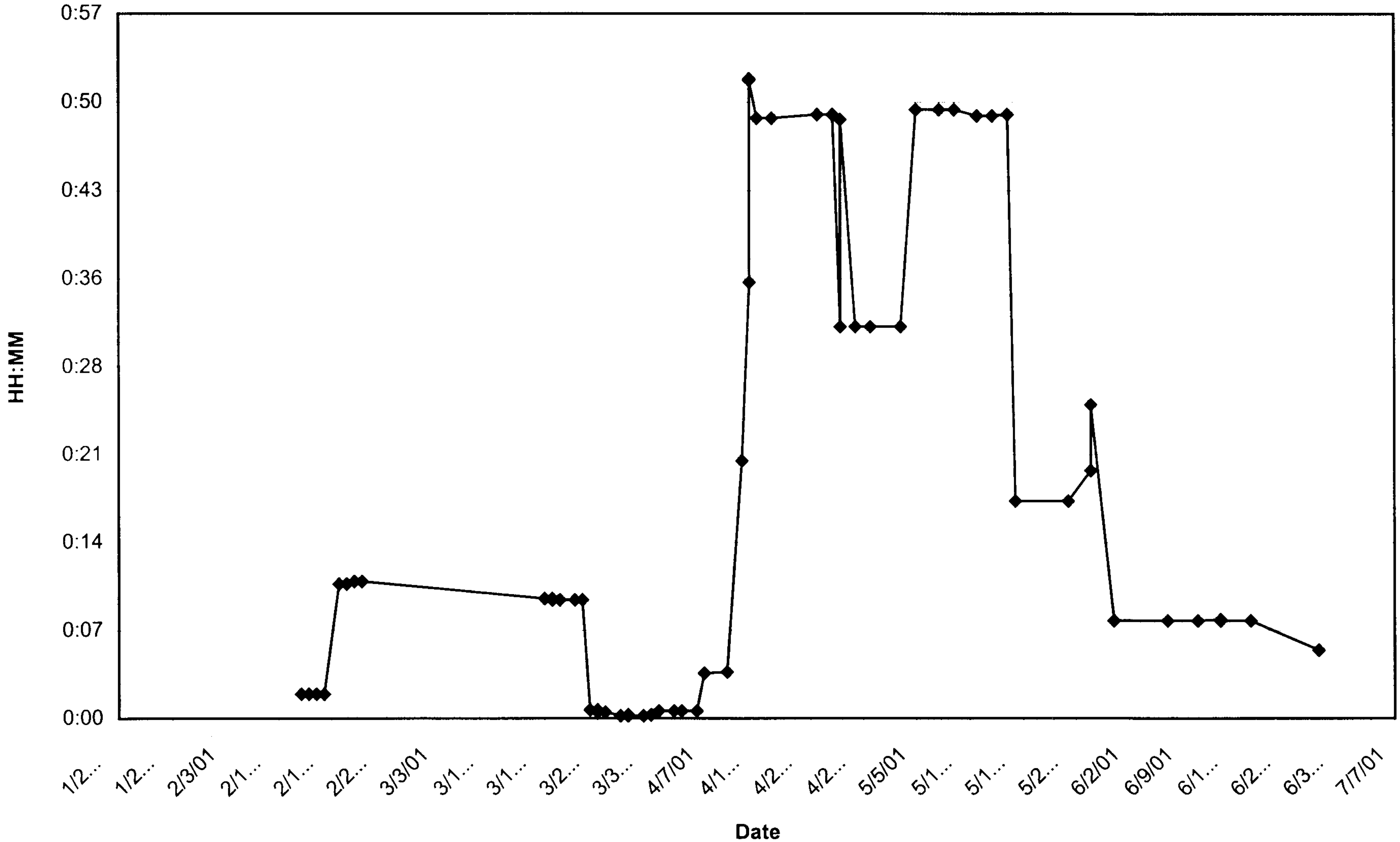
60-Day Average Charge Time - Vehicle BTE-09



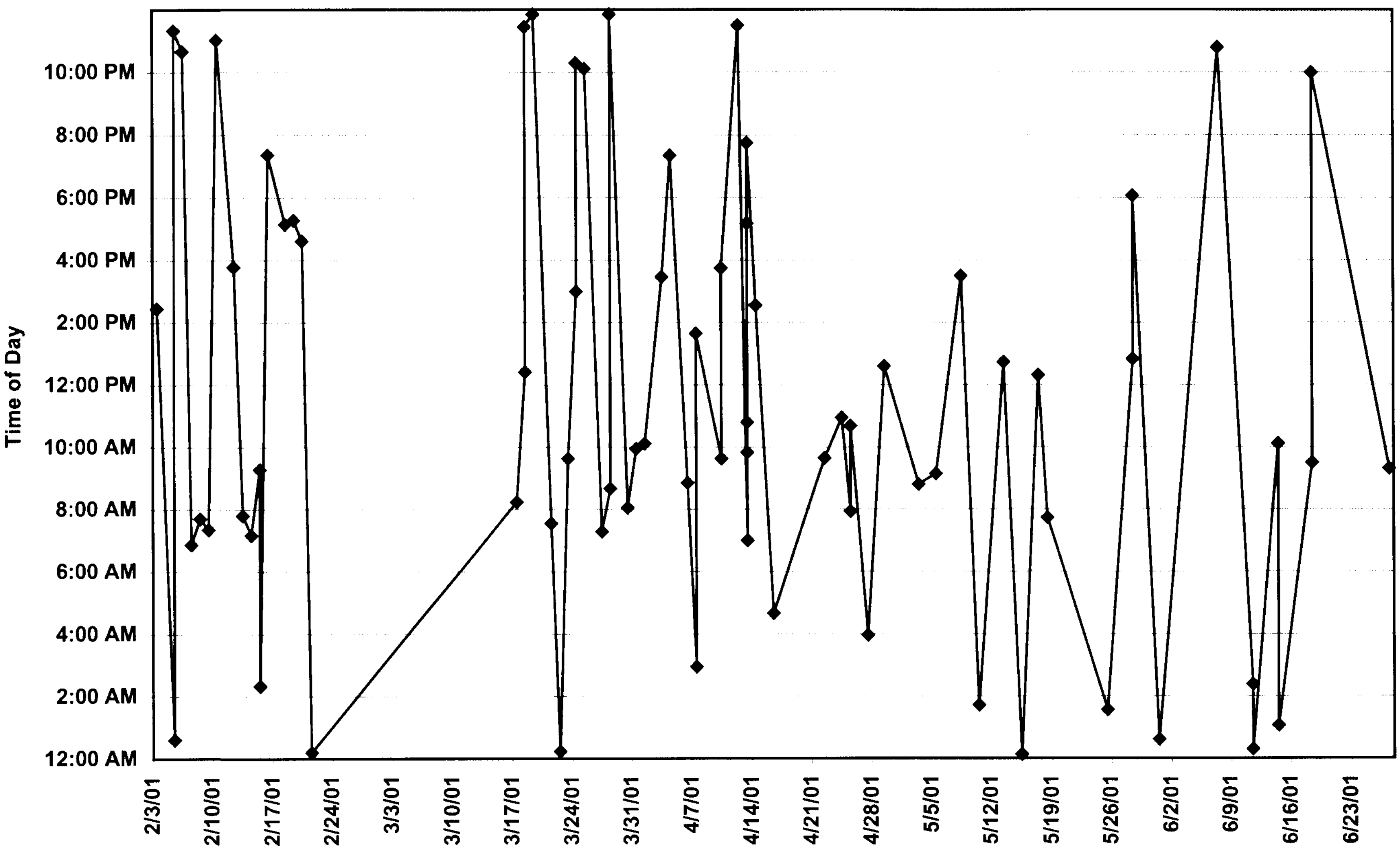
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-09

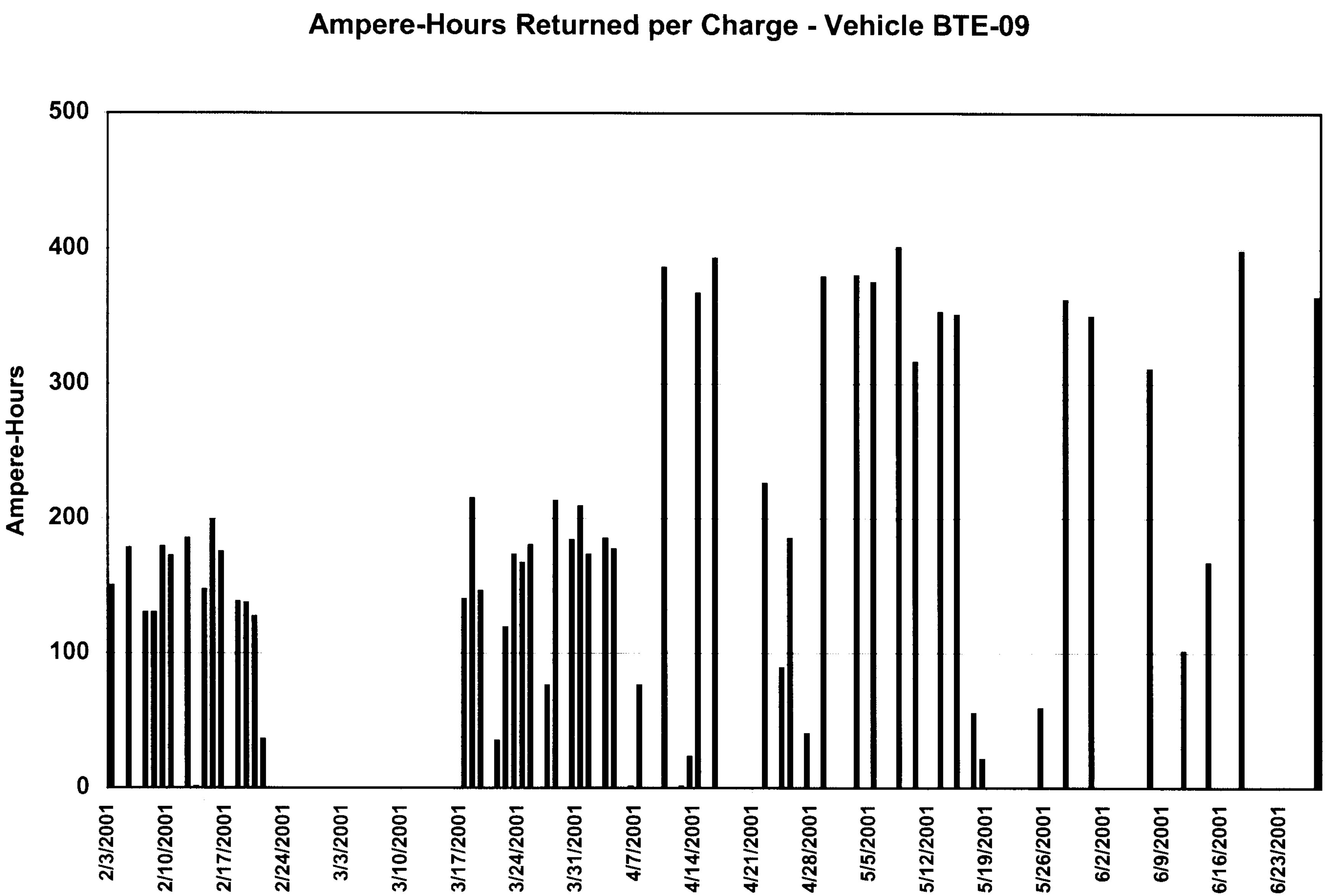


10-Cycle Average Connect Standby Time - Vehicle BTE-09



Charge Start Times - Vehicle BTE-09



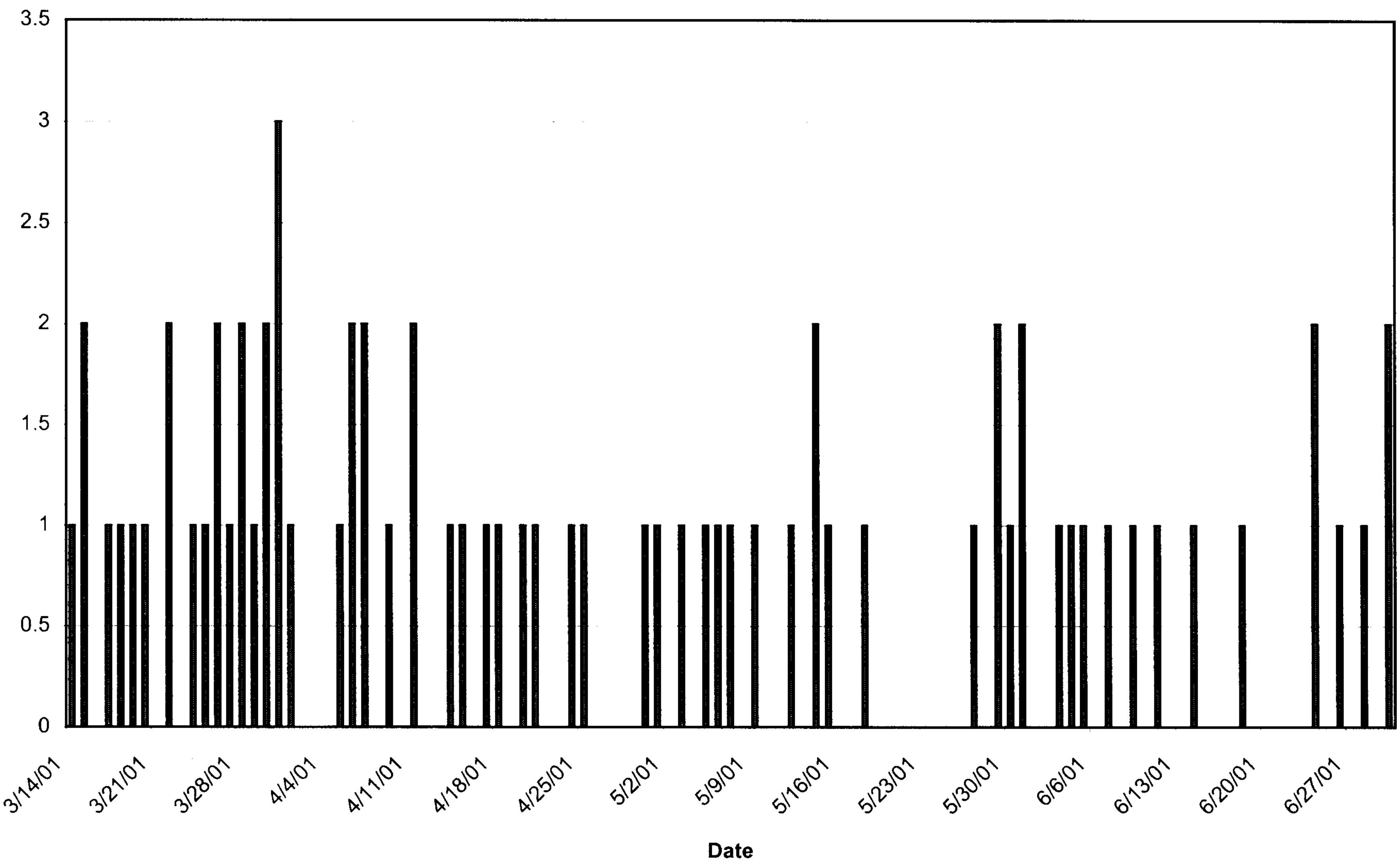


Ampere-Hours Returned per Charge - Vehicle BTE-09
Ampere-Hours
500
400
300
200
100
0
2/3/2001
2/10/2001
2/17/2001
2/24/2001
3/3/2001
3/10/2001
3/17/2001
3/24/2001
3/31/2001
4/7/2001
4/14/2001
4/21/2001
4/28/2001
5/5/2001
5/12/2001
5/19/2001
5/26/2001
6/2/2001
6/9/2001
6/16/2001
6/23/2001

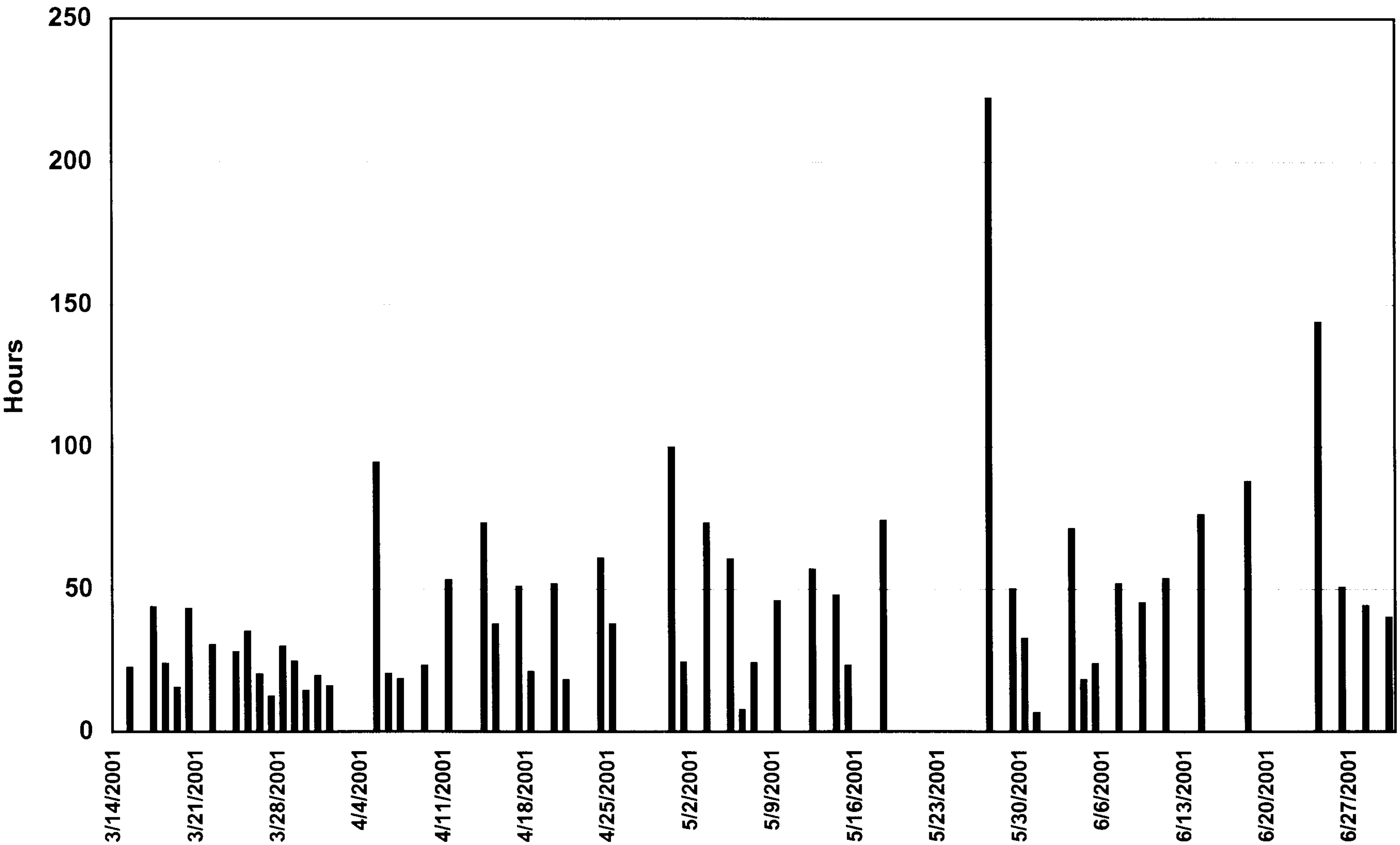
DATA GRAPHS

TRACTOR
BTE-10

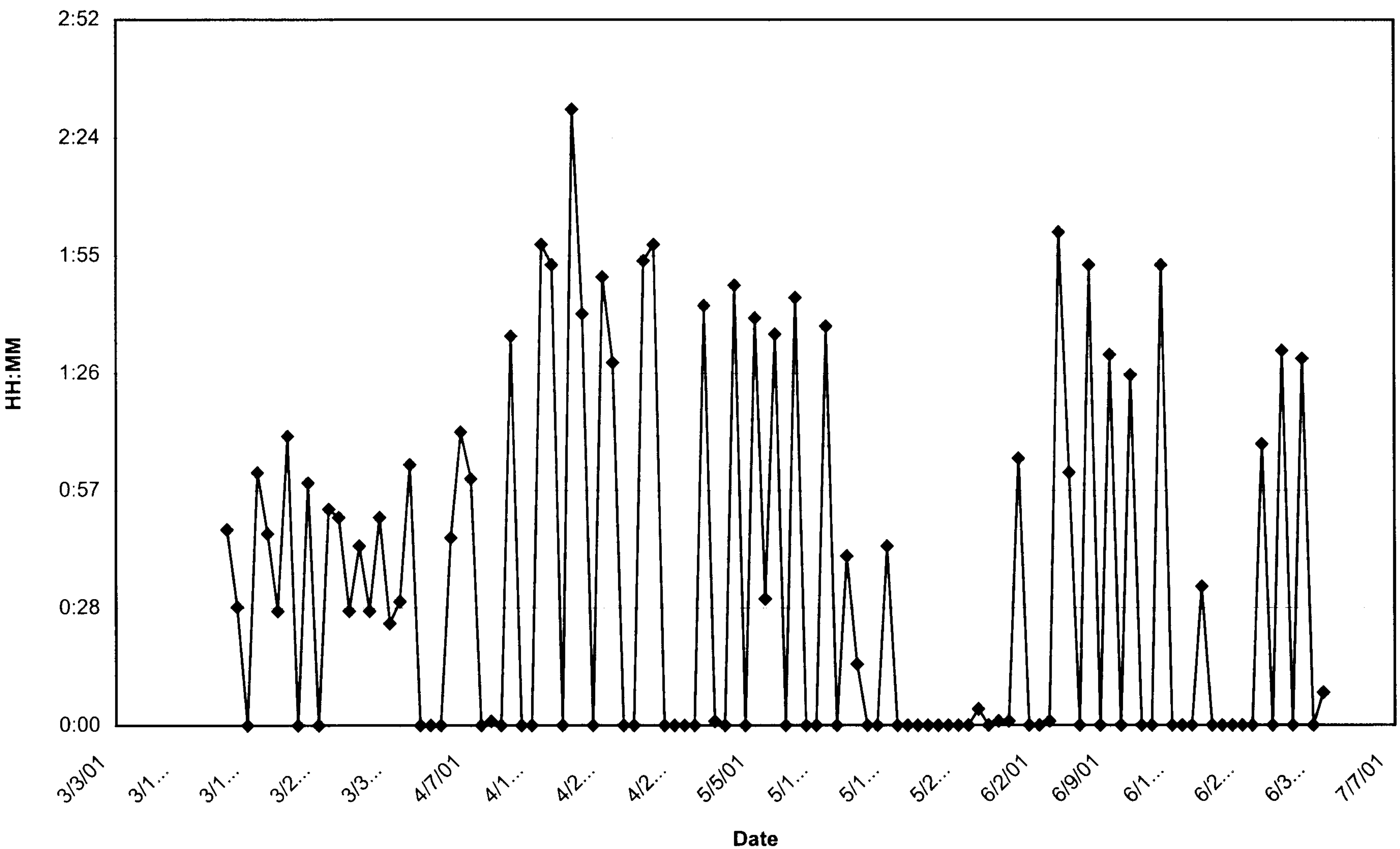
Charges Per Day - Vehicle BTE-10



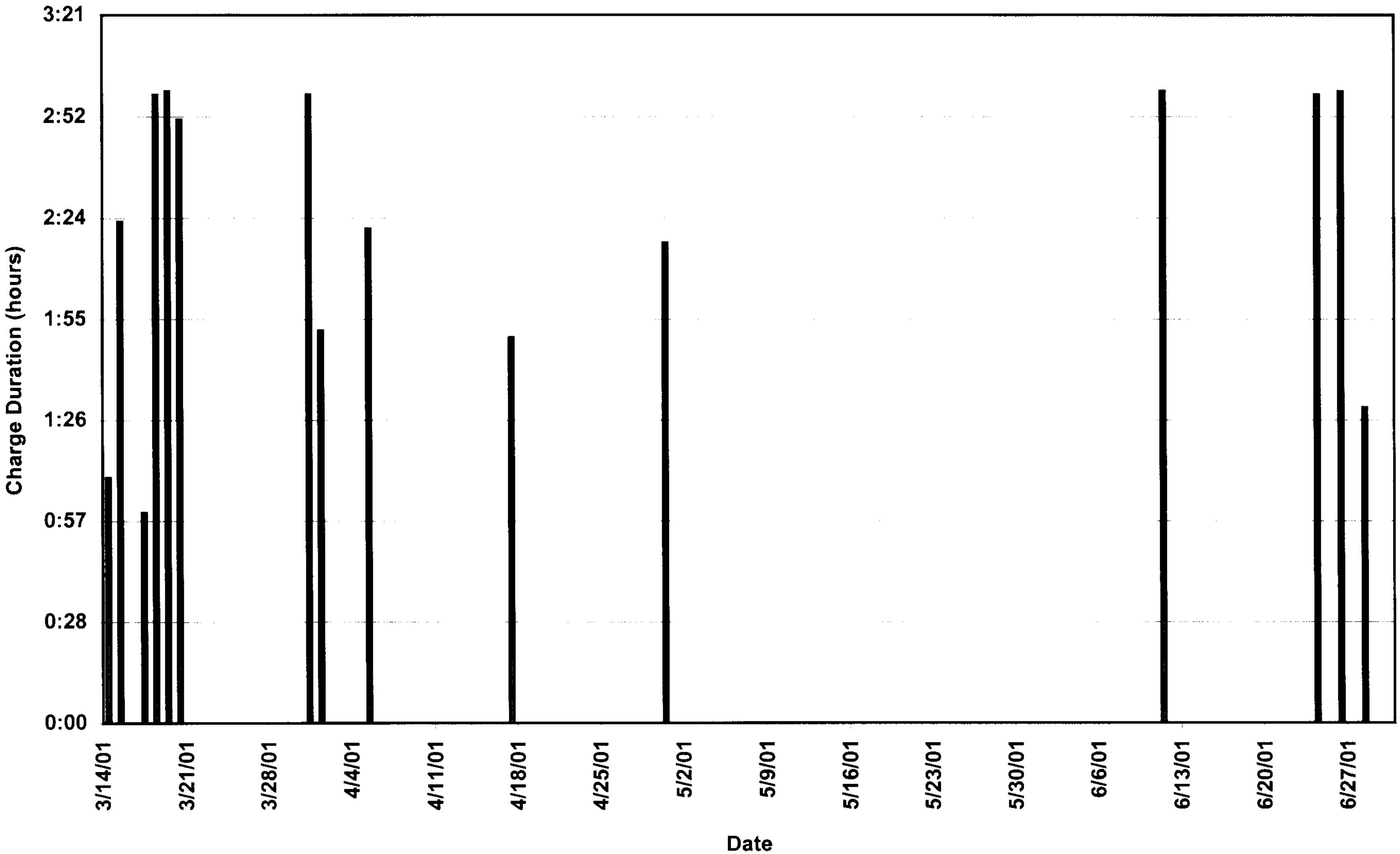
Time Between Charges - Vehicle BTE-10



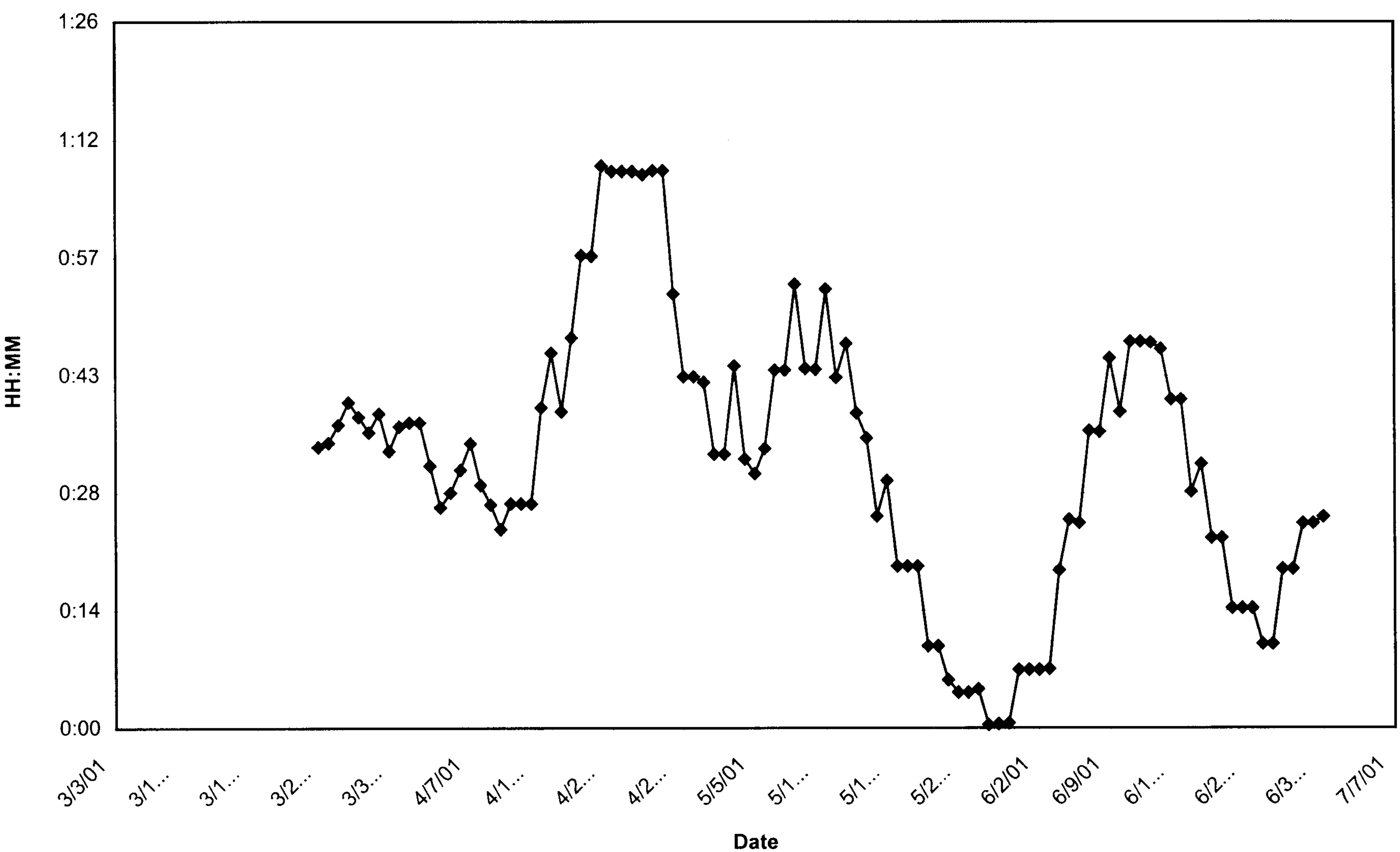
Average Charge Time - Vehicle BTE-10



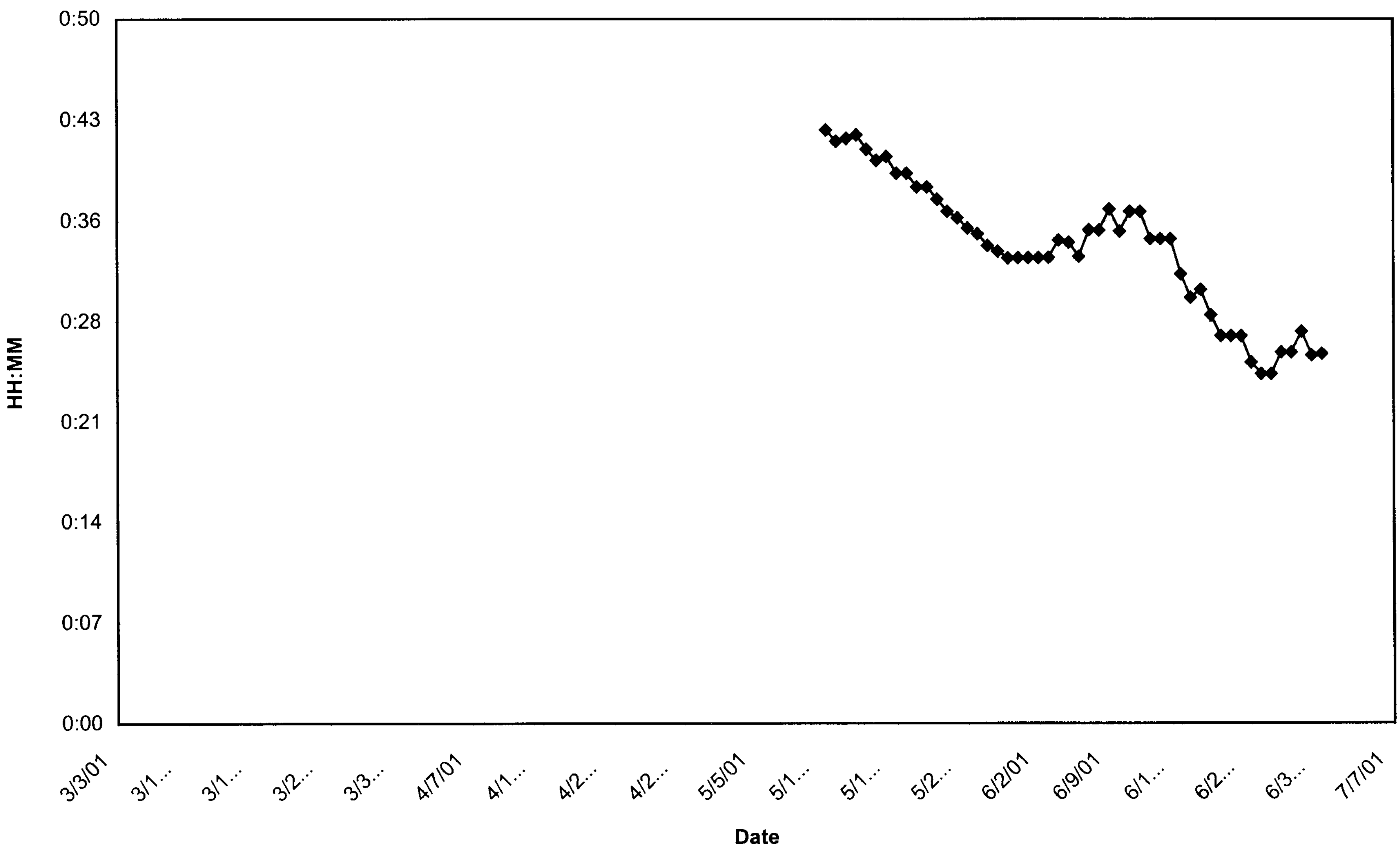
Time on Equalize Charge - Vehicle BTE-10



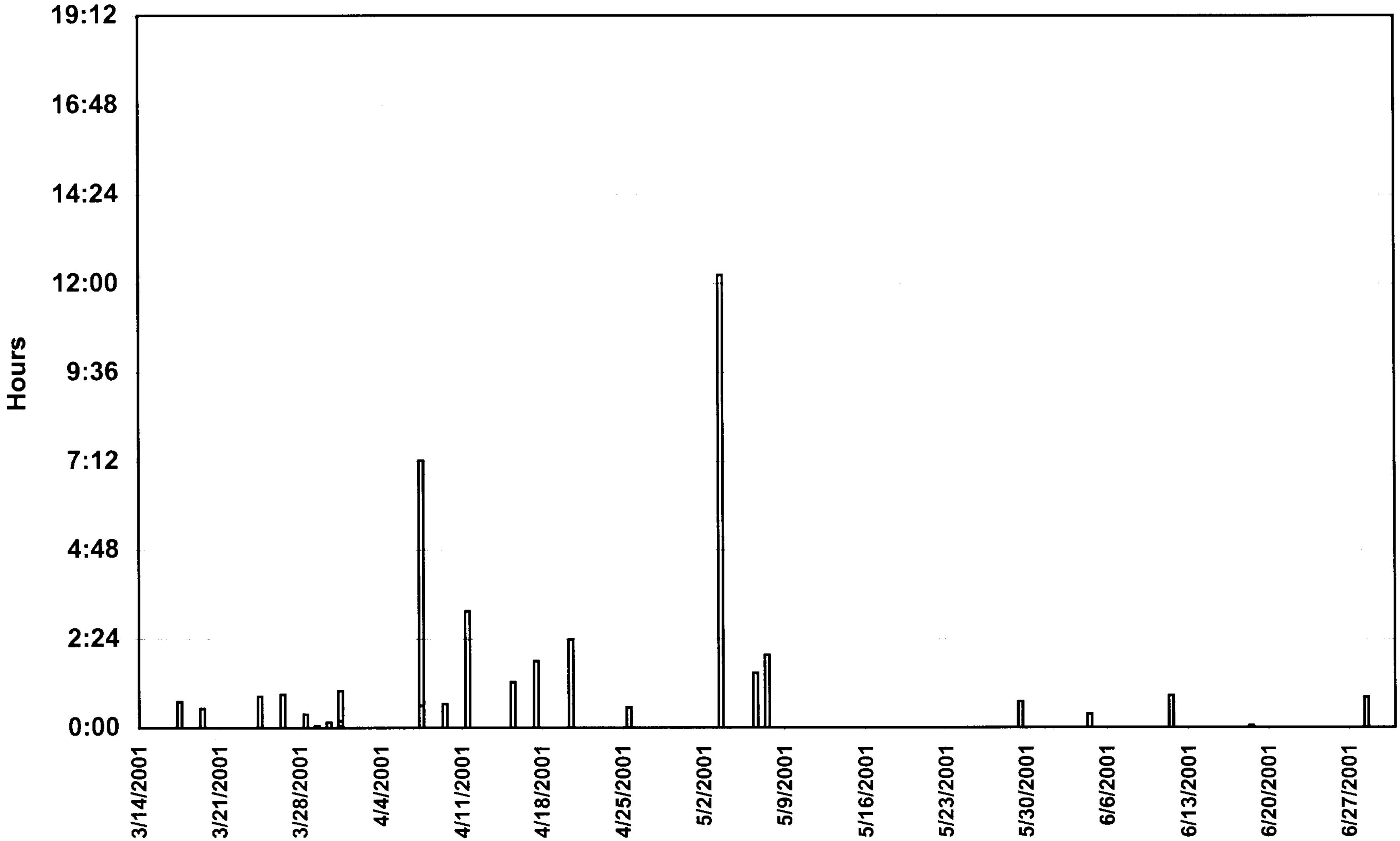
10 day Average Charge Time - Vehicle BTE-10



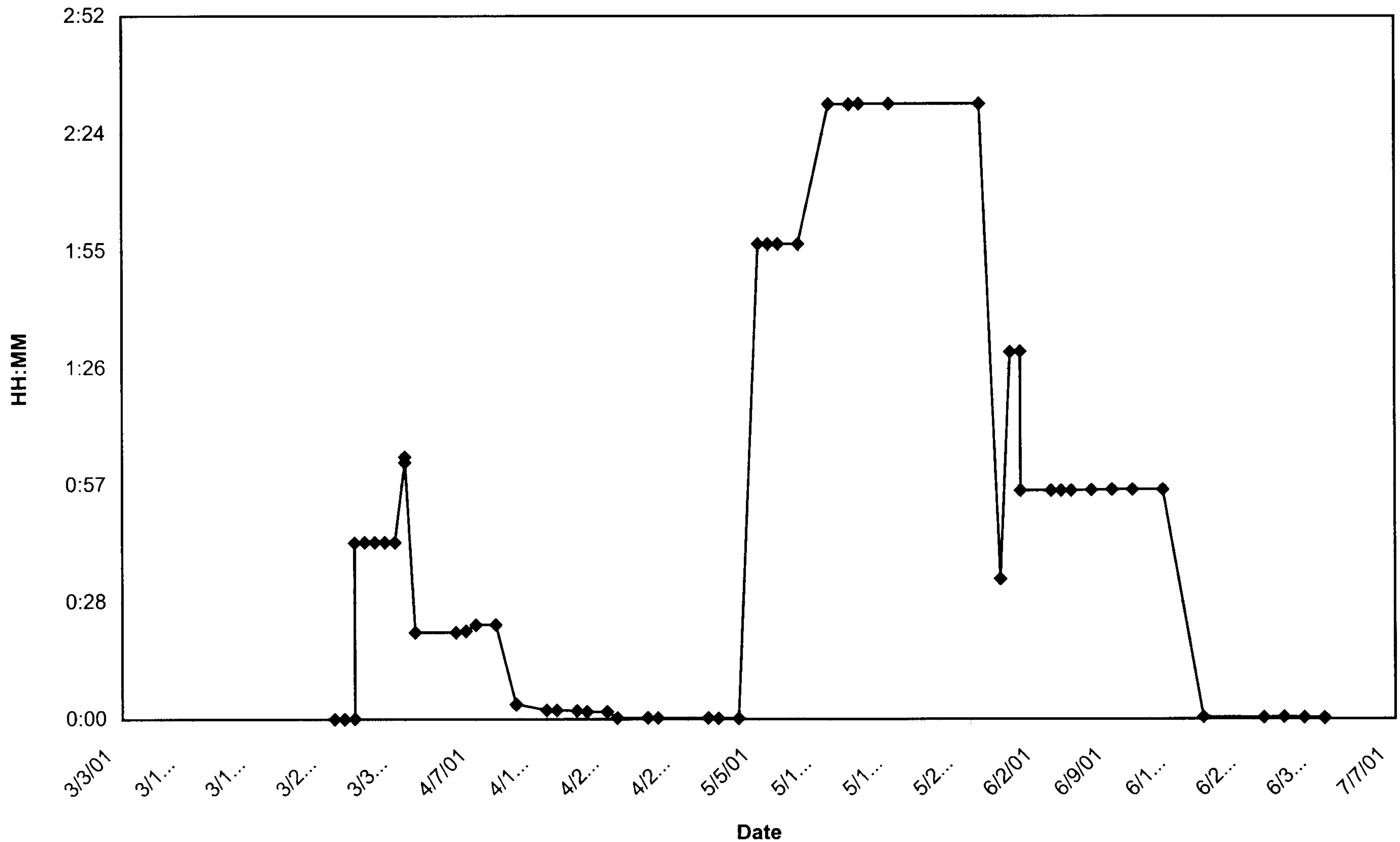
60 Day Average Charge Time - Vehicle BTE-10



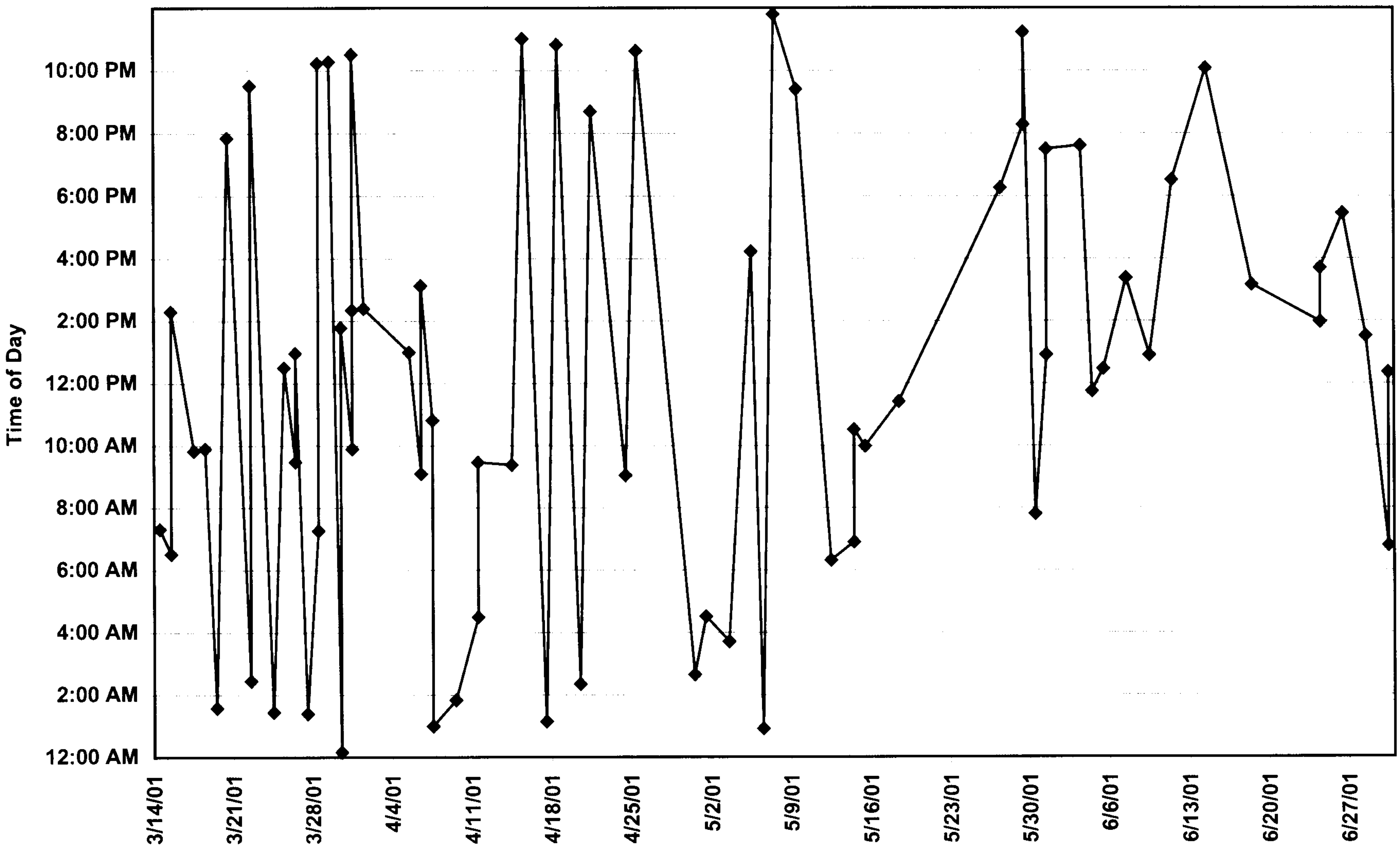
Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-10



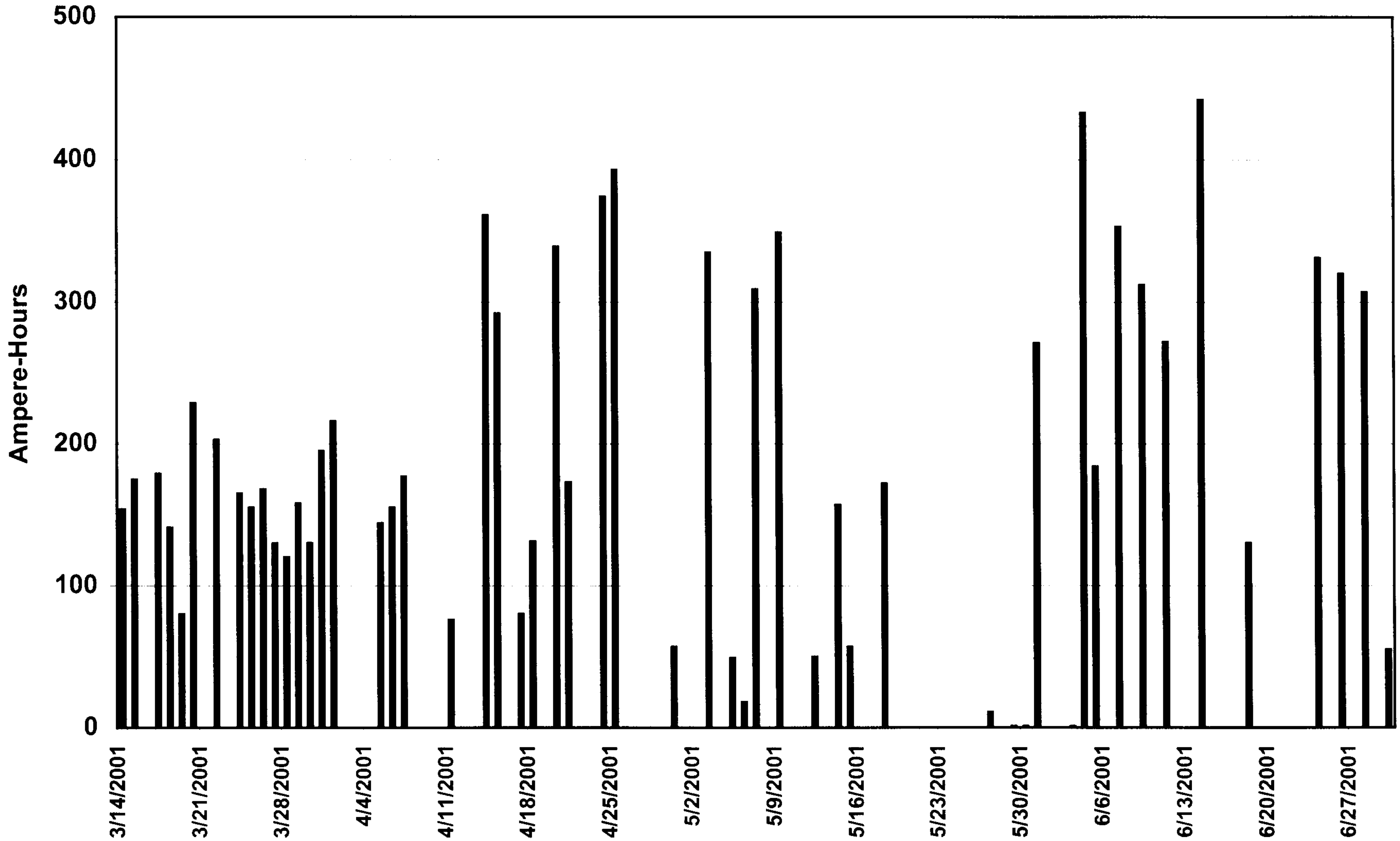
10-Cycle Average Connect Standby Time - Vehicle BTE-10



Charge Start Times - Vehicle BTE-10



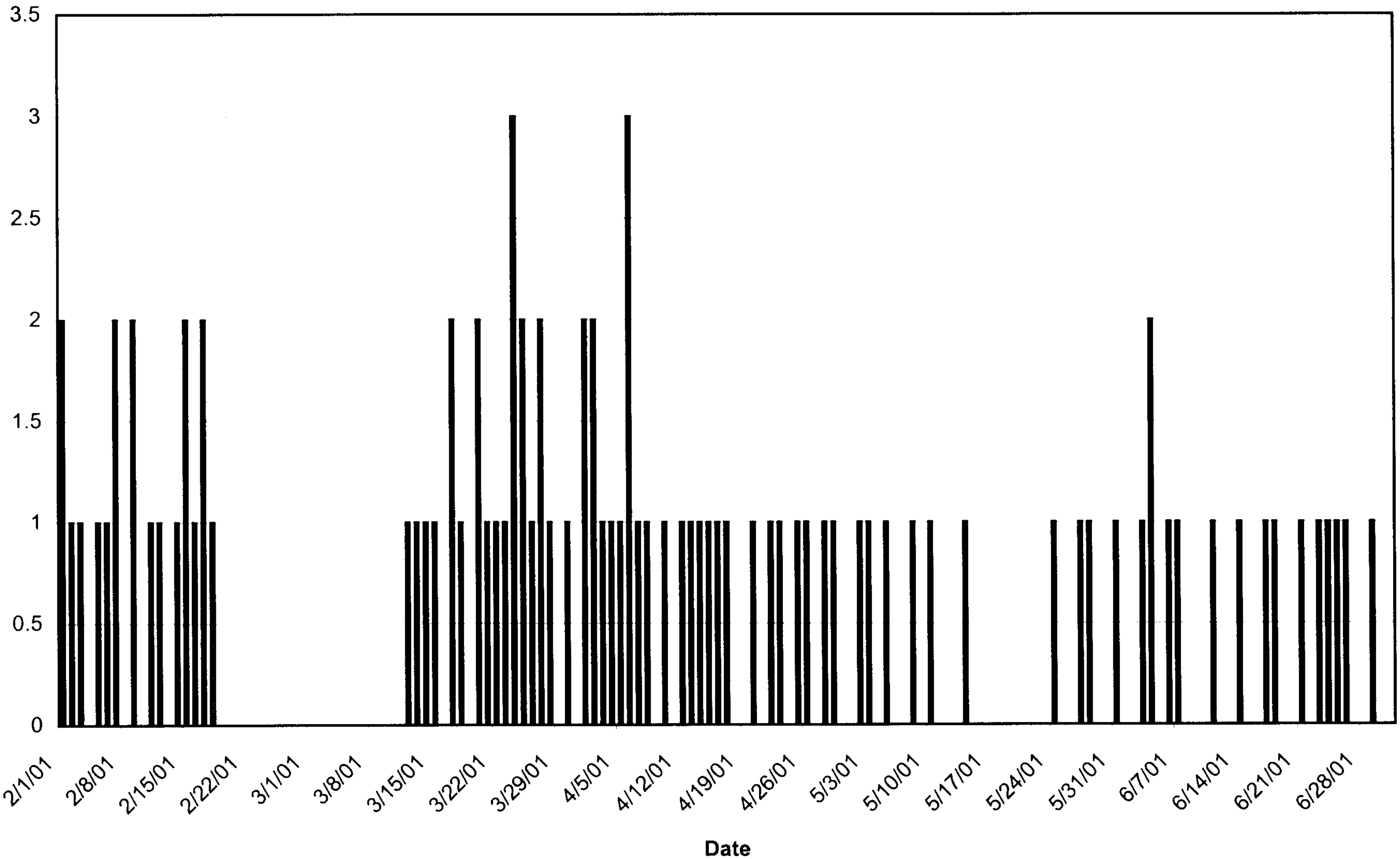
Ampere-Hours Returned per Charge - Vehicle BTE-10



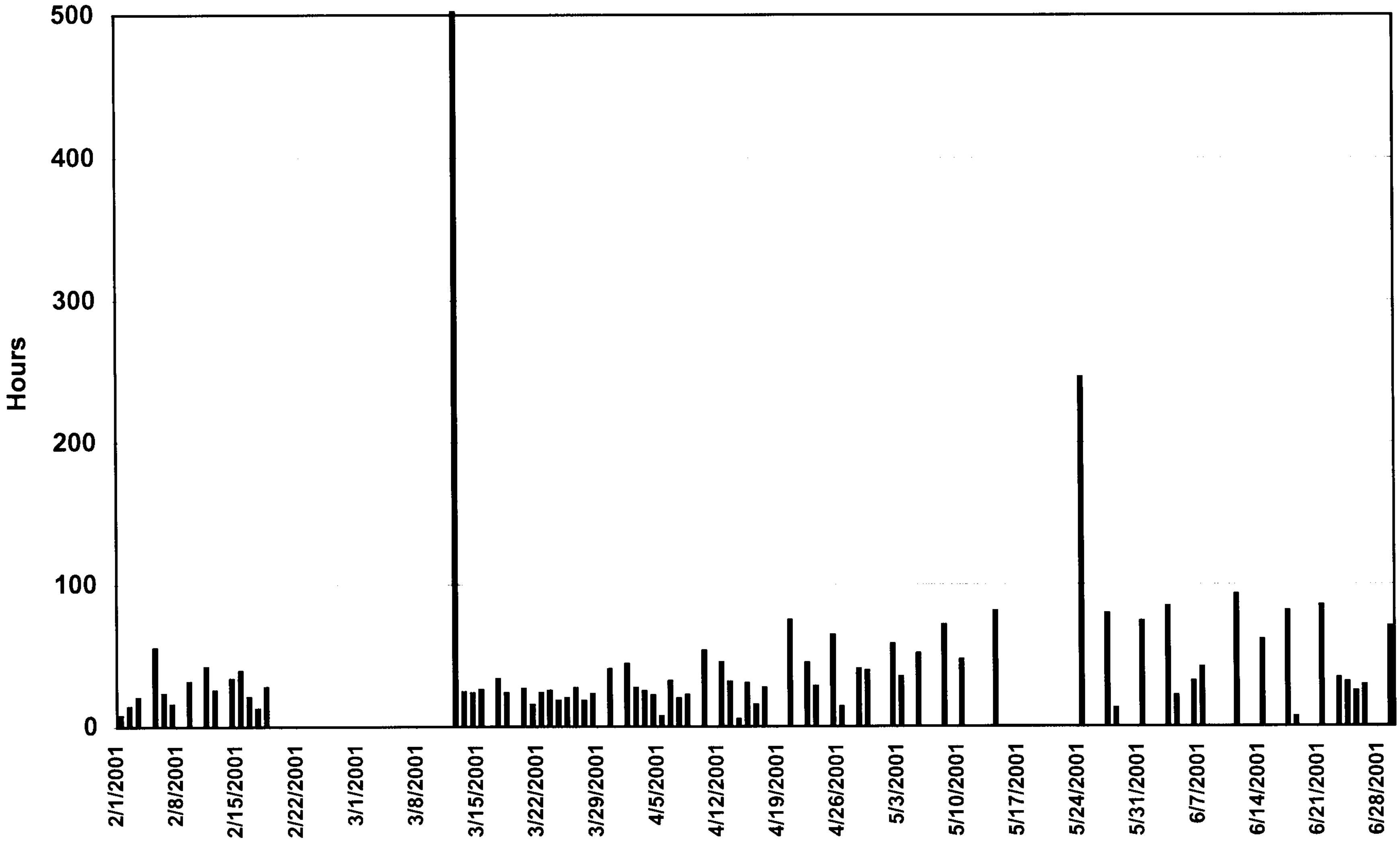
DATA GRAPHS

TRACTOR
BTE-11

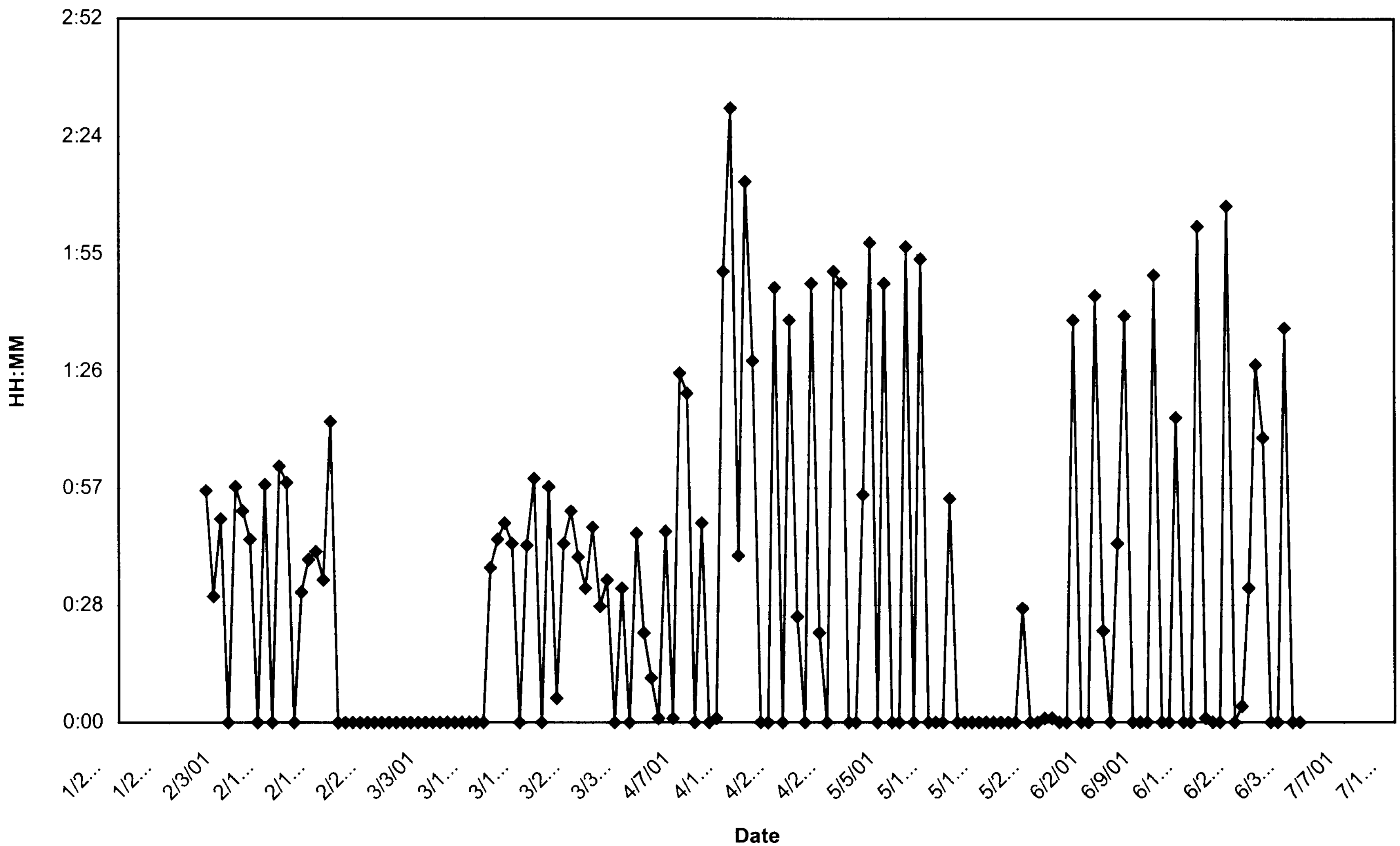
Charges Per Day - Vehicle BTE-11



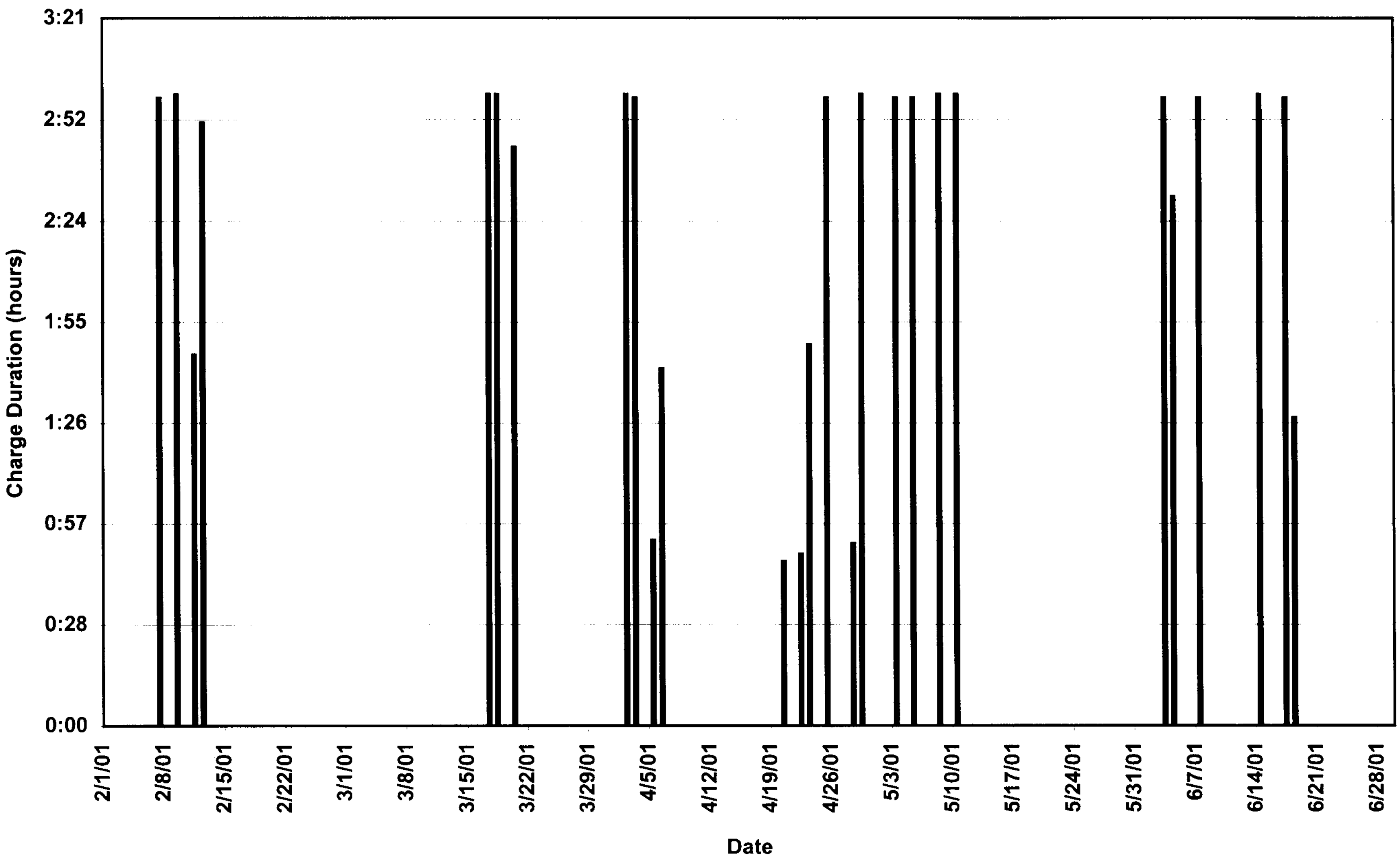
Time Between Charges - Vehicle BTE-11



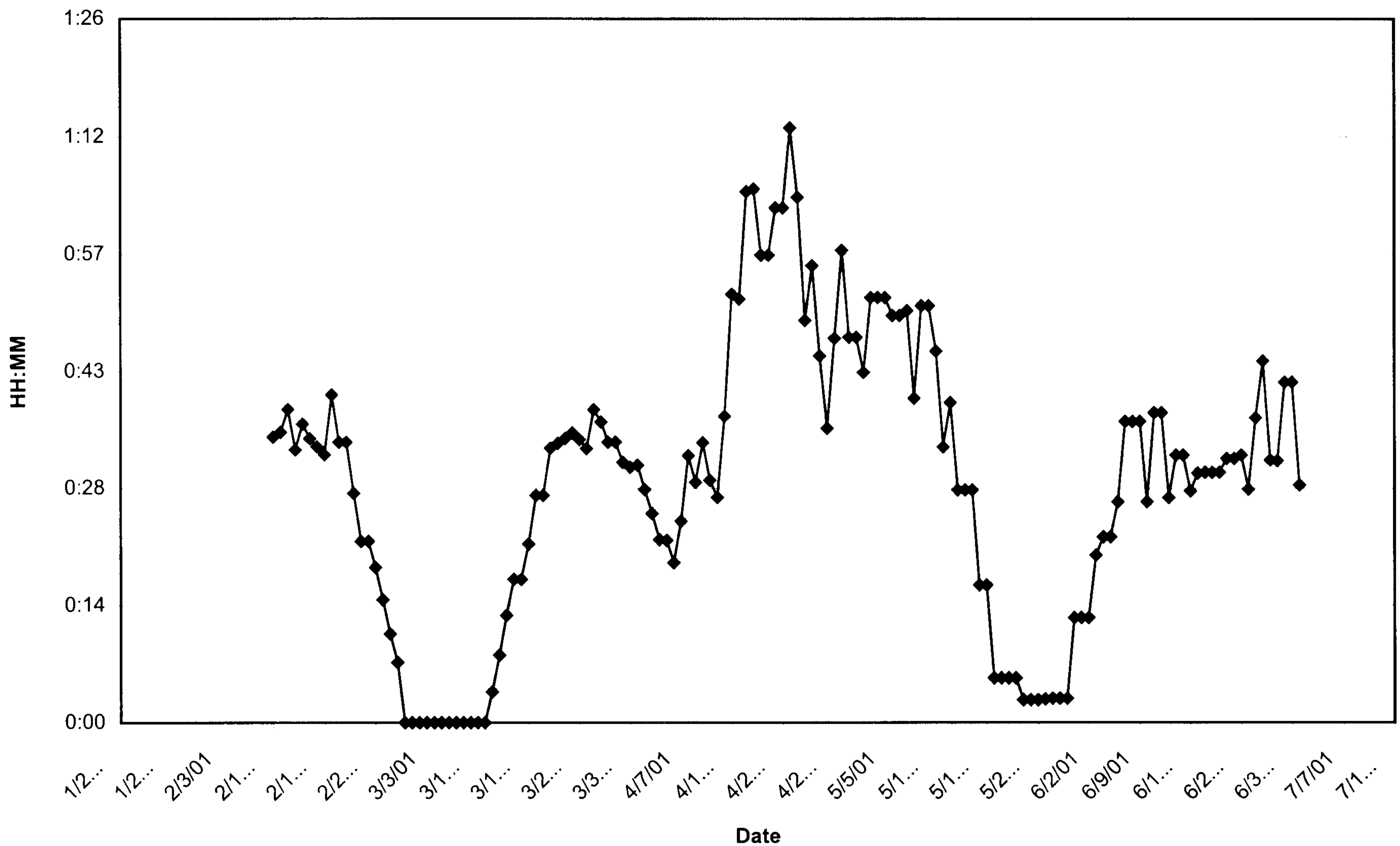
Average Charge Time - Vehicle BTE-11



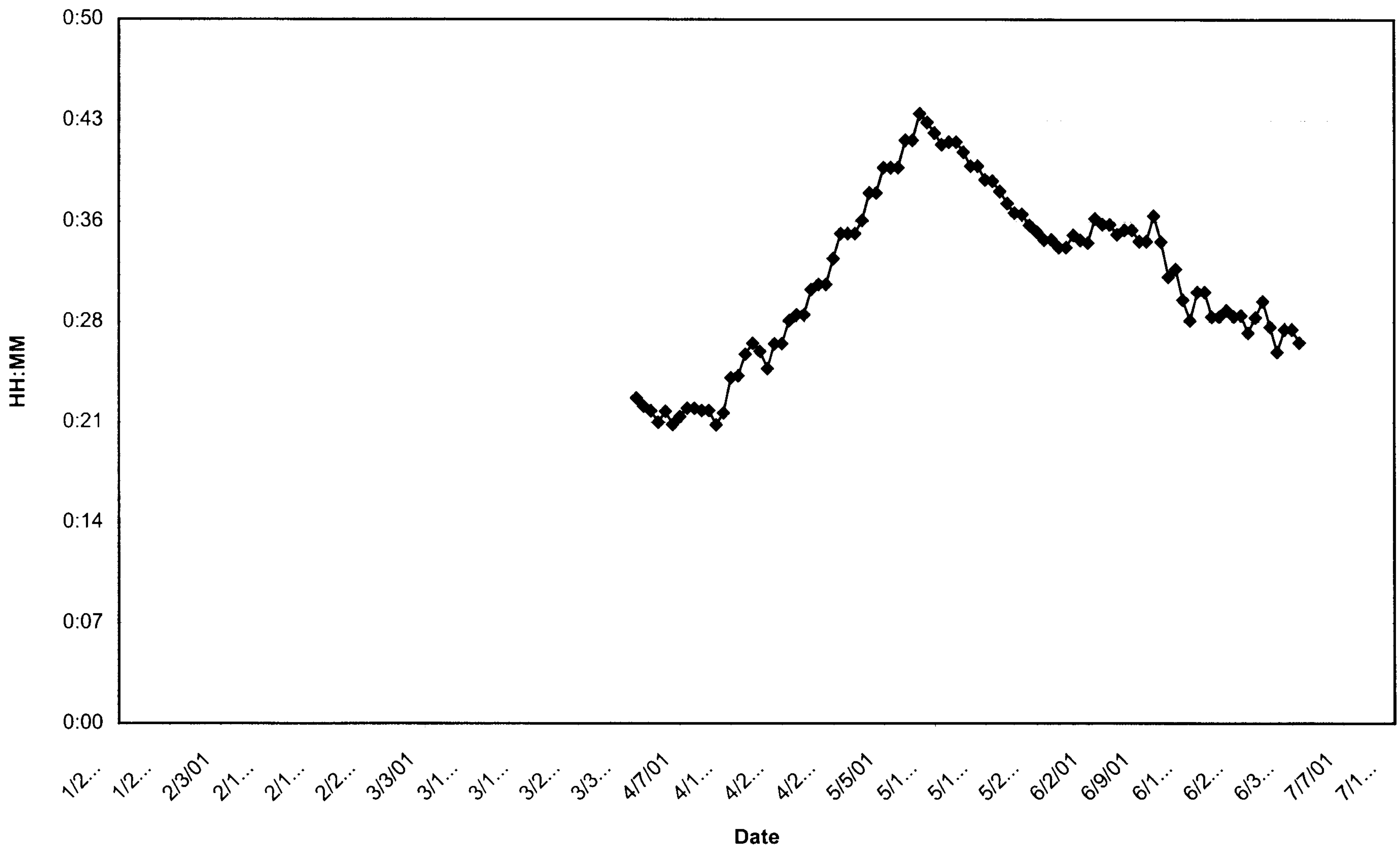
Time on Equalize Charge - Vehicle BTE-11



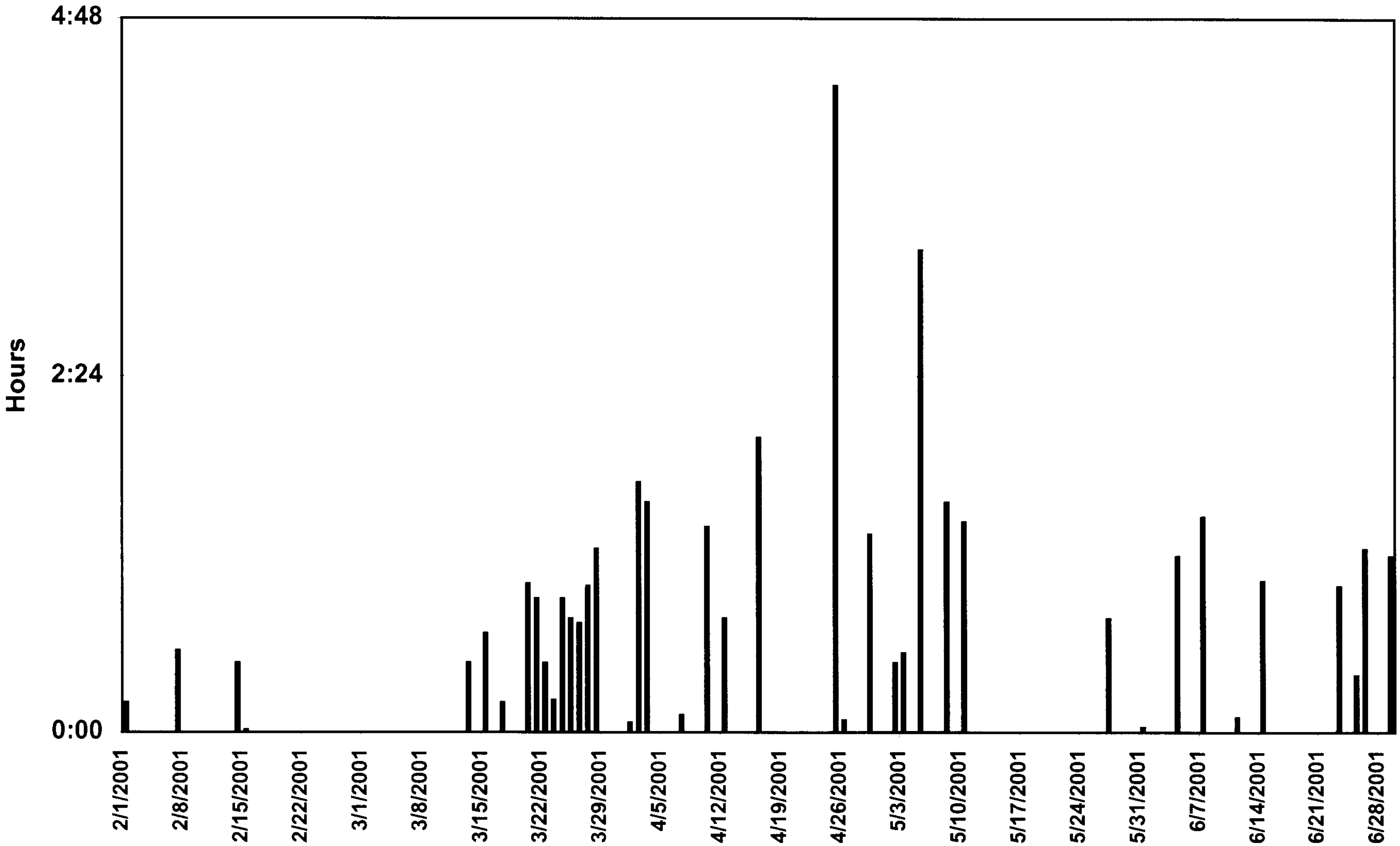
10-Day Average Charge Time - Vehicle BTE-11



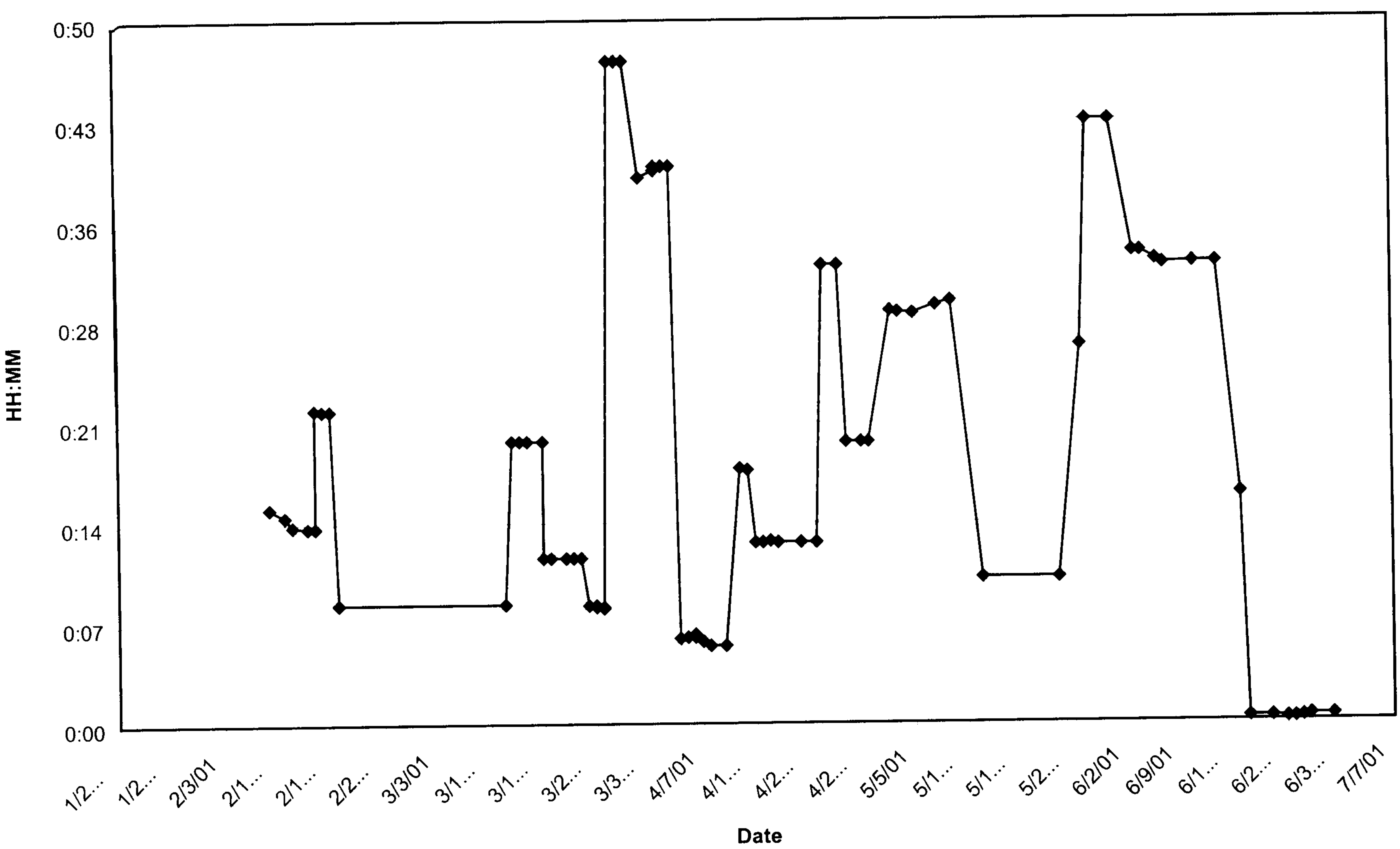
60-Day Average Charge Time - Vehicle BTE-11

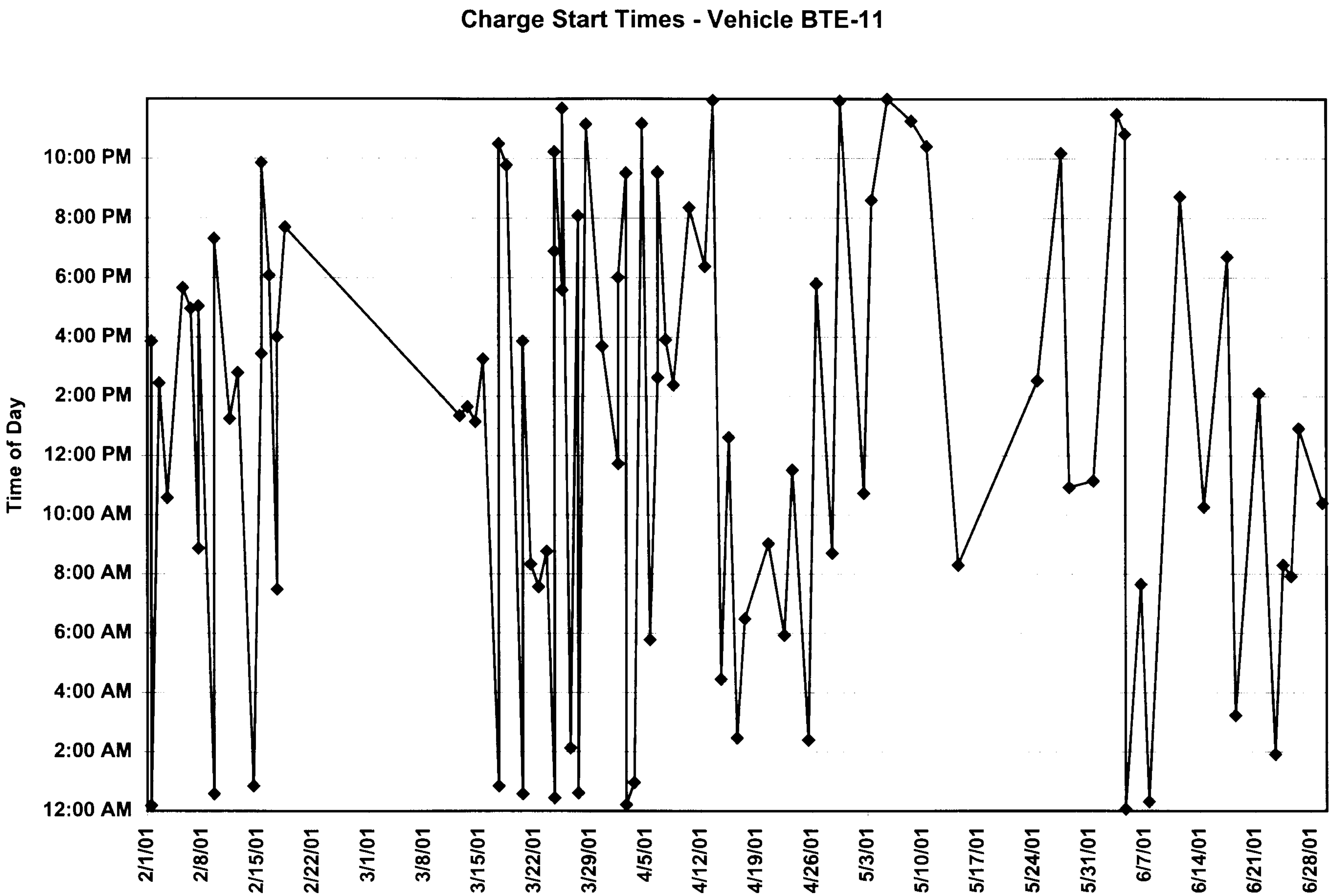


Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-11

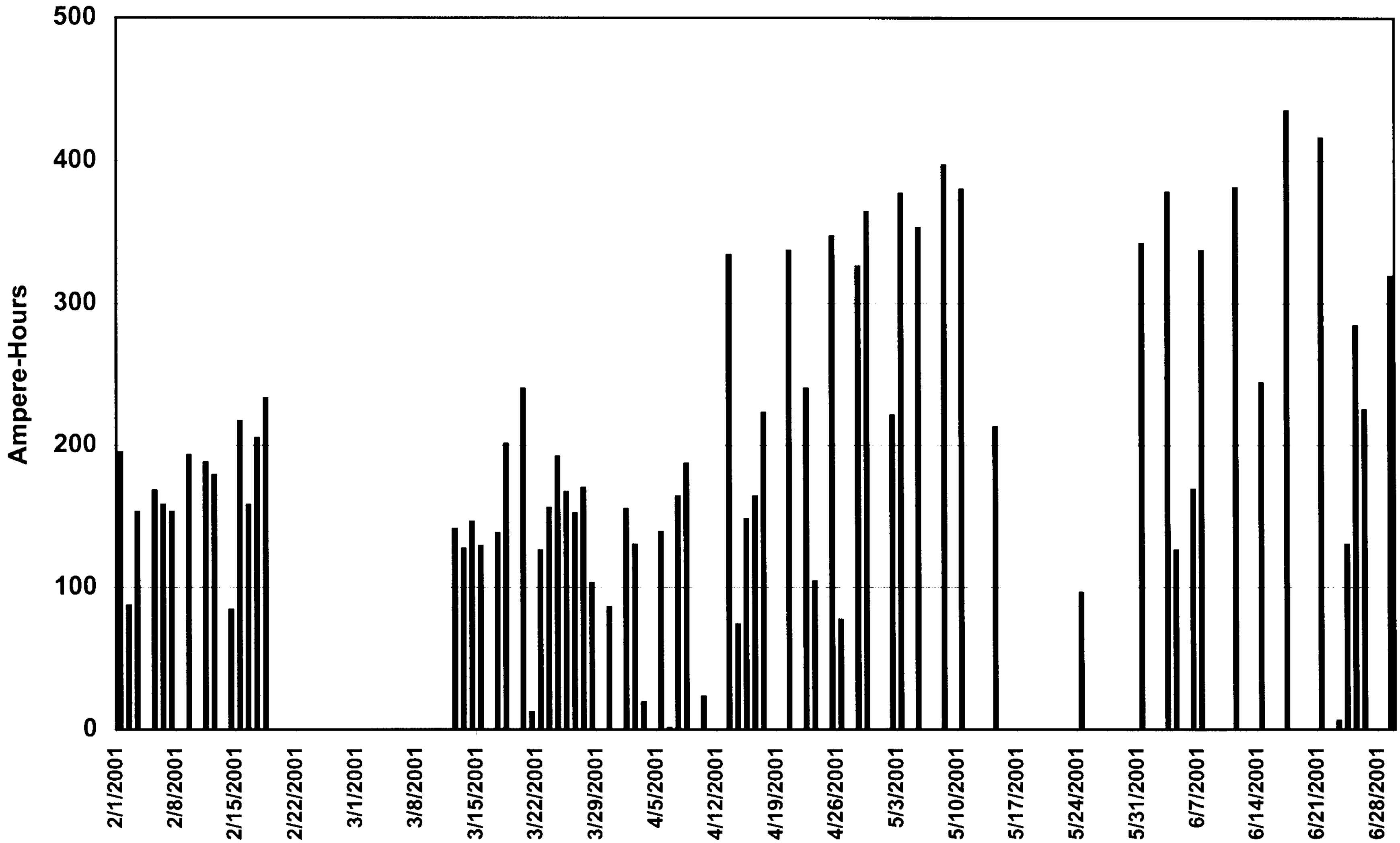


10-Cycle Average Connect Standby Time - Vehicle BTE-11




Charge Start Times - Vehicle BTE-11
Time of Day
10:00 PM
8:00 PM
6:00 PM
4:00 PM
2:00 PM
12:00 PM
10:00 AM
8:00 AM
6:00 AM
4:00 AM
2:00 AM
12:00 AM
2/1/01
2/8/01
2/15/01
2/22/01
3/1/01
3/8/01
3/15/01
3/22/01
3/29/01
4/5/01
4/12/01
4/19/01
4/26/01
5/3/01
5/10/01
5/17/01
5/24/01
5/31/01
6/7/01
6/14/01
6/21/01
6/28/01

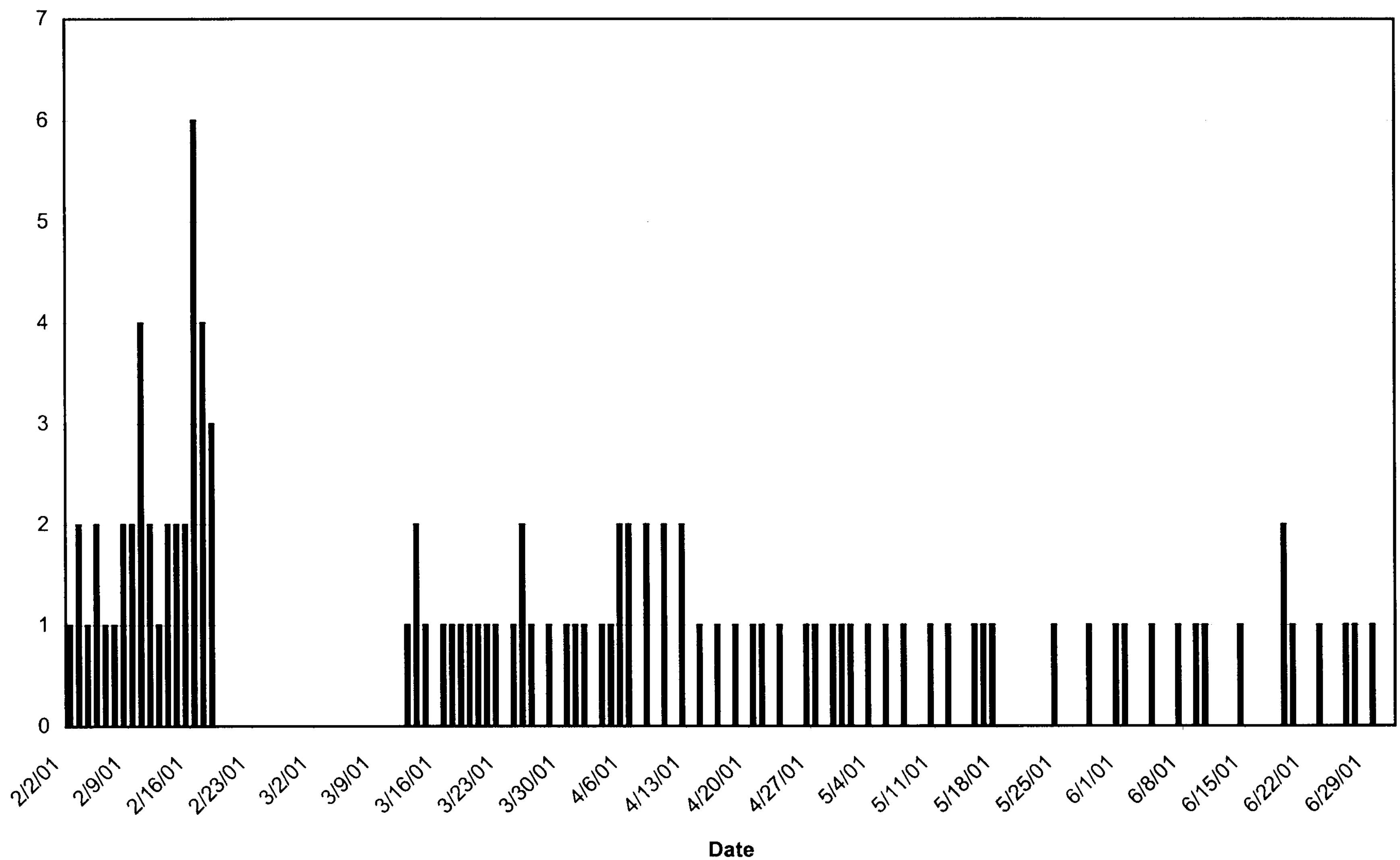
Ampere-Hours Returned per Charge - Vehicle BTE-11



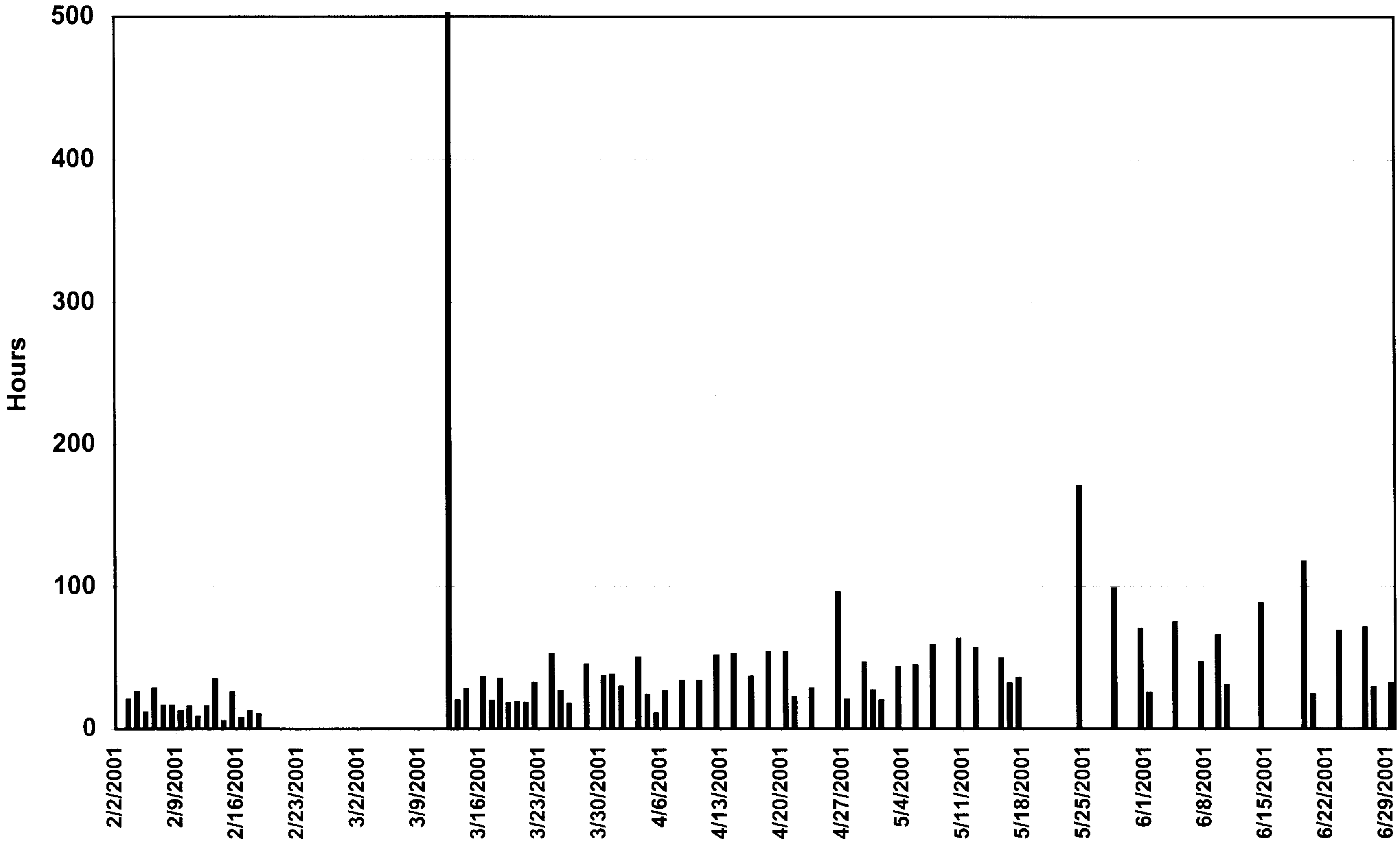
DATA GRAPHS

TRACTOR
BTE-12

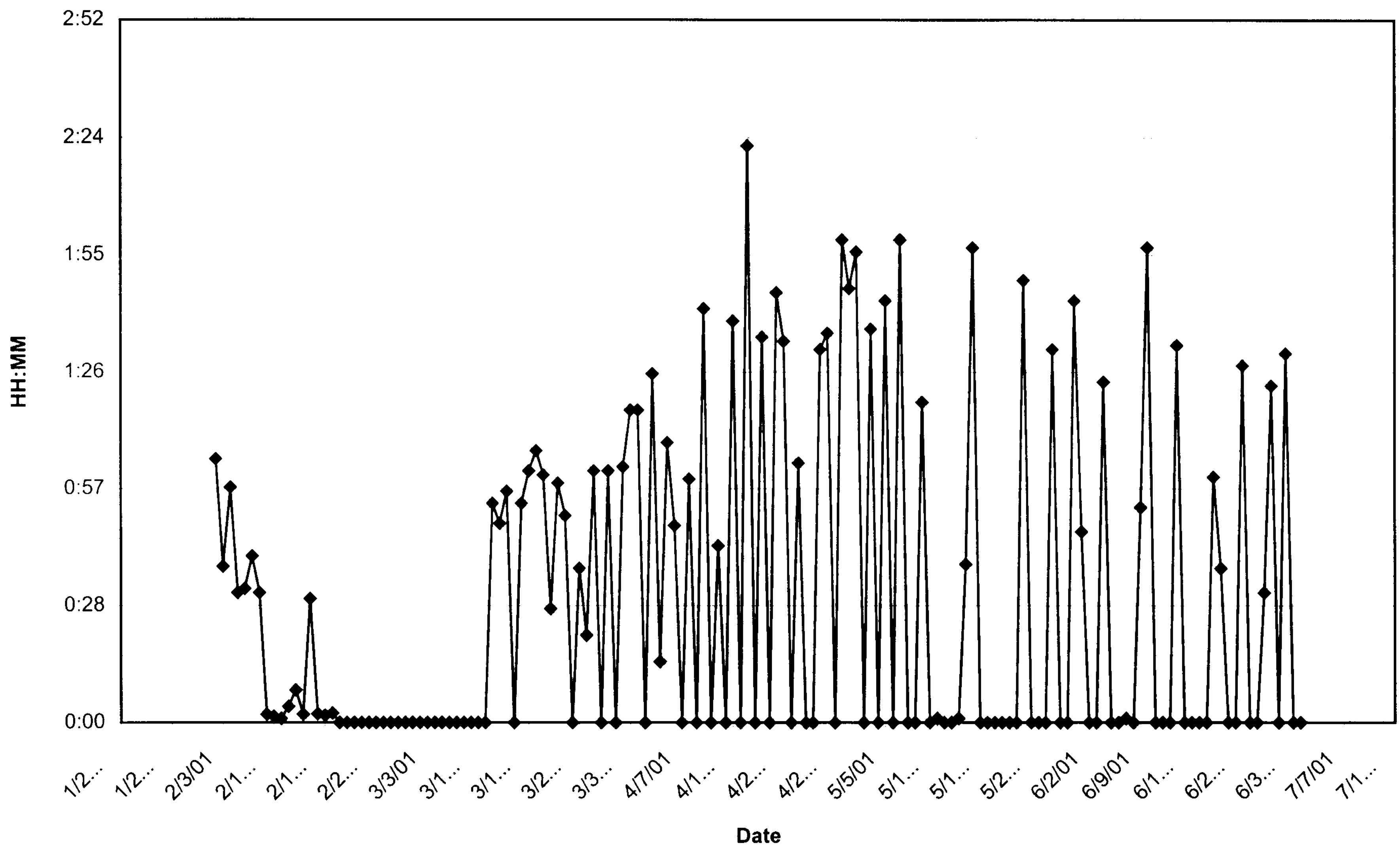
Charges Per Day - Vehicle BTE-12



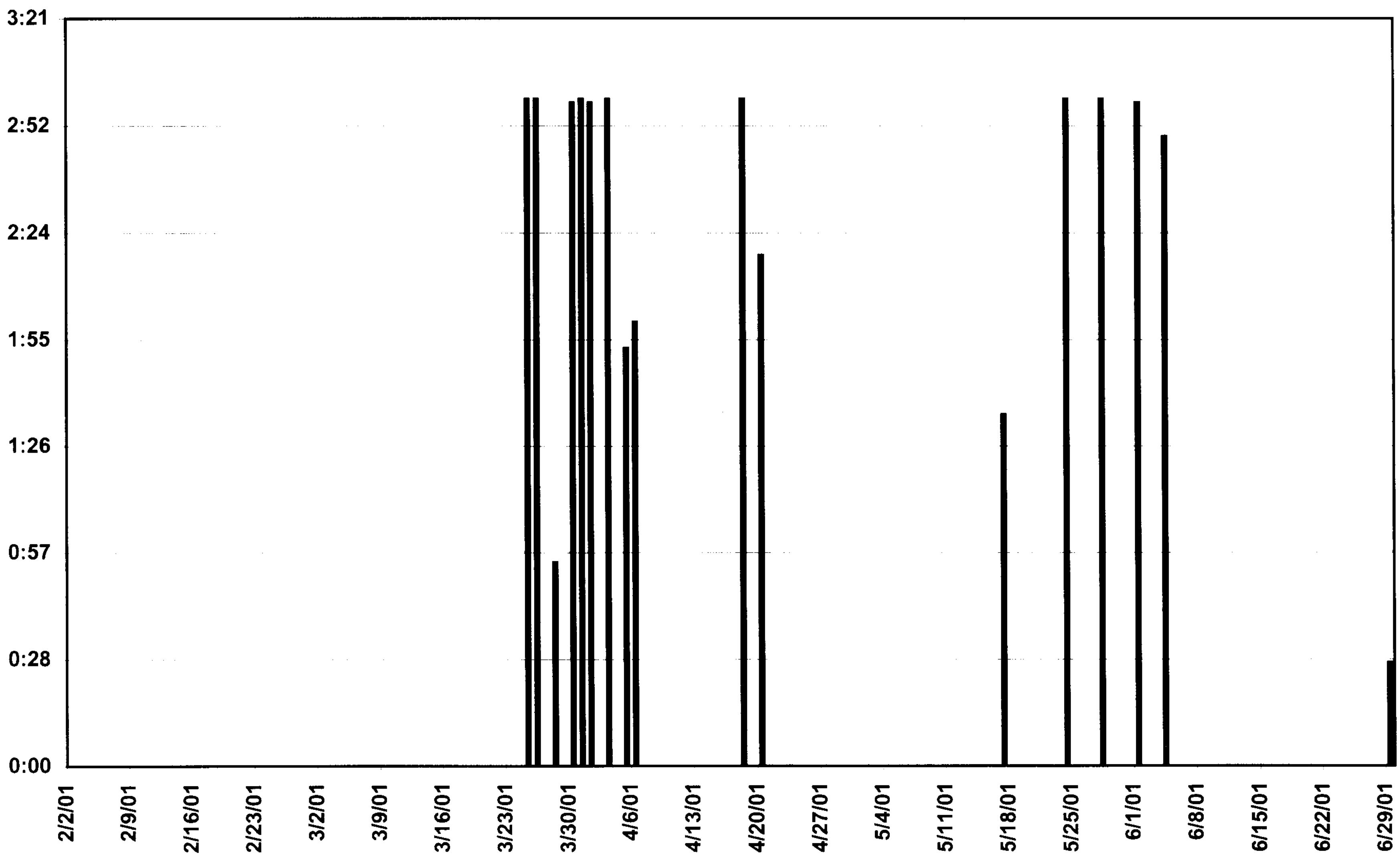
Time Between Charges - Vehicle BTE-12

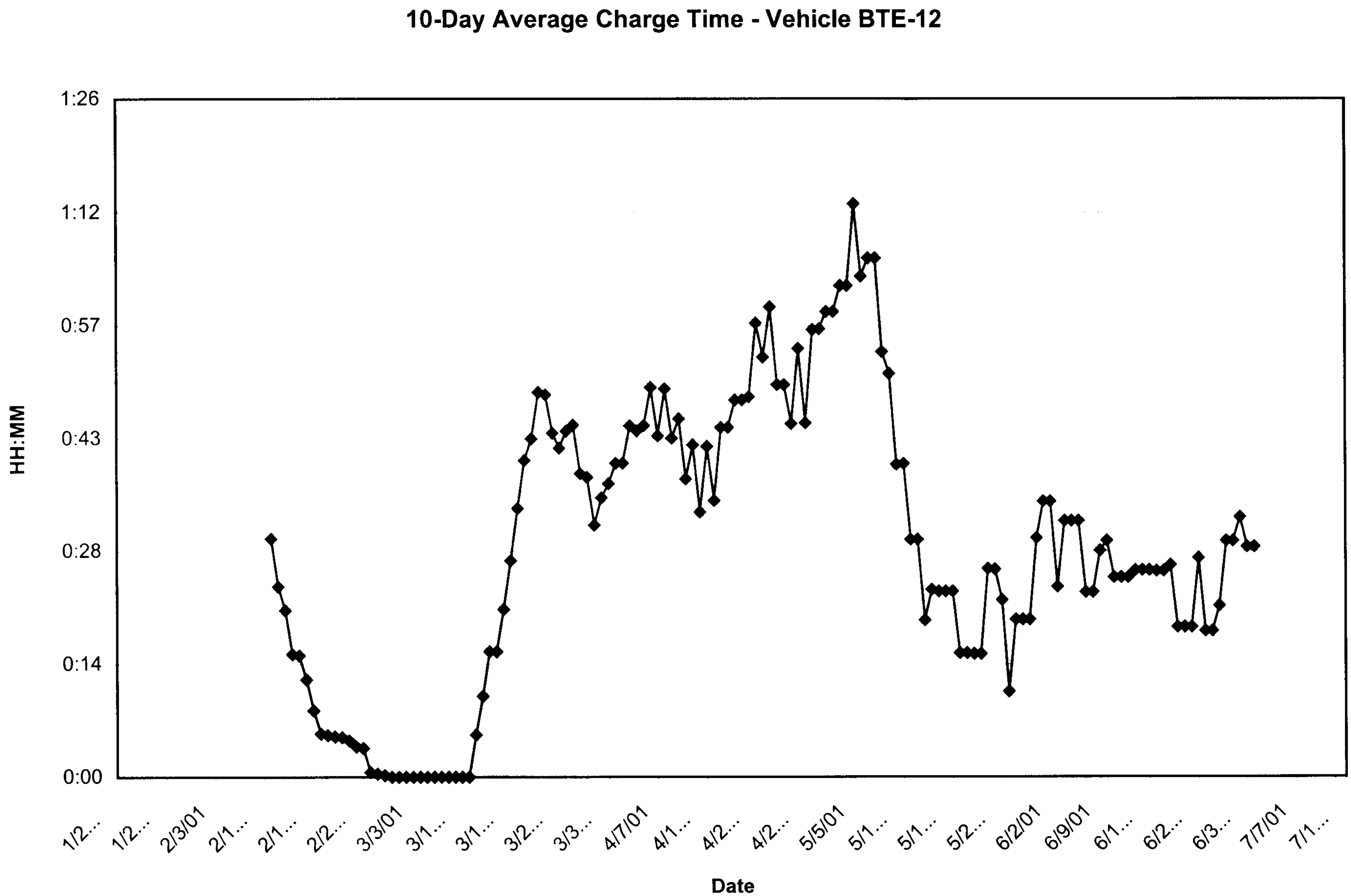


Average Charge Time - Vehicle BTE-12



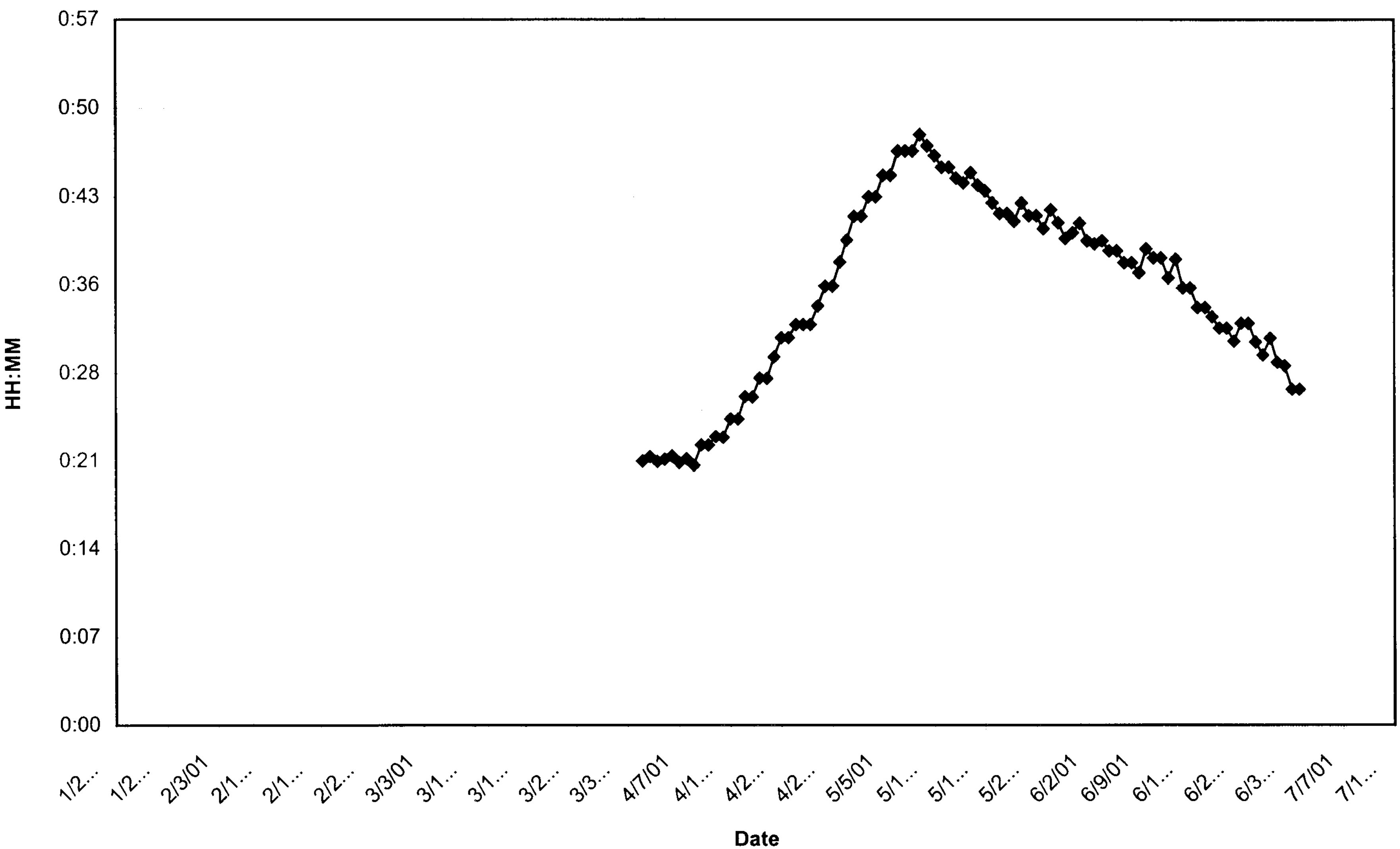
Time on Equalize Charge - Vehicle BTE-12



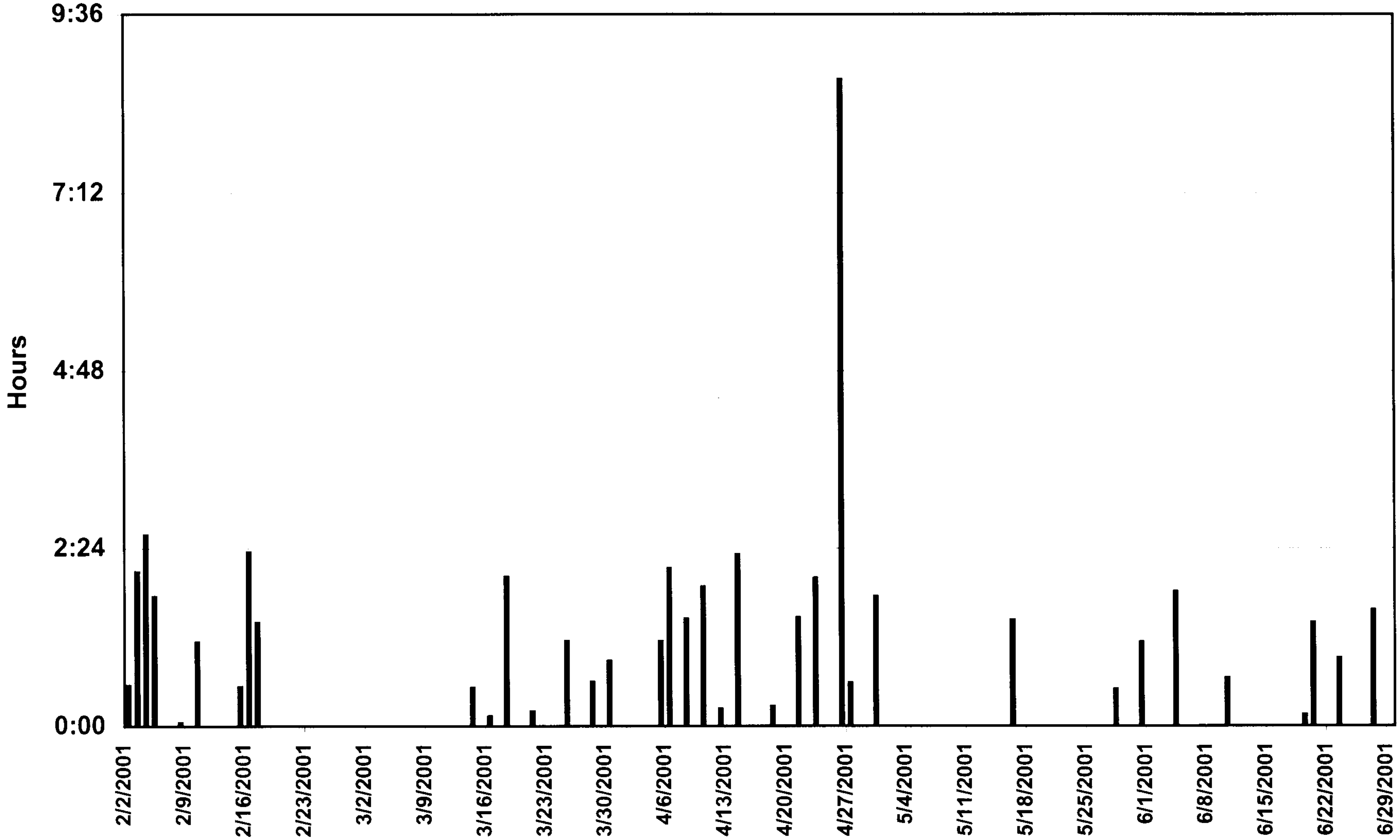


10-Day Average Charge Time - Vehicle BTE-12
HH:MM
1:26
1:12
0:57
0:43
0:28
0:14
0:00
1/2...
1/2...
2/3/01
2/1...
2/1...
2/2...
3/3/01
3/1...
3/1...
3/2...
3/3...
4/7/01
4/1...
4/2...
4/2...
5/5/01
5/1...
5/1...
5/2...
6/2/01
6/9/01
6/1...
6/2...
6/3...
7/7/01
7/1...
Date

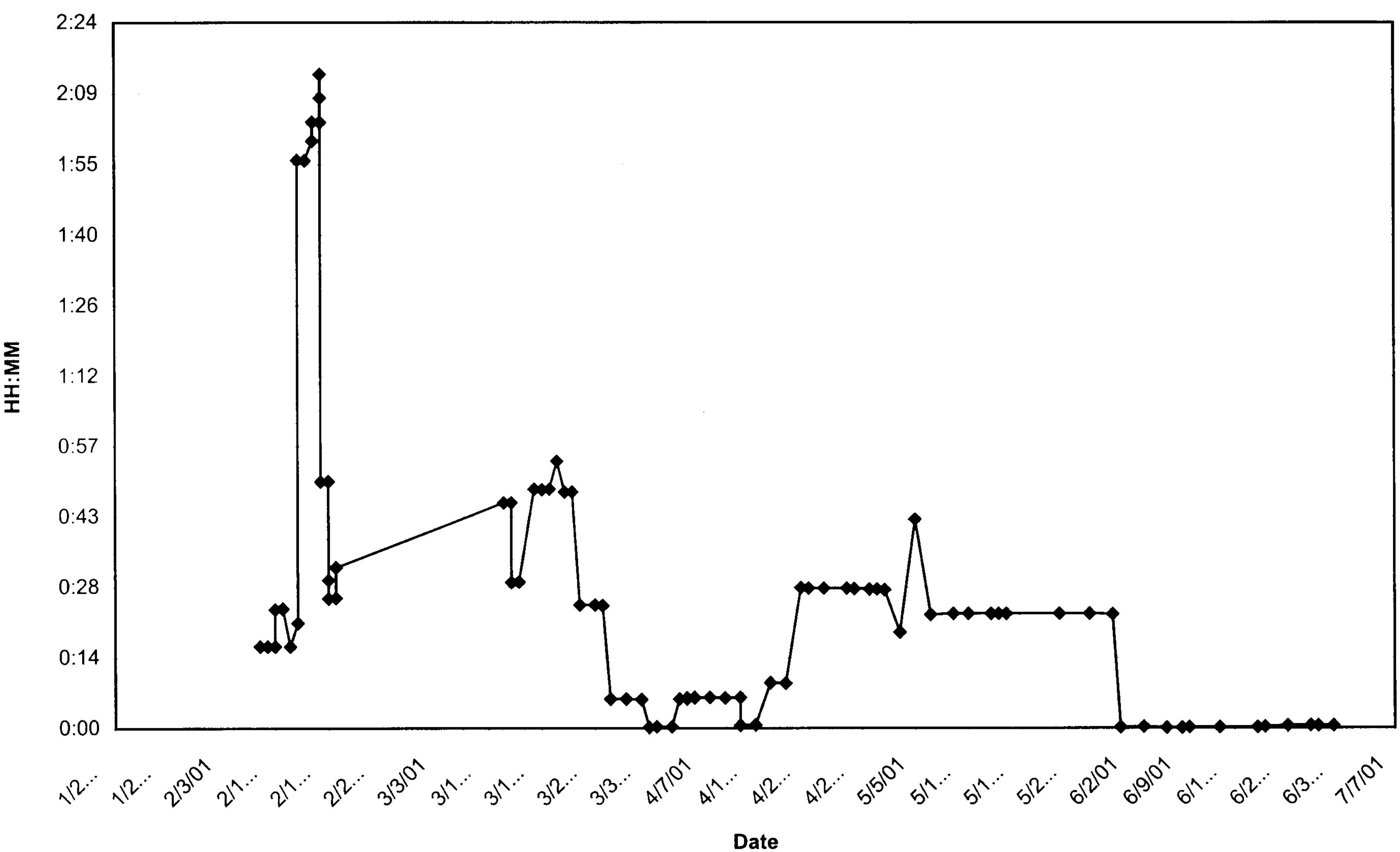
60-Day Average Charge Time - Vehicle BTE-12

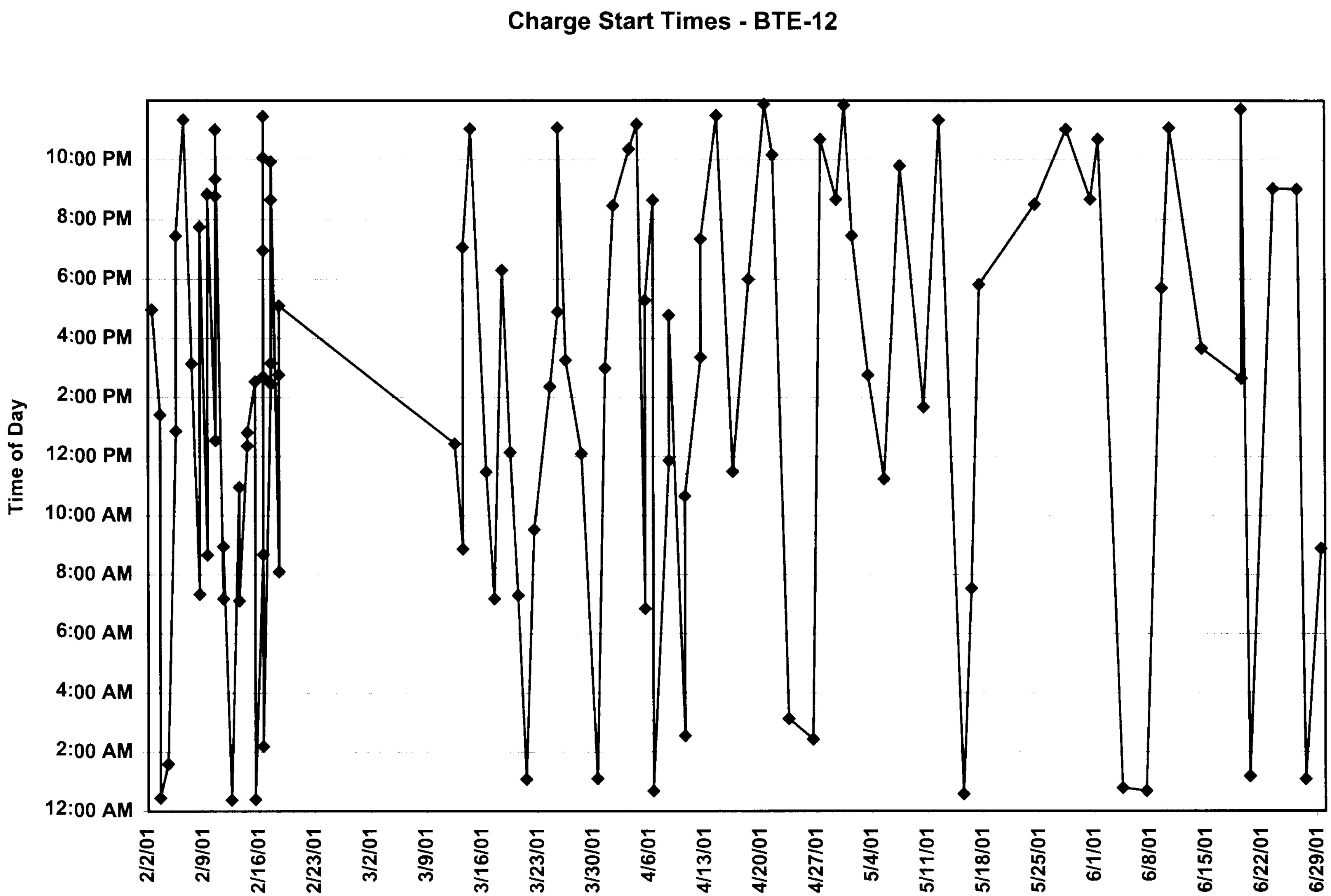


Individual Charge Cycle Pre-Charge Stand By Time - Vehicle BTE-12

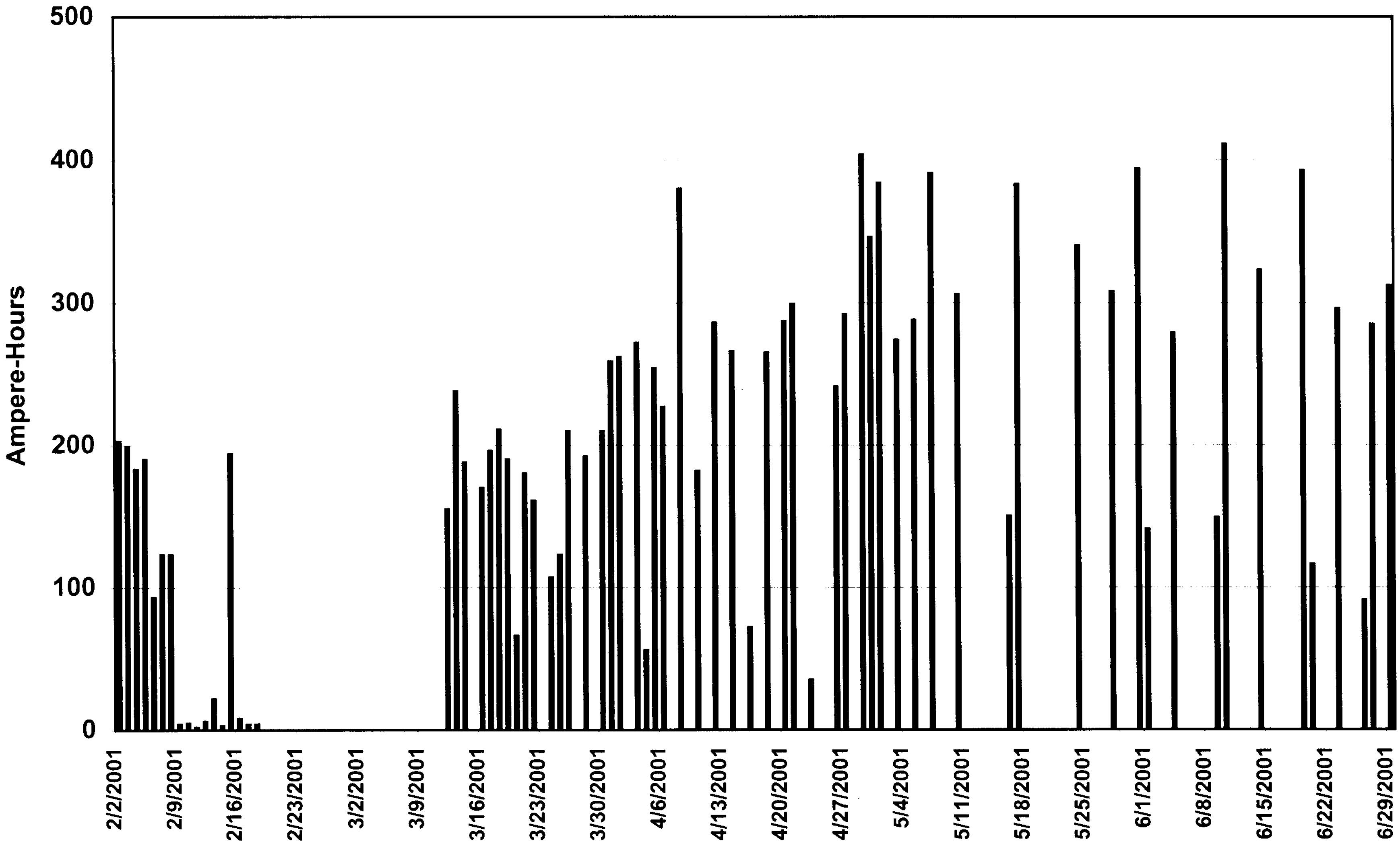


10-Cycle Average Standby Connect Time - Vehicle BTE-12



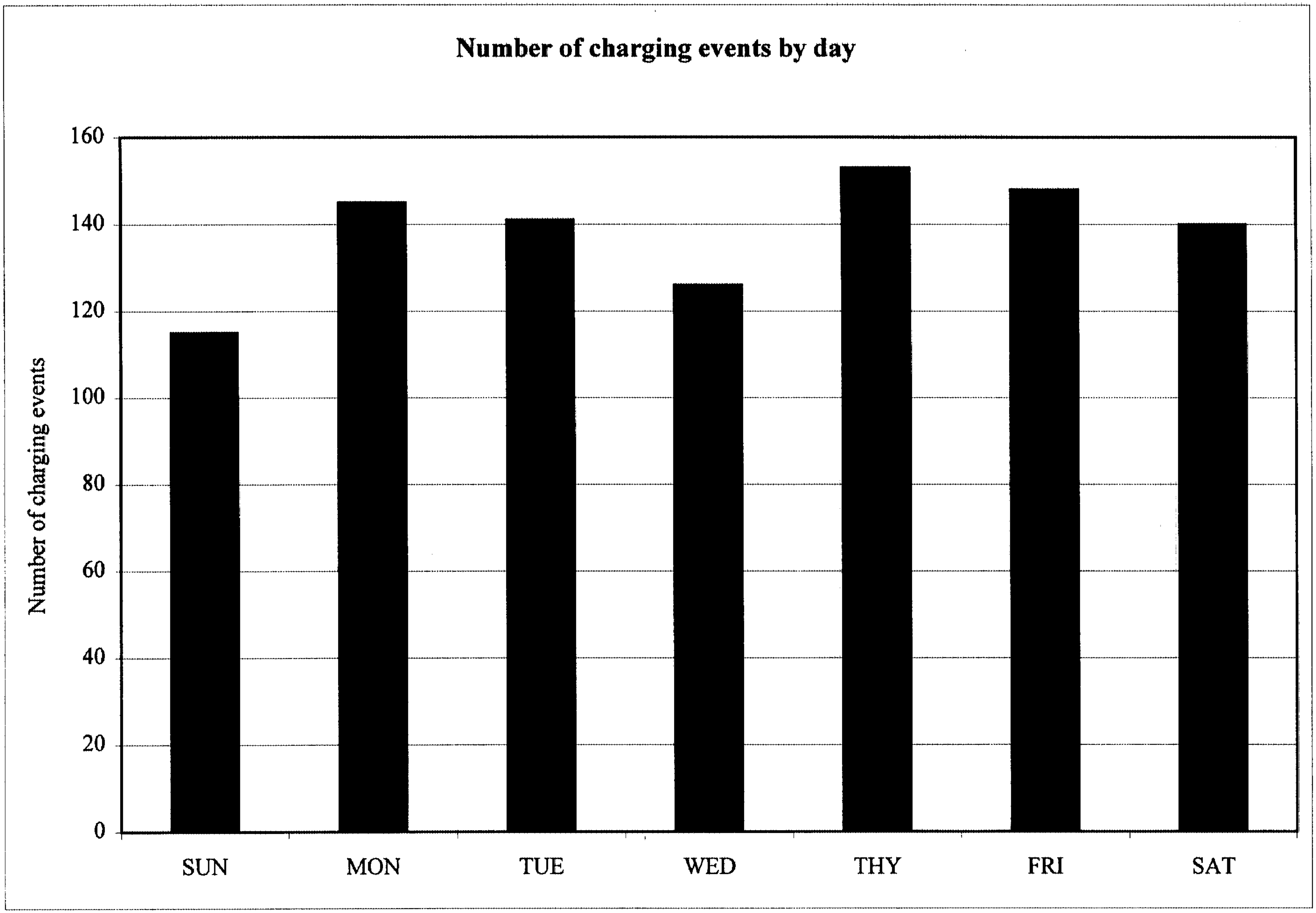

Charge Start Times - BTE-12
Time of Day
10:00 PM
8:00 PM
6:00 PM
4:00 PM
2:00 PM
12:00 PM
10:00 AM
8:00 AM
6:00 AM
4:00 AM
2:00 AM
12:00 AM
2/2/01
2/9/01
2/16/01
2/23/01
3/2/01
3/9/01
3/16/01
3/23/01
3/30/01
4/6/01
4/13/01
4/20/01
4/27/01
5/4/01
5/11/01
5/18/01
5/25/01
6/1/01
6/8/01
6/15/01
6/22/01
6/29/01

Ampere-Hours Returned per Charge - Vehicle BTE-12

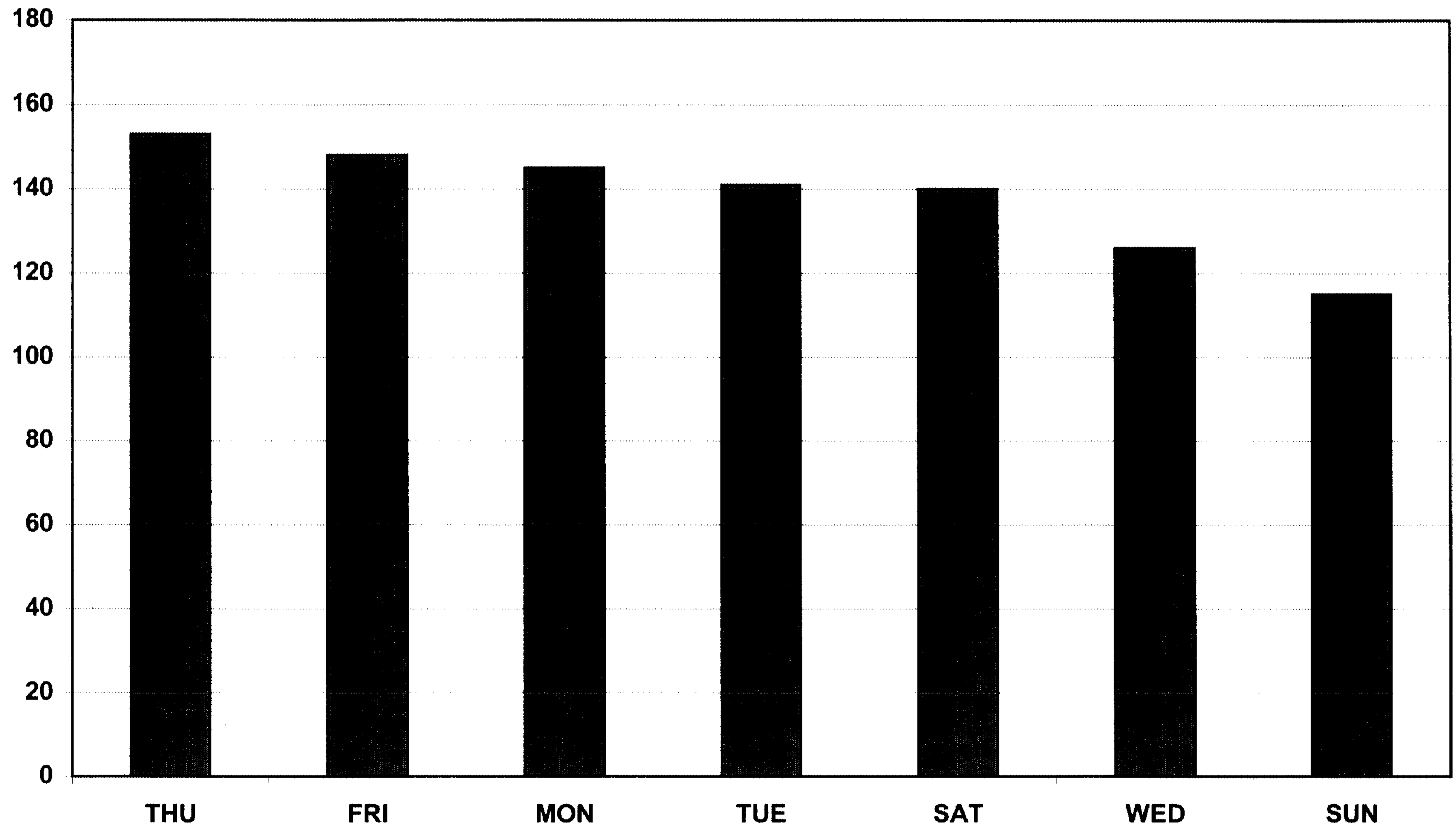


APPENDIX B

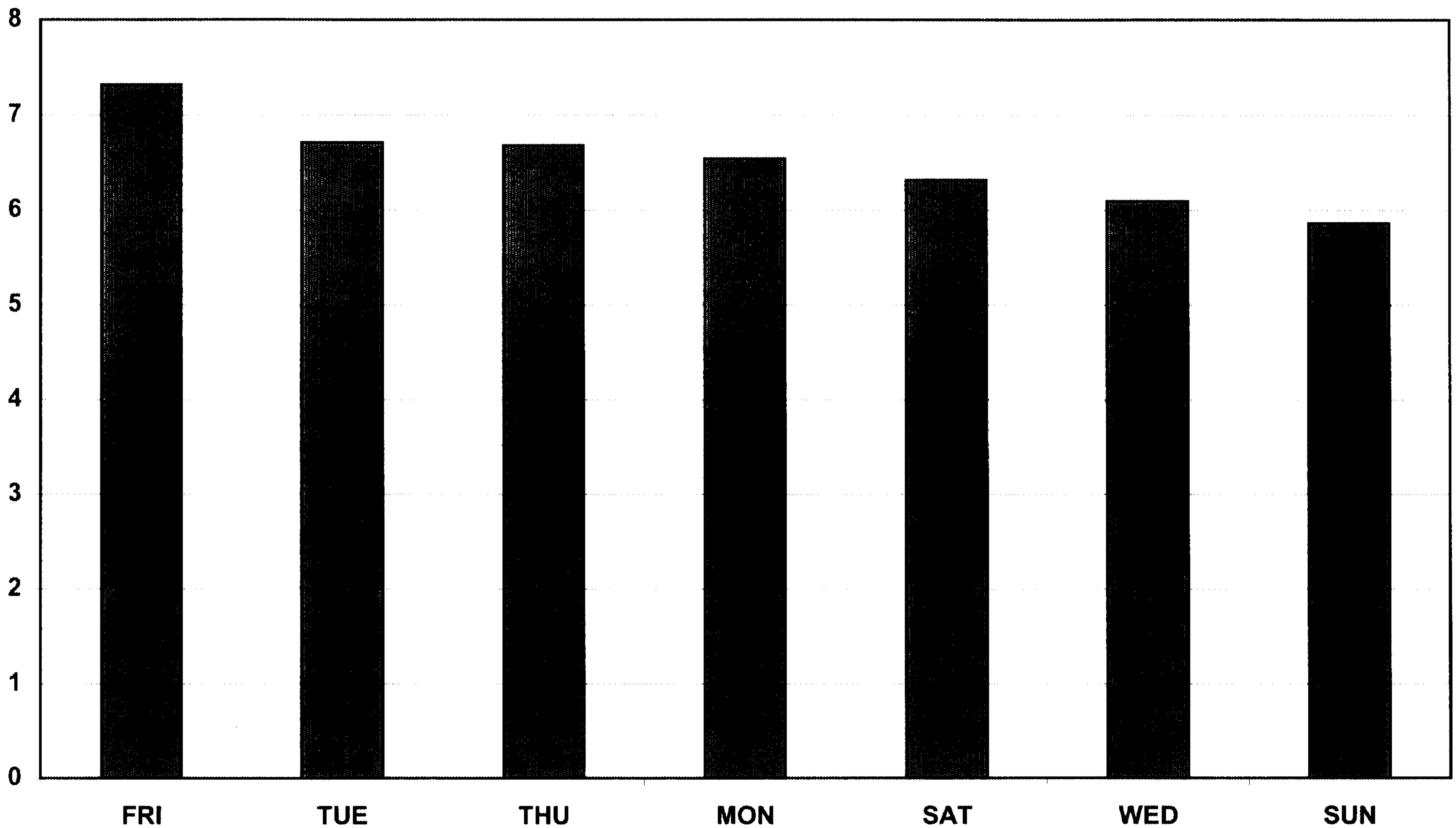
CHARGE DATA: SUPERCHARGE™


Number of charging events by day
Number of charging events
160
140
120
100
80
60
40
20
0
SUN
MON
TUE
WED
THY
FRI
SAT

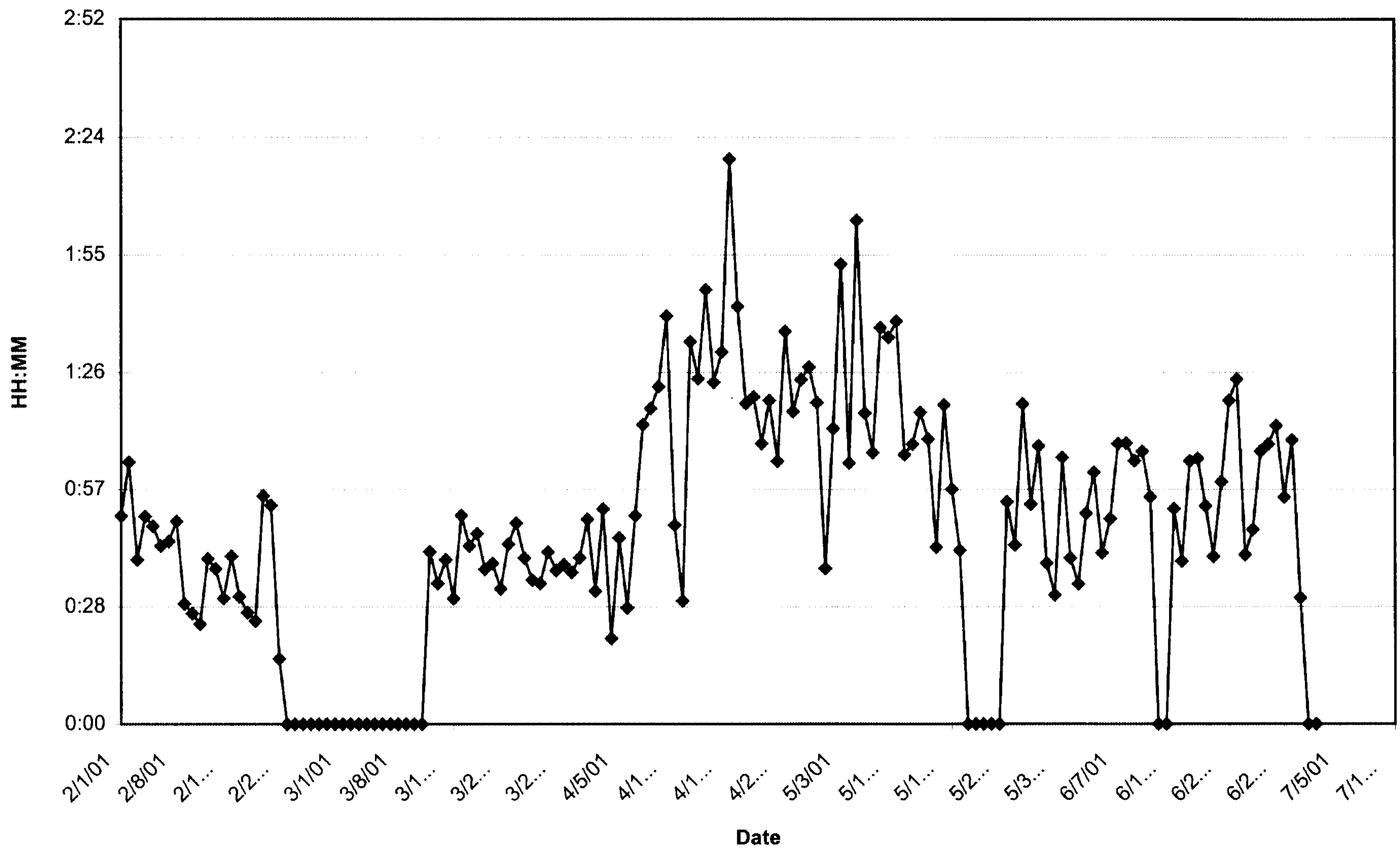
Charges per Day Total (All Events)
1 Feb 2001 through 30 Jun 2001



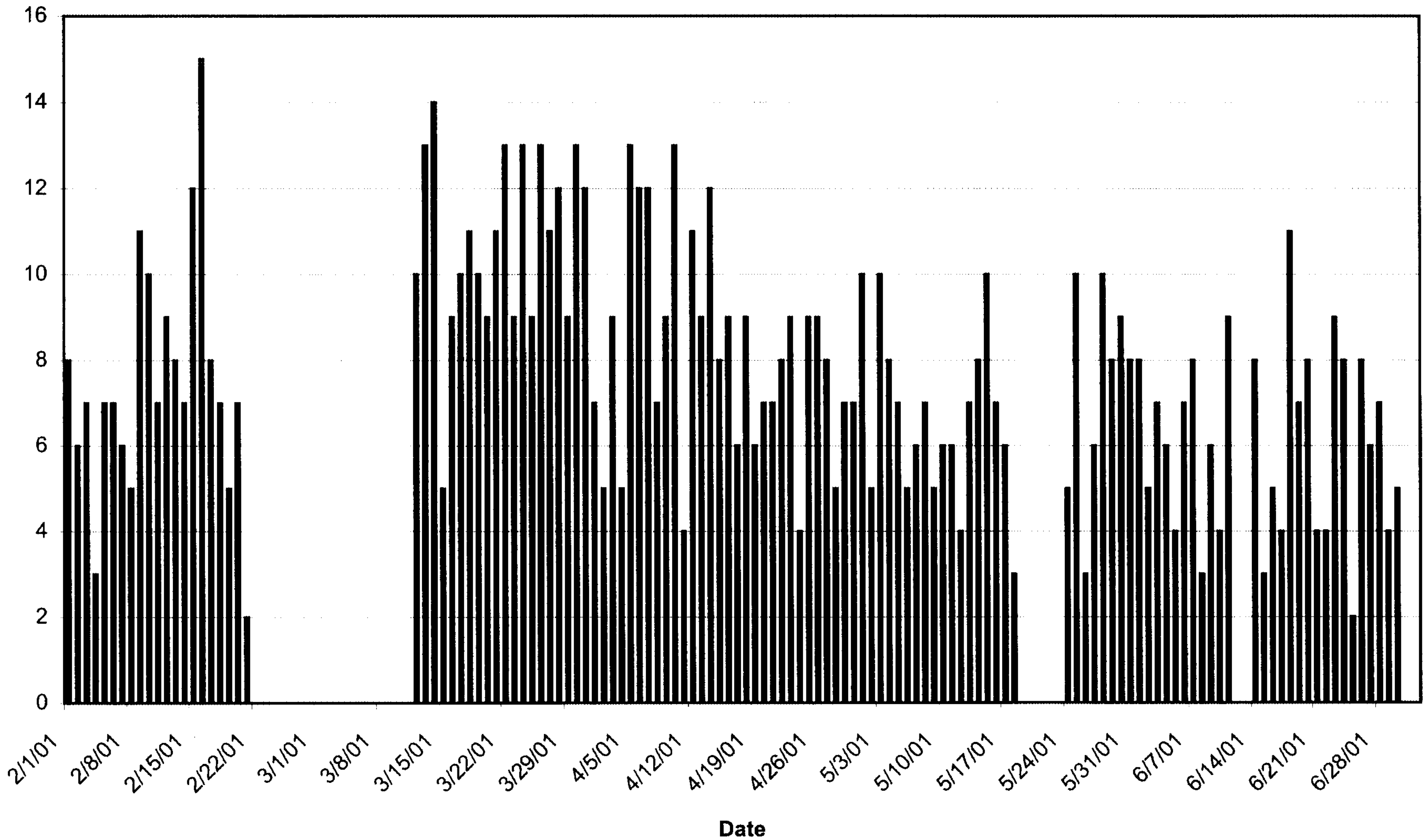
Average Charges Per Day - Charger
1 Feb 2001 through 30 Jun 2001



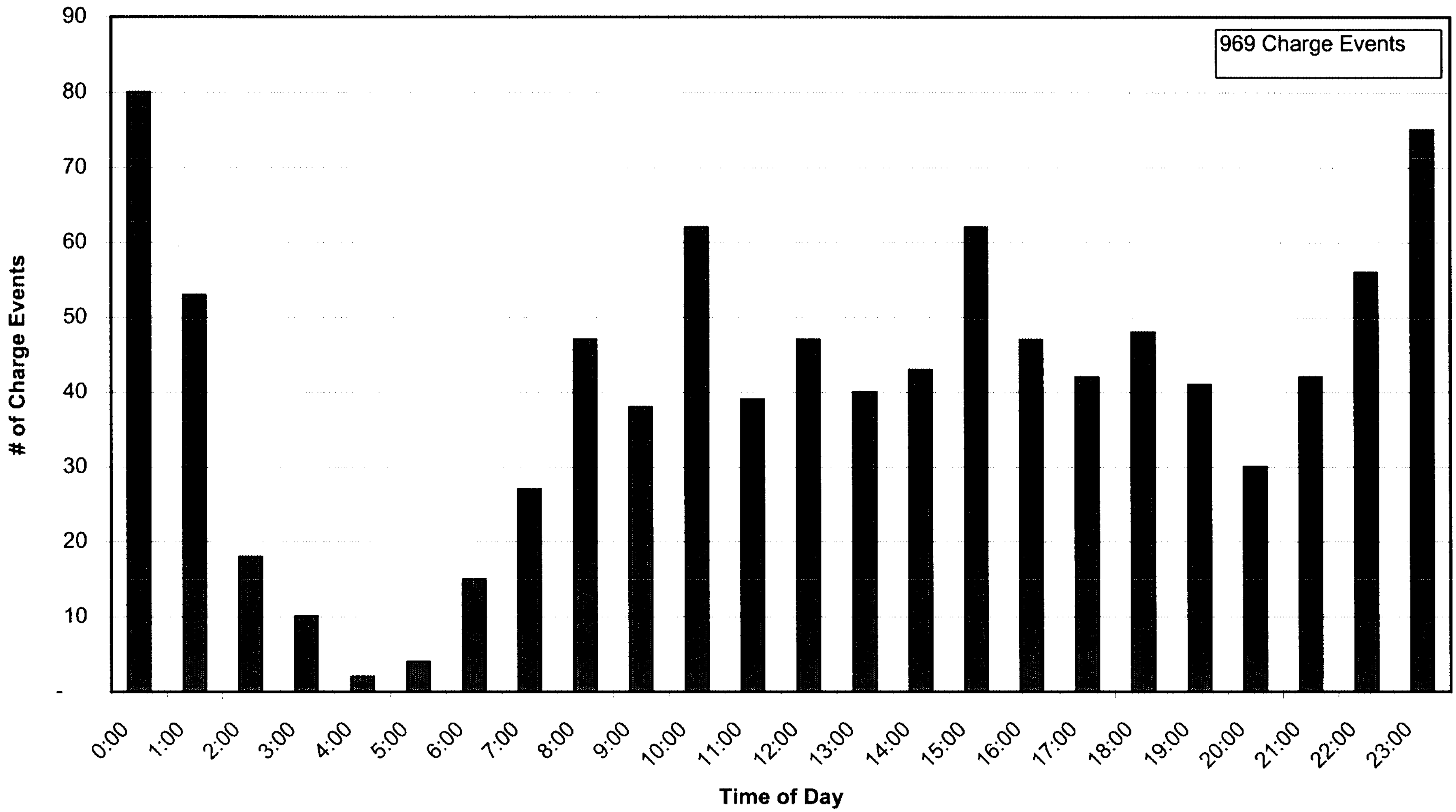
SuperCharge StationAverage Charge Time



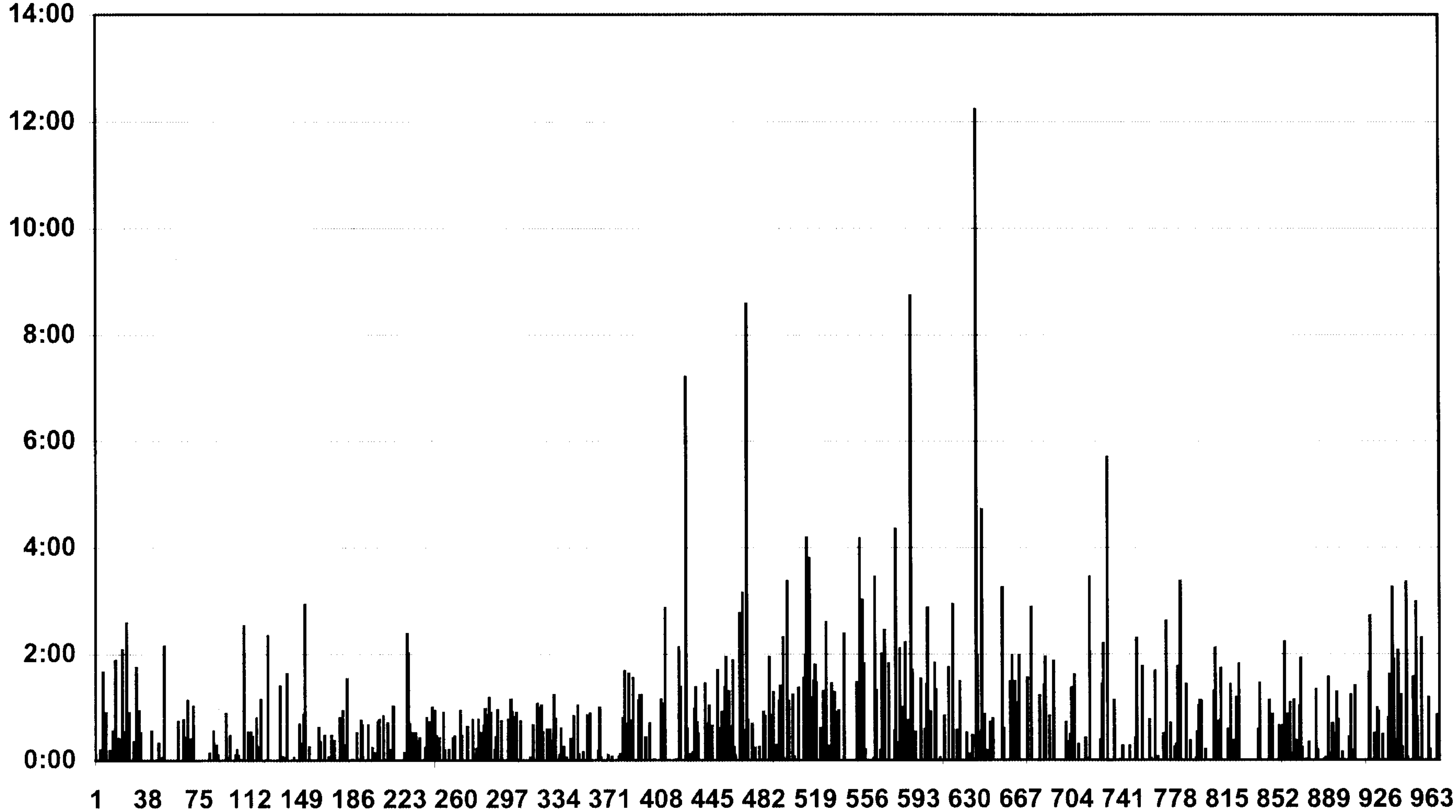
SuperCharge Station
Charges Per Day - Chronological Order



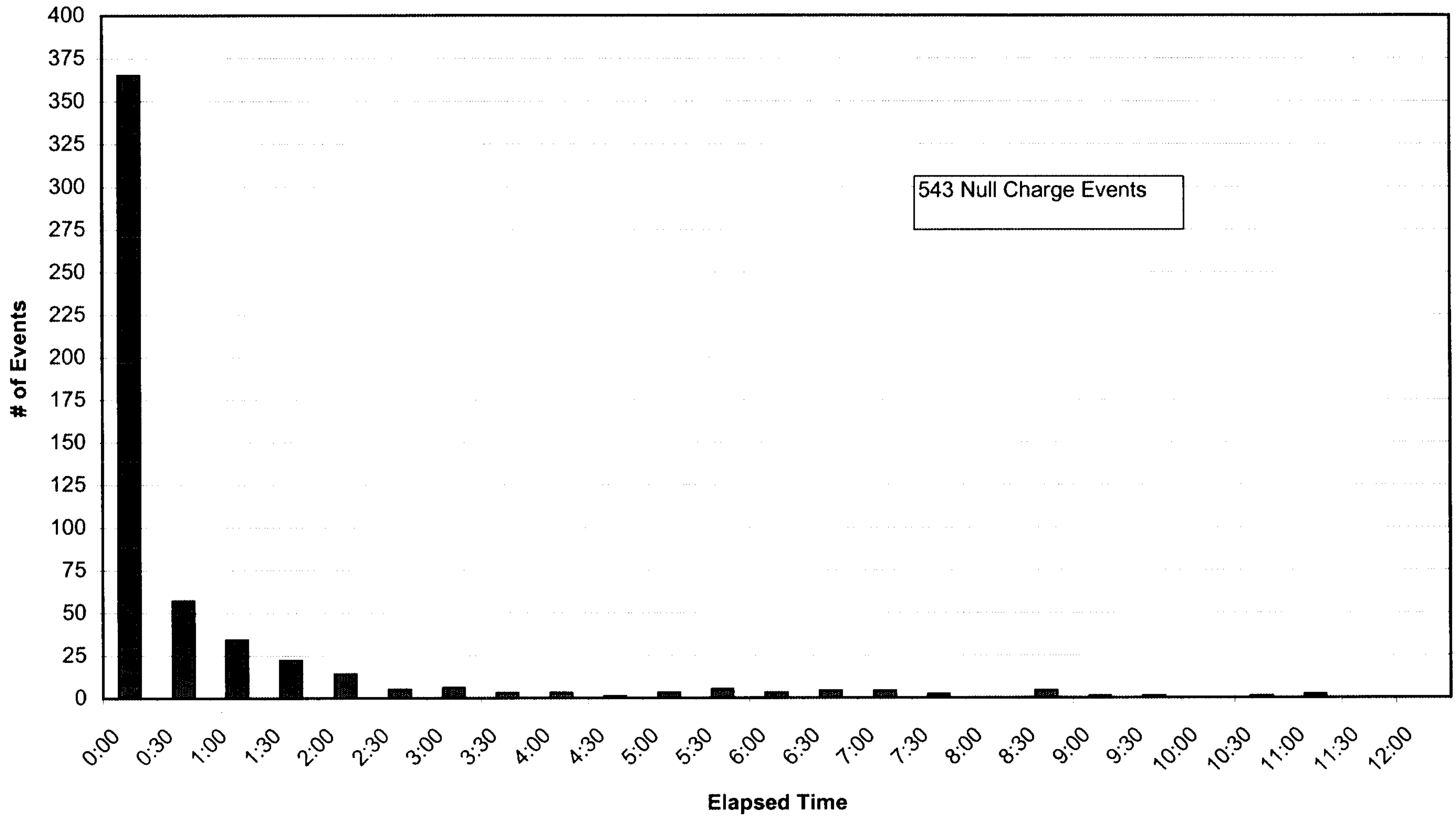
SuperCharge Station Time Of Day Analysis
Frequency of Charge Events for 1 Hour Increments
Complete Data Set for 2/1/01-6/30/01



StandBy Time per Charge Event - All Charges All Tractors
(Feb 2 through June 30)



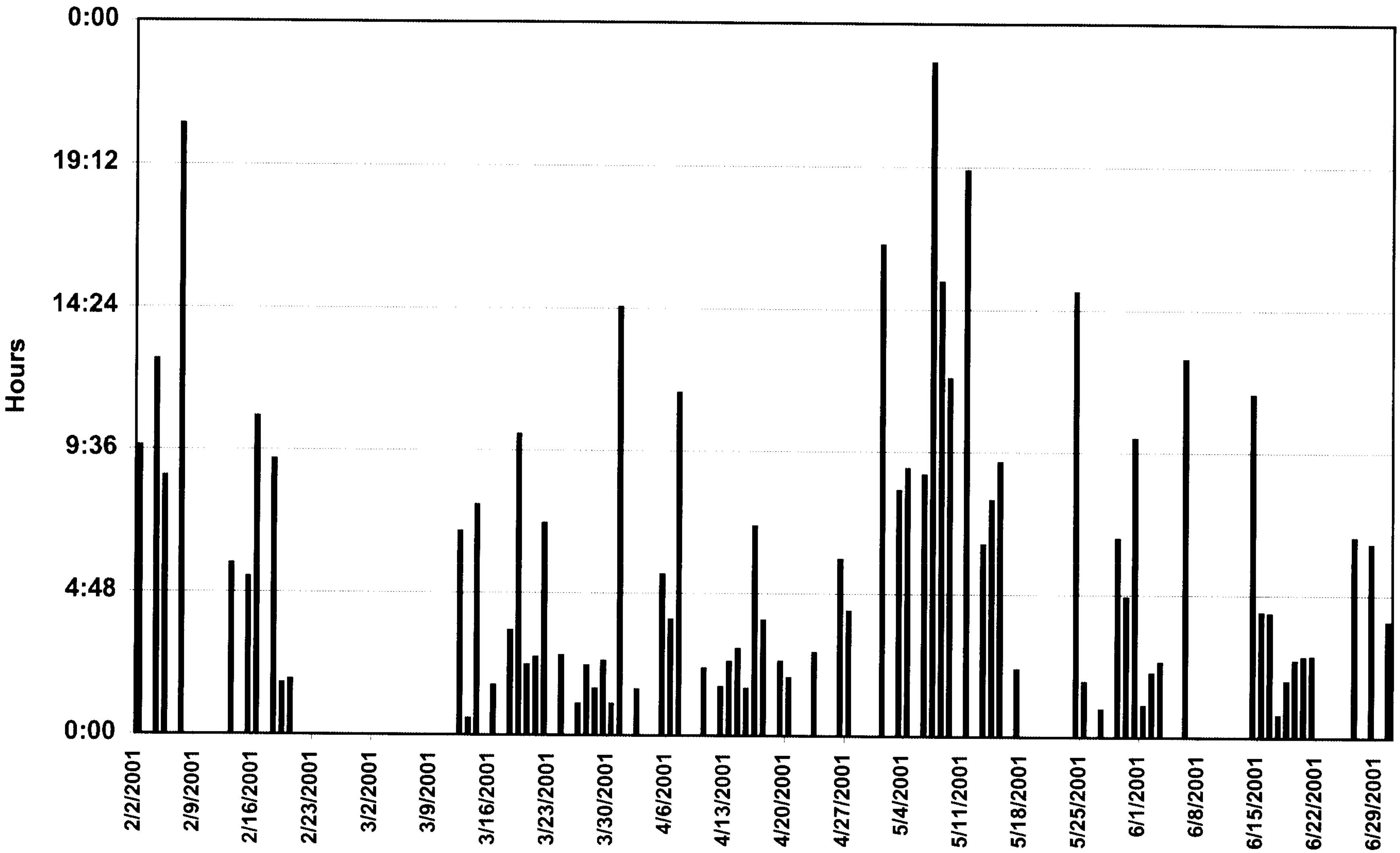
SuperCharge Station
Null Charge Standby Analysis
Time Spent on Standby for Events in Which No Charge Occurred



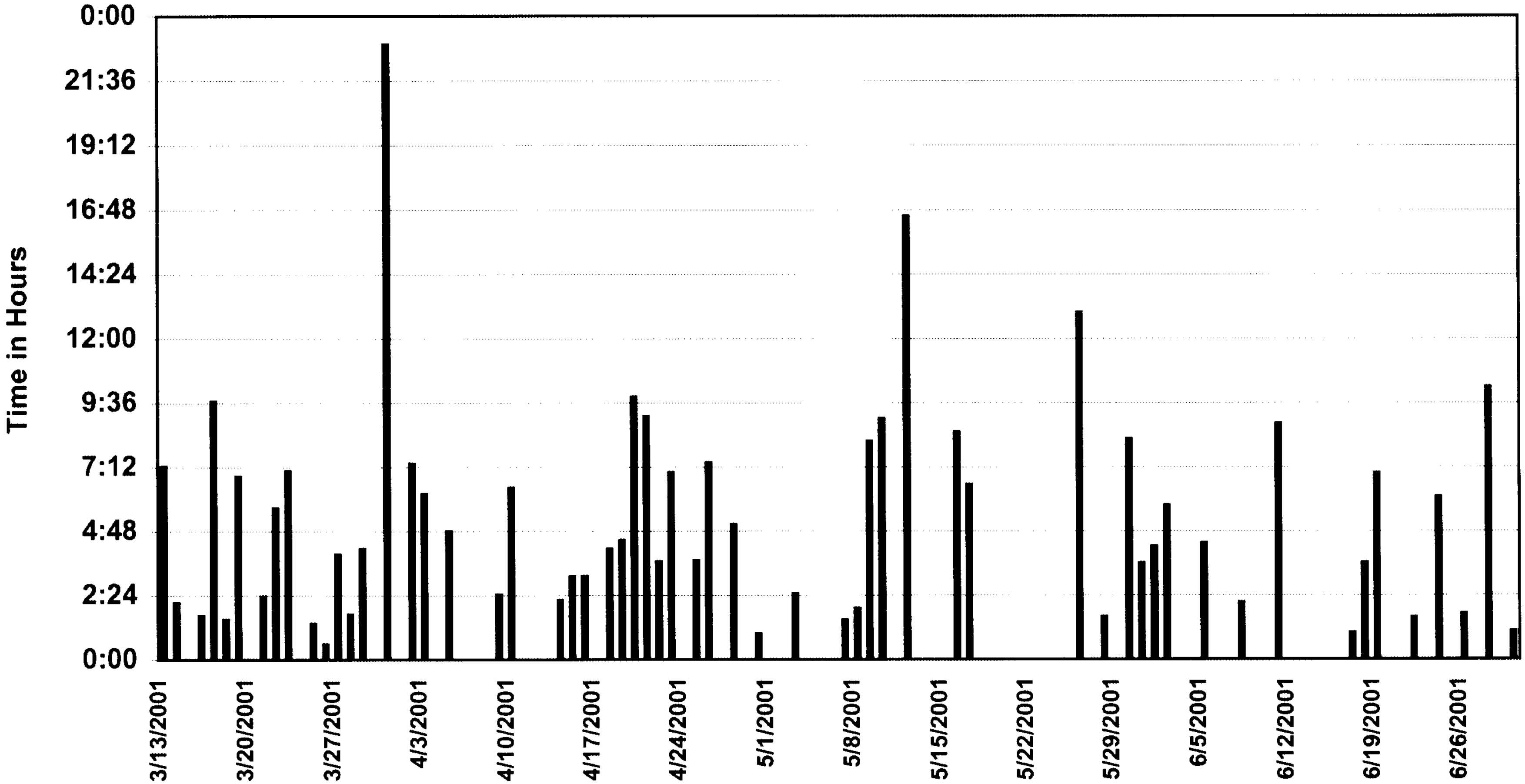
APPENDIX C

CHARGE DATA: NON-CHARGING TIME OF VEHICLES AT THE CHARGE STATION

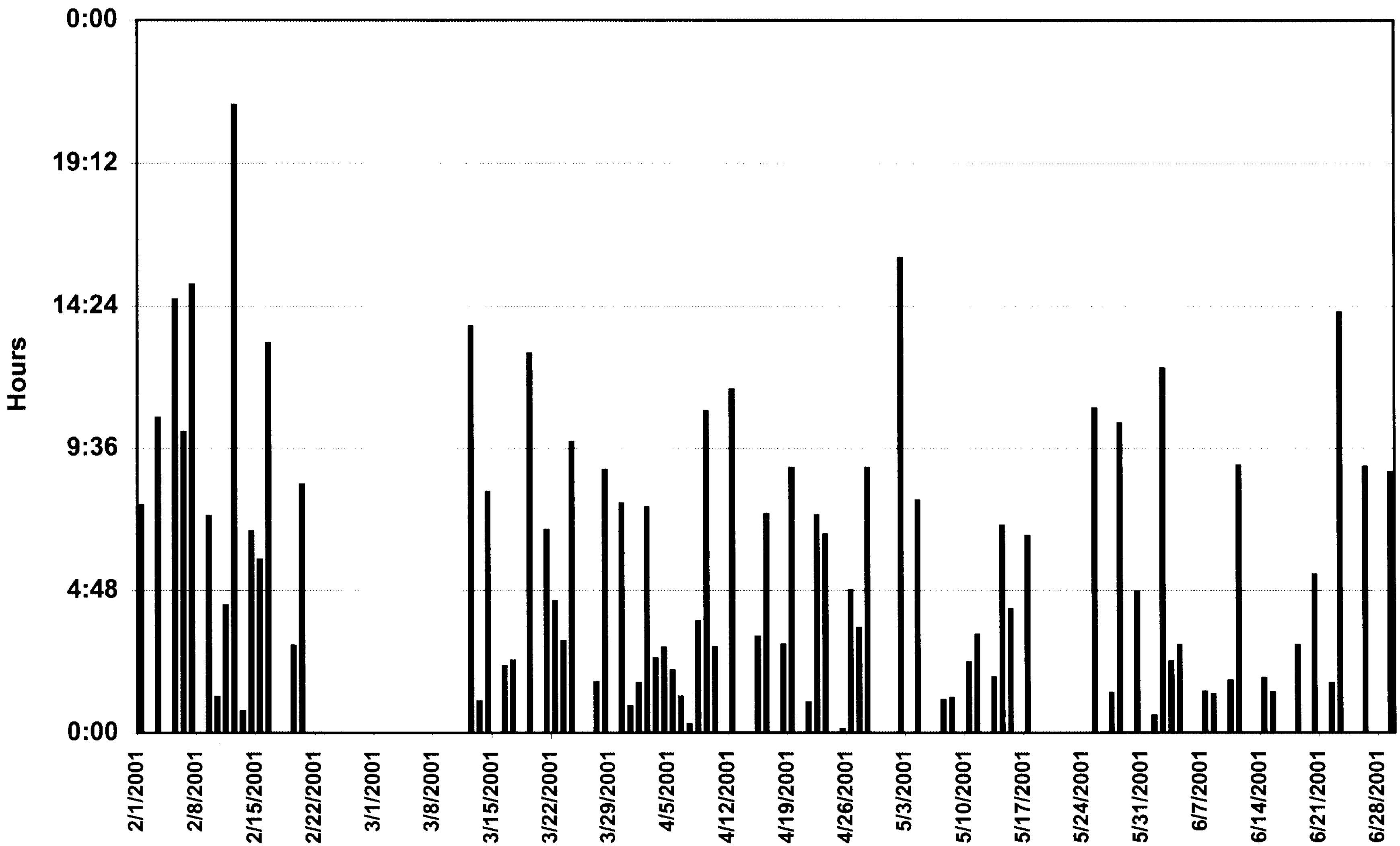
Elapsed Time - Vehicle BTE-01



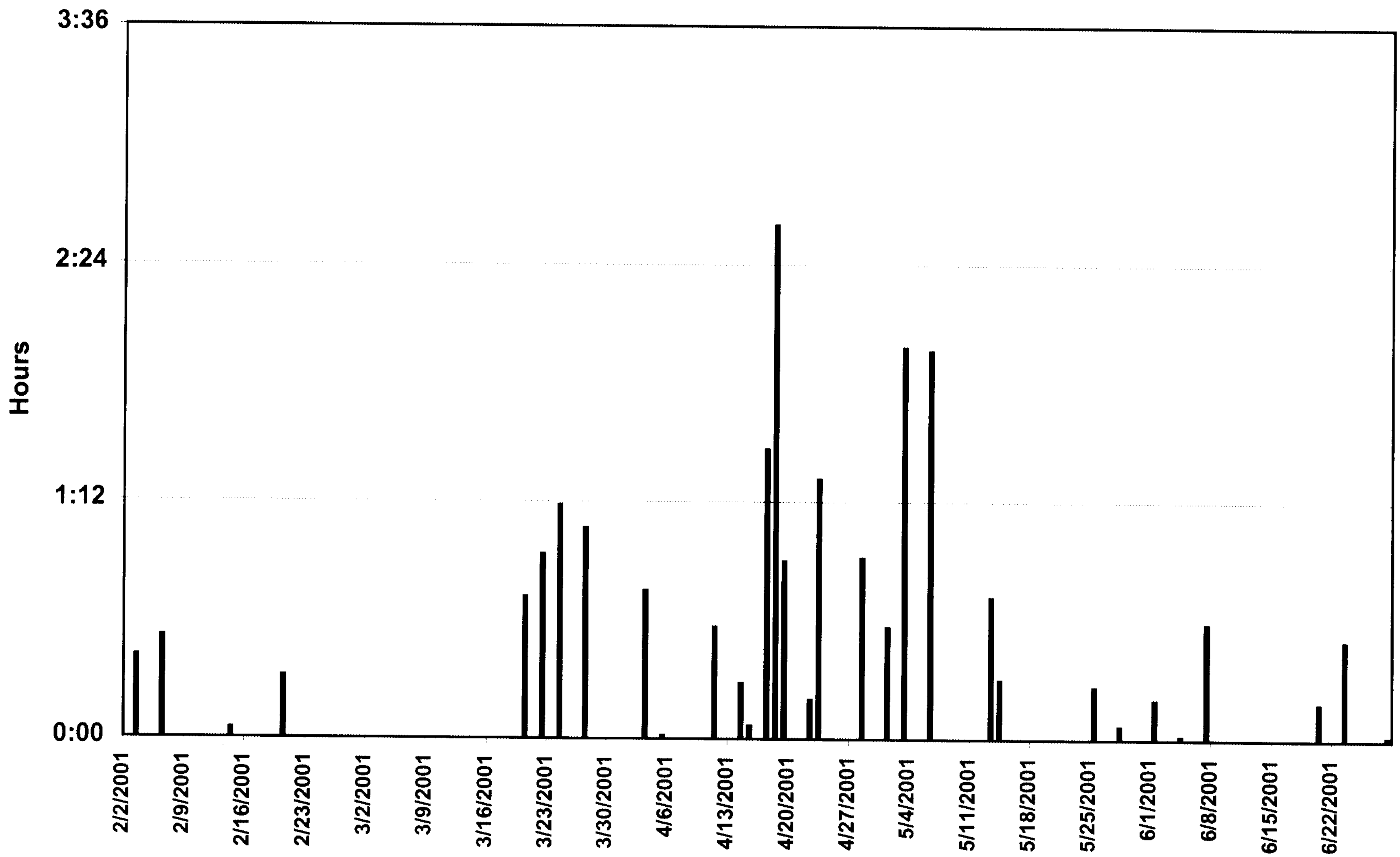
Elapsed Time - Vehicle BTE-02



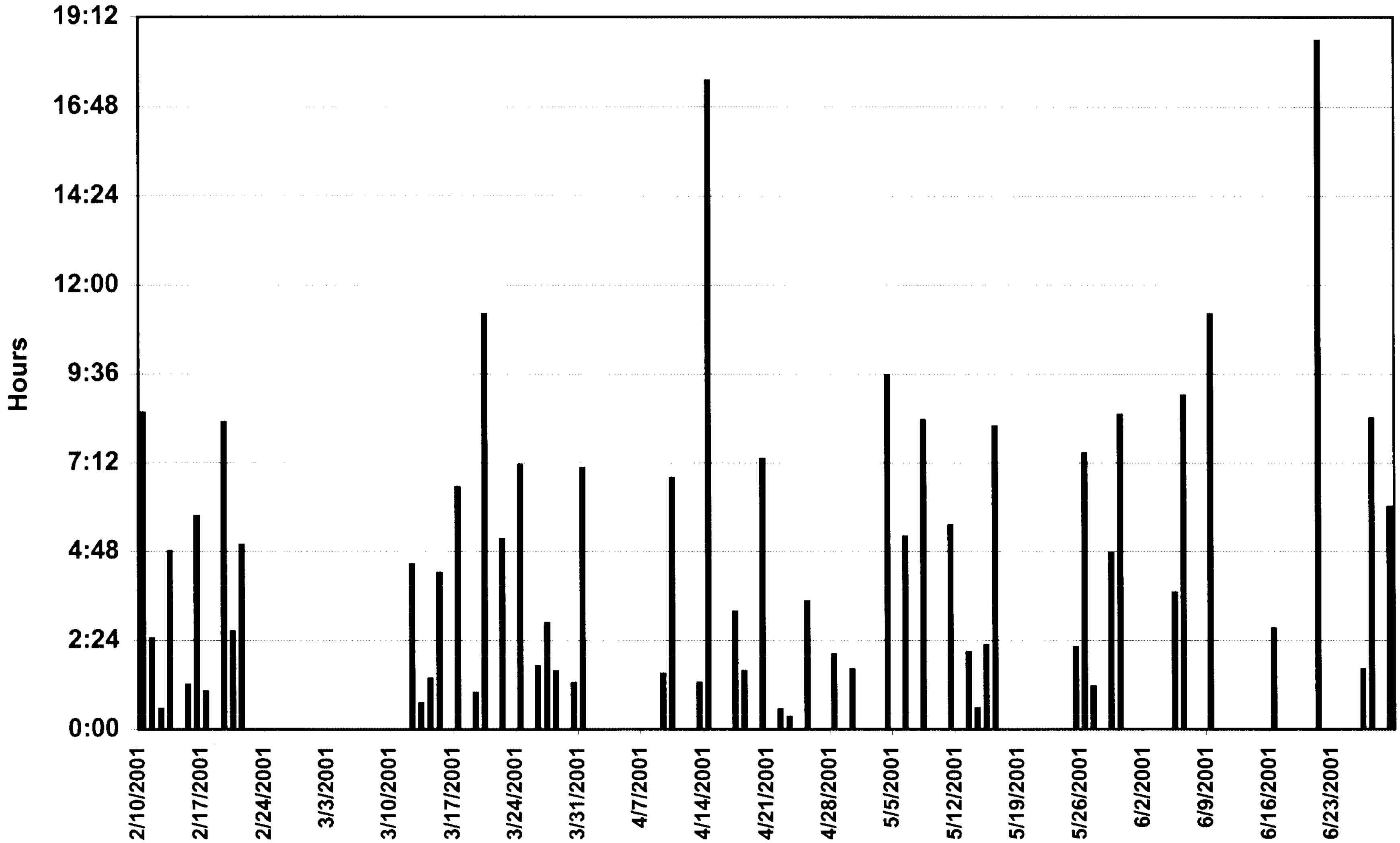
Elapsed Time - Vehicle BTE-03

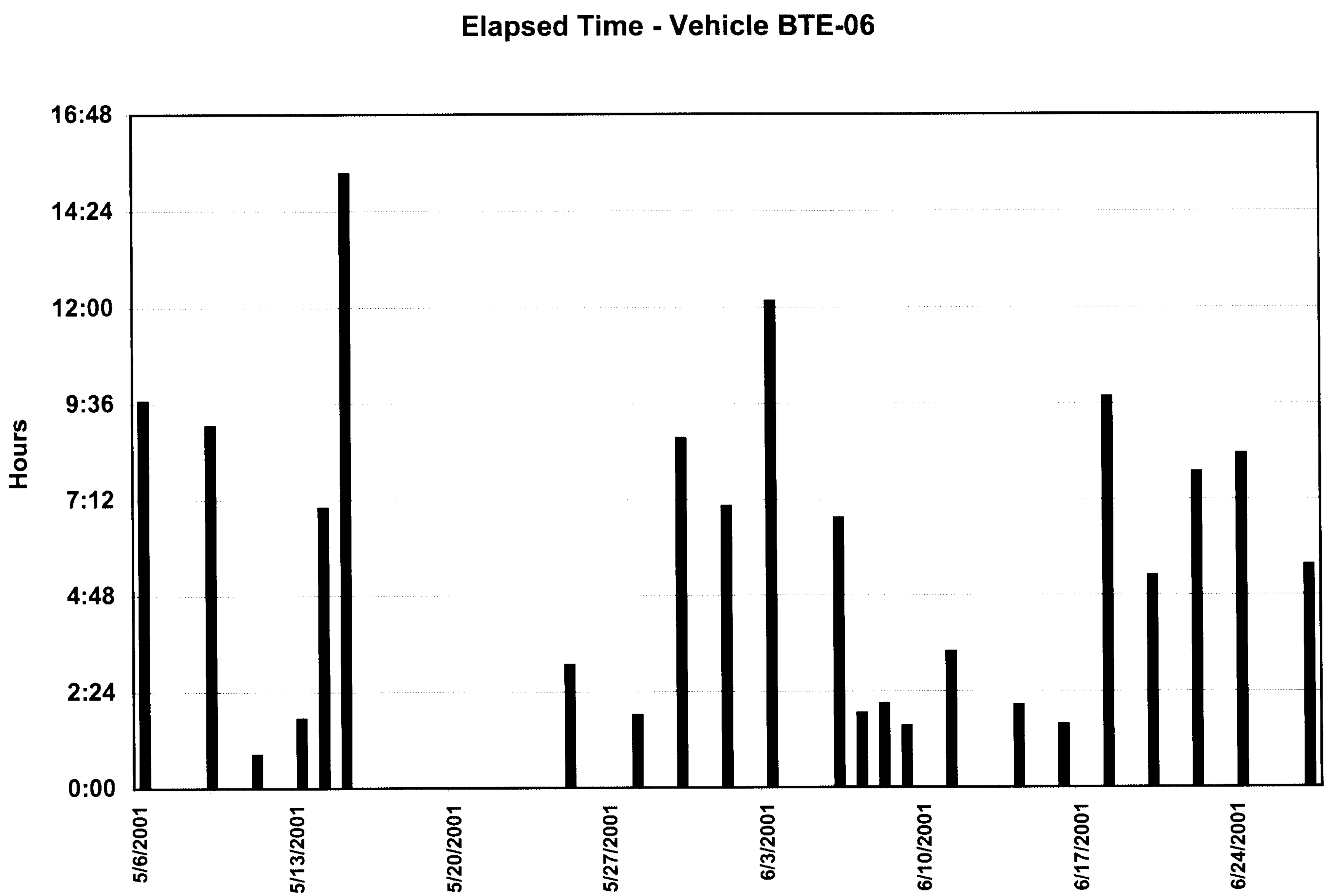


Elapsed Time - Vehicle BTE-04

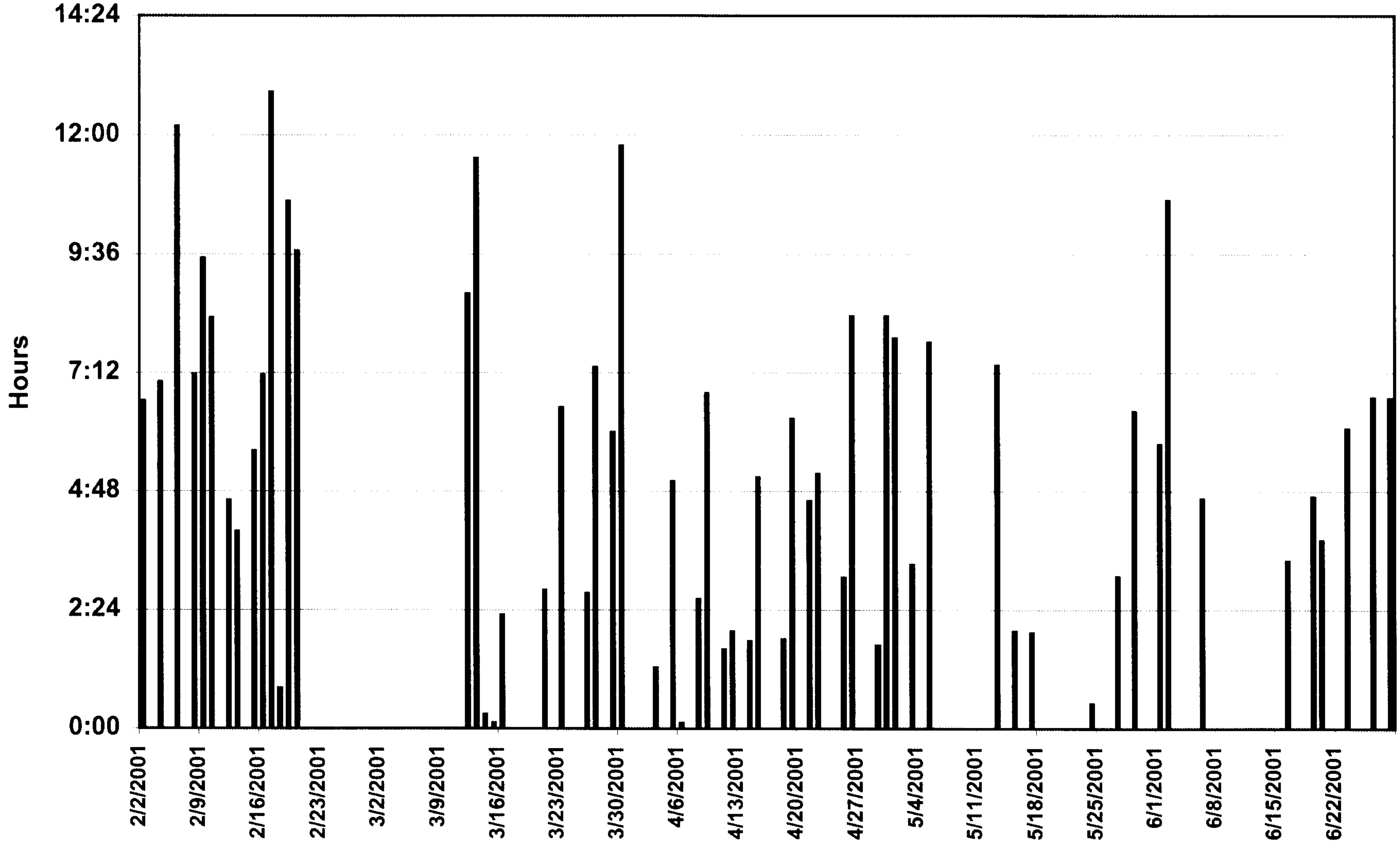


Elapsed Time - Vehicle BTE-05

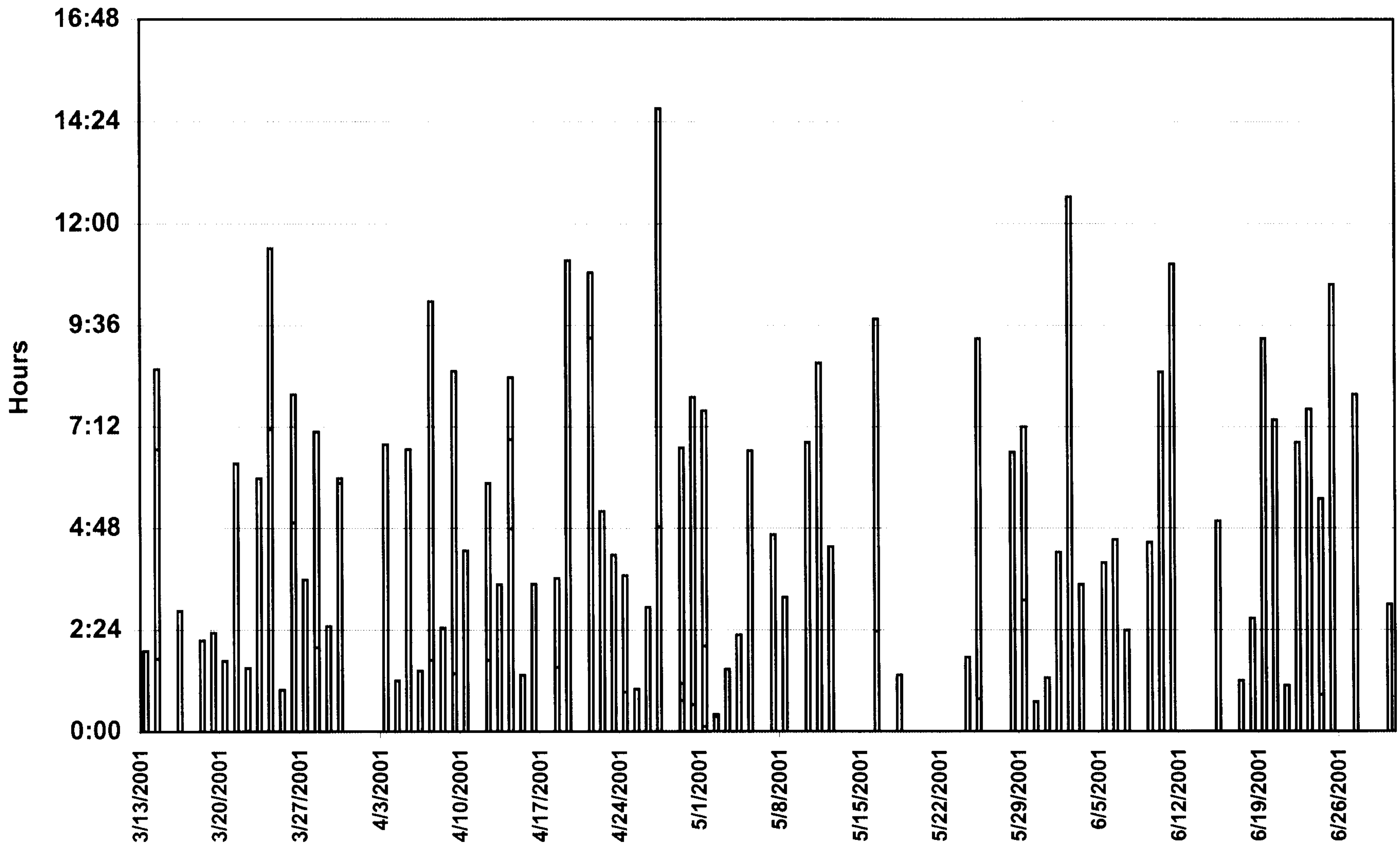


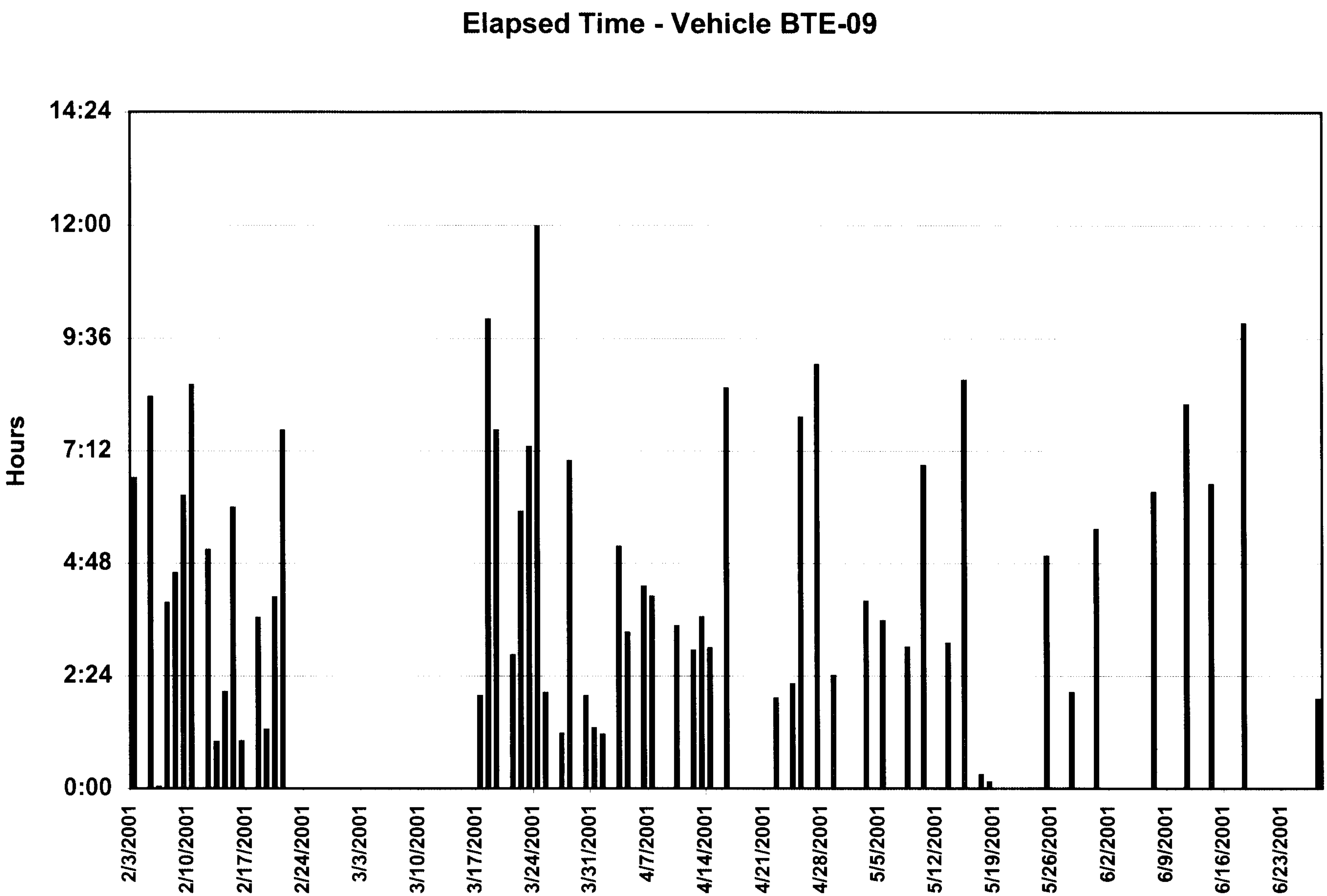

Elapsed Time - Vehicle BTE-06
Hours
16:48
14:24
12:00
9:36
7:12
4:48
2:24
0:00
5/6/2001
5/13/2001
5/20/2001
5/27/2001
6/3/2001
6/10/2001
6/17/2001
6/24/2001

Elapsed Time - Vehicle BTE-07



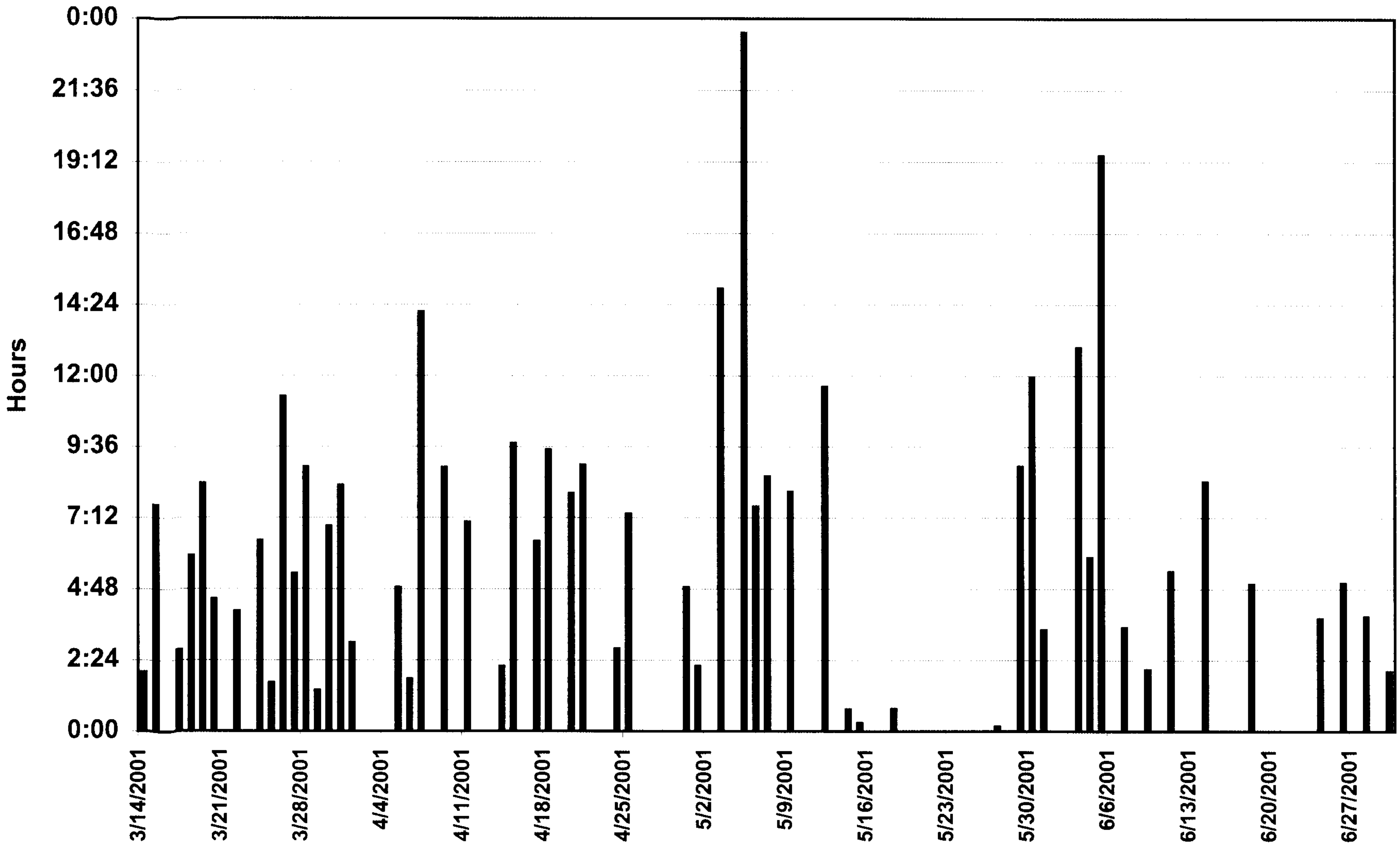
Elapsed Time - Vehicle BTE-08



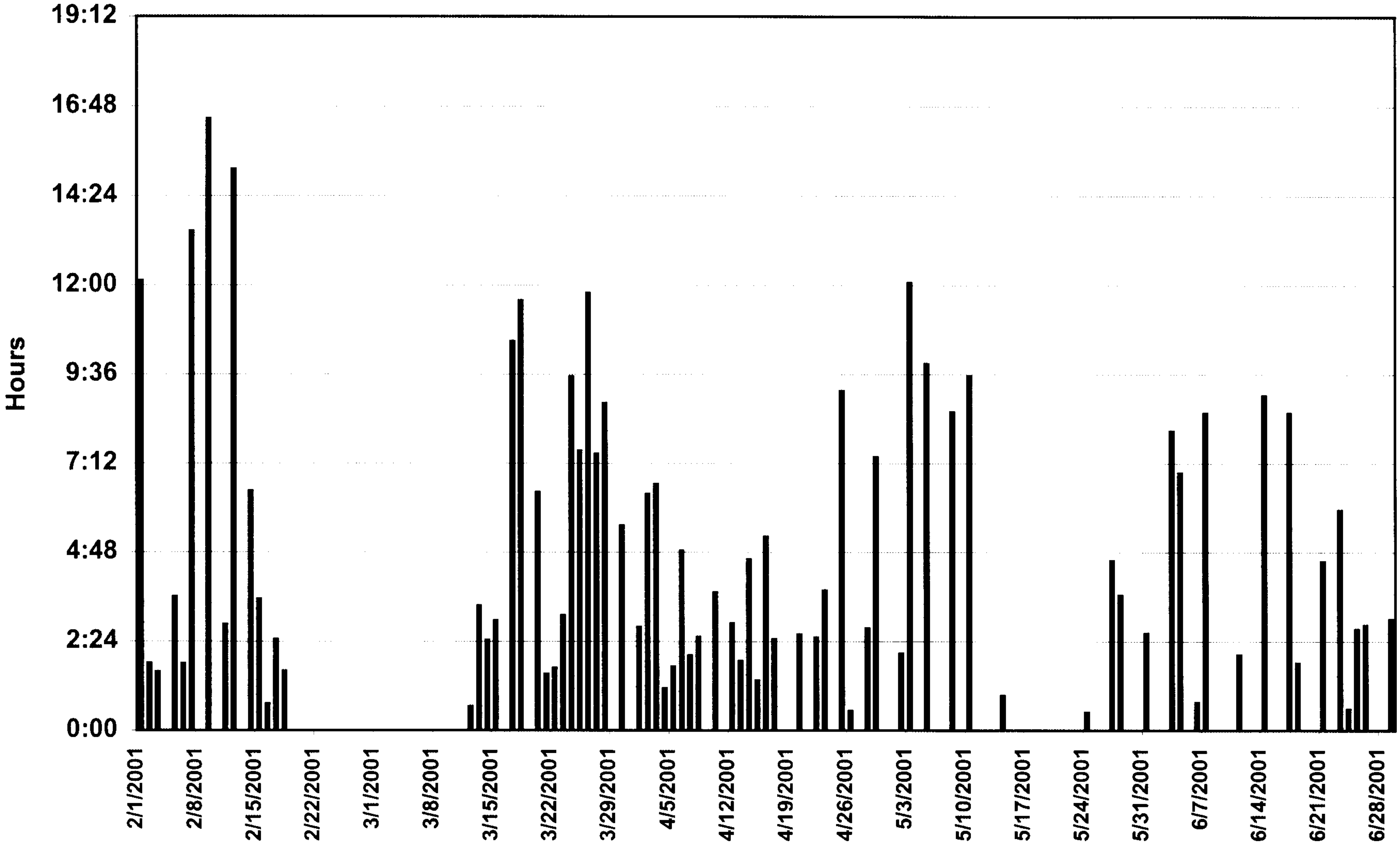


Elapsed Time - Vehicle BTE-09
Hours
14:24
12:00
9:36
7:12
4:48
2:24
0:00
2/3/2001
2/10/2001
2/17/2001
2/24/2001
3/3/2001
3/10/2001
3/17/2001
3/24/2001
3/31/2001
4/7/2001
4/14/2001
4/21/2001
4/28/2001
5/5/2001
5/12/2001
5/19/2001
5/26/2001
6/2/2001
6/9/2001
6/16/2001
6/23/2001

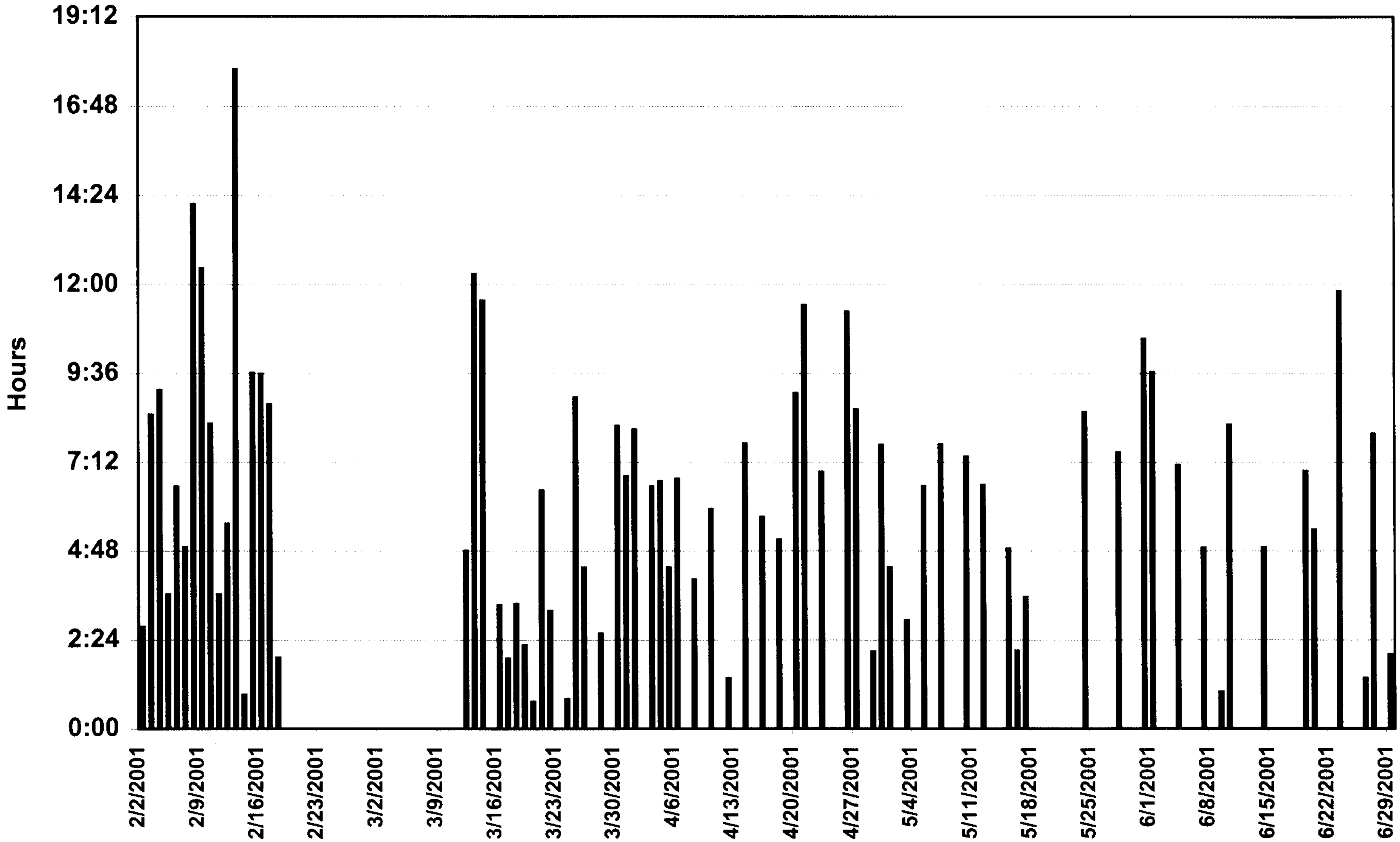
Elapsed Time - Vehicle BTE-10



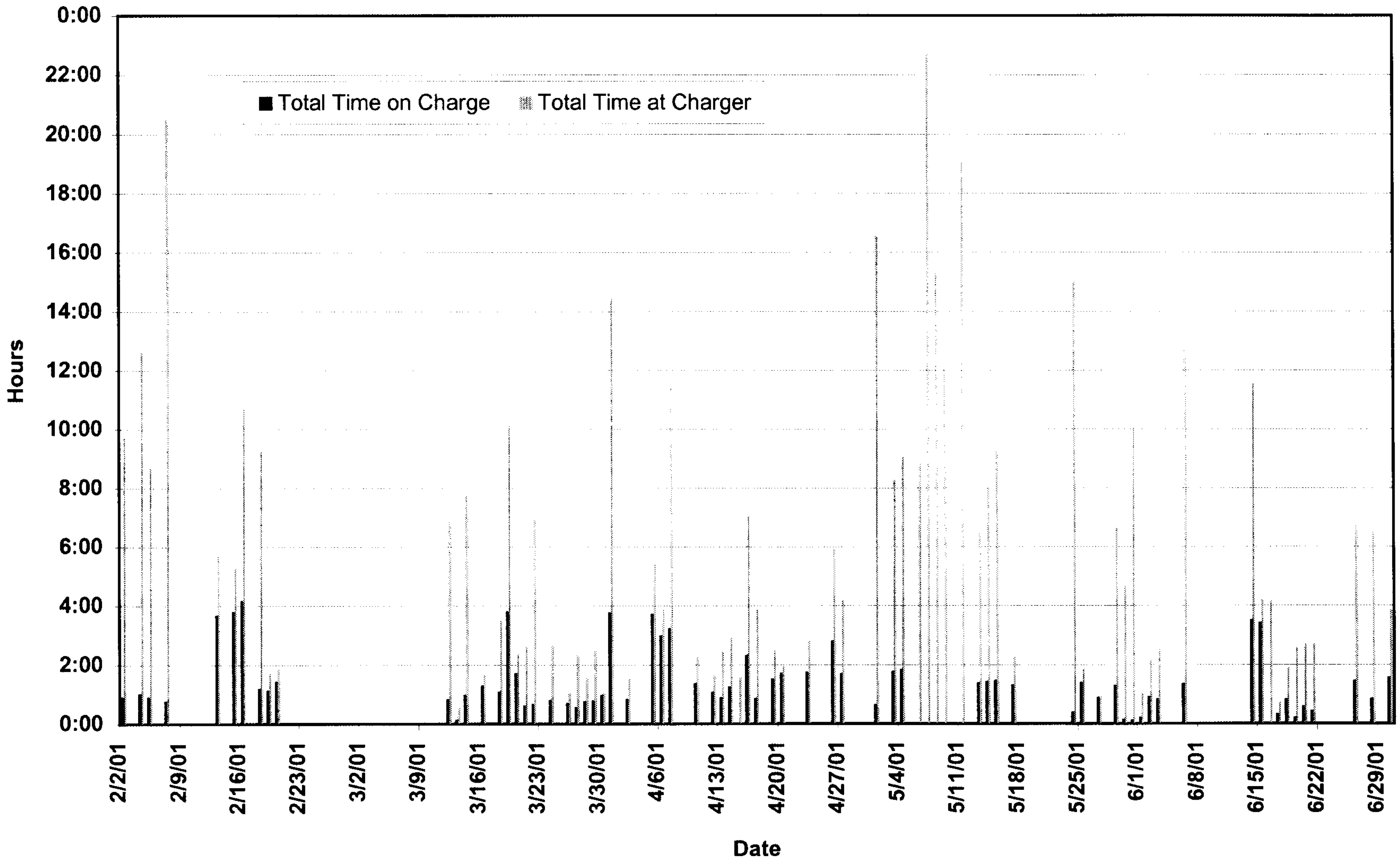
Elapsed Time - Vehicle BTE-11

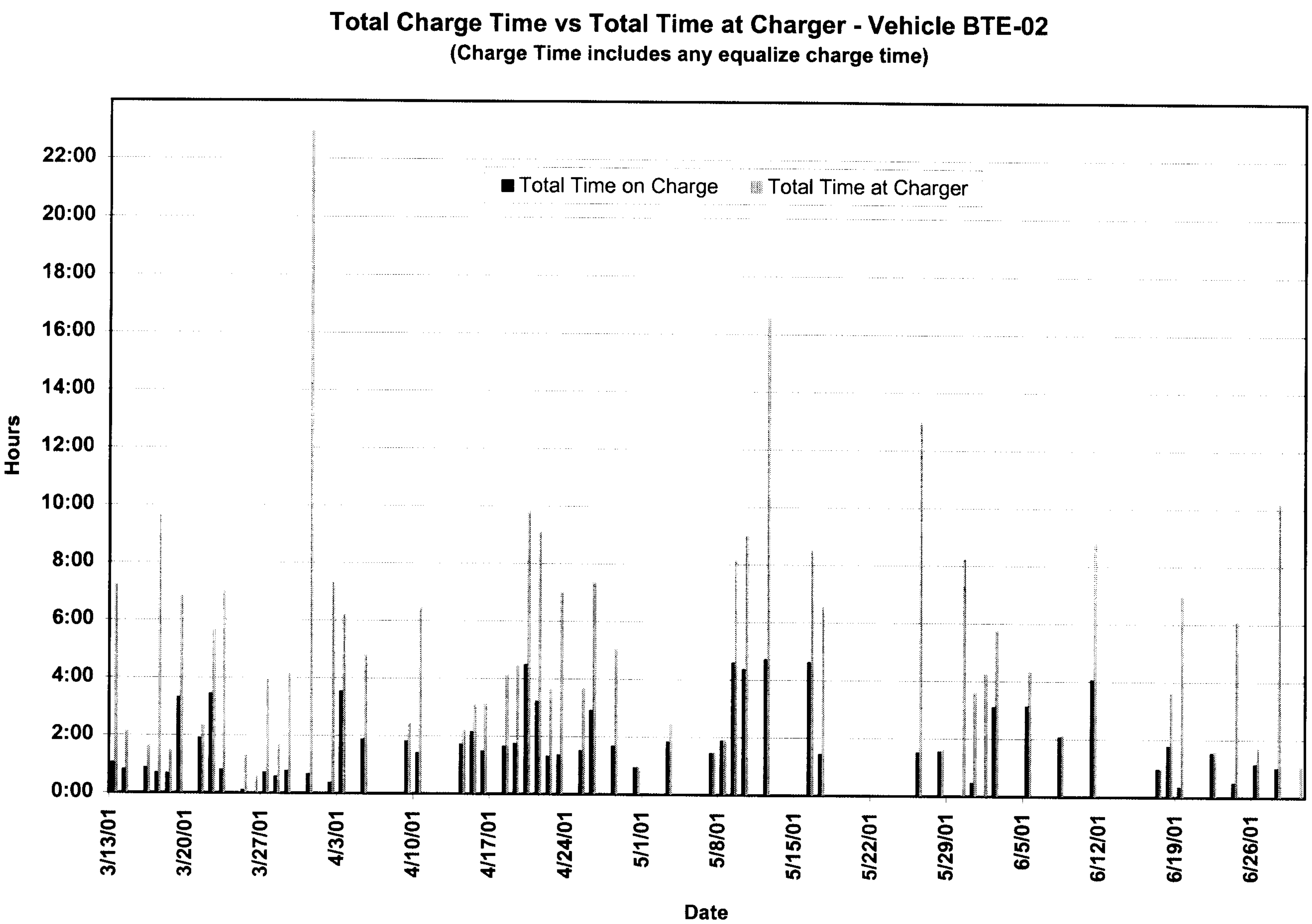


Elapsed Time - Vehicle BTE-12

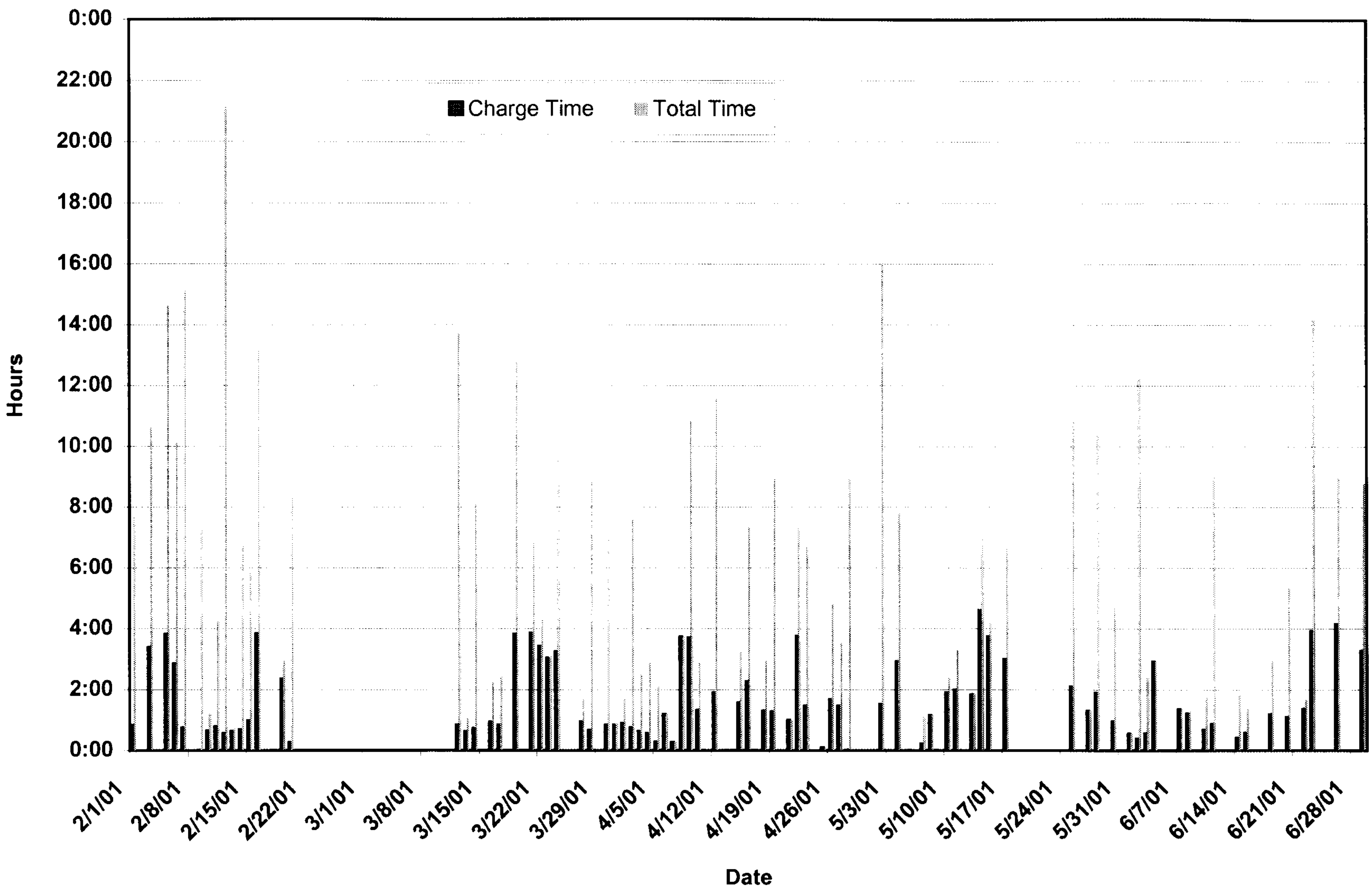


Total Charge Time vs Total Time at Charger - Vehicle BTE-01
(Charge Time includes any equalize charge time)

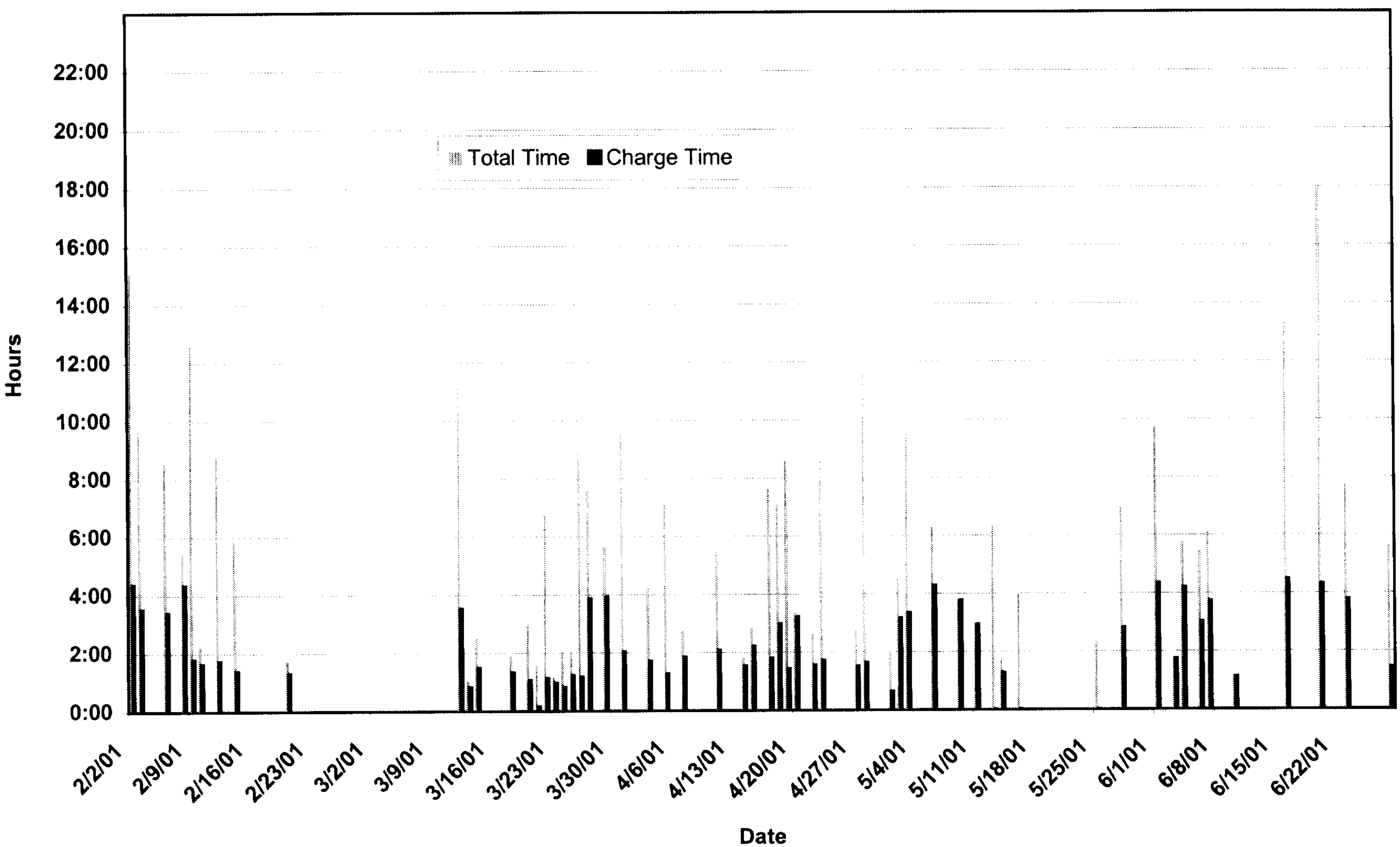


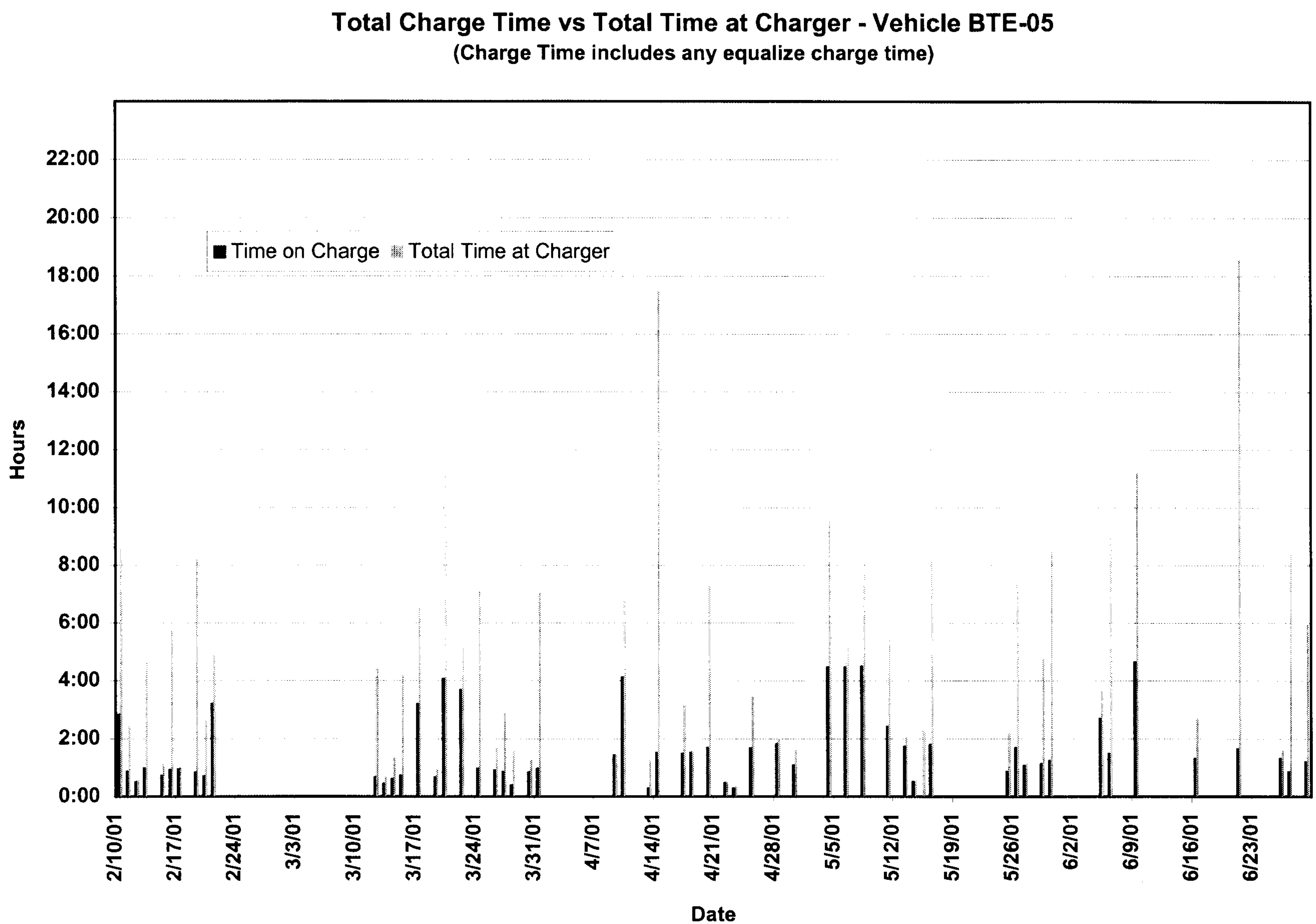

Total Charge Time vs Total Time at Charger - Vehicle BTE-02
(Charge Time includes any equalize charge time)
Total Time on Charge
Total Time at Charger
Hours
22:00
20:00
18:00
16:00
14:00
12:00
10:00
8:00
6:00
4:00
2:00
0:00
3/13/01
3/20/01
3/27/01
4/3/01
4/10/01
4/17/01
4/24/01
5/1/01
5/8/01
5/15/01
5/22/01
5/29/01
6/5/01
6/12/01
6/19/01
6/26/01
Date

Total Charge Time vs Total Time at Charger - Vehicle BTE-03
(Charge Time includes any equalize charge time)



Total Charge Time vs Total Time at Charger - Vehicle BTE-04
(Charge Time includes any equalize charge time)

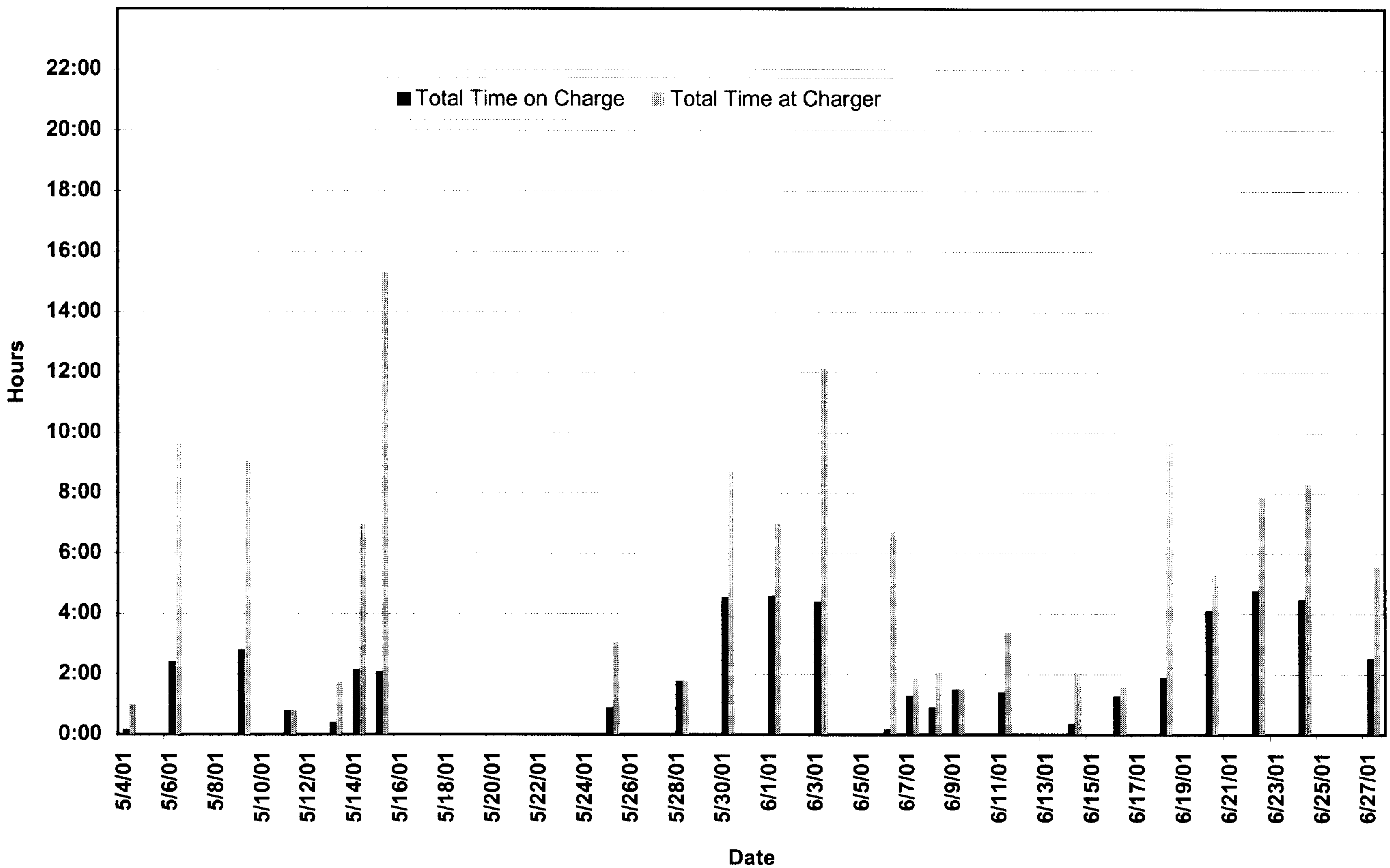




Total Charge Time vs Total Time at Charger - Vehicle BTE-05
(Charge Time includes any equalize charge time)
Time on Charge
Total Time at Charger
Hours
22:00
20:00
18:00
16:00
14:00
12:00
10:00
8:00
6:00
4:00
2:00
0:00
2/10/01
2/17/01
2/24/01
3/3/01
3/10/01
3/17/01
3/24/01
3/31/01
4/7/01
4/14/01
4/21/01
4/28/01
5/5/01
5/12/01
5/19/01
5/26/01
6/2/01
6/9/01
6/16/01
6/23/01
Date

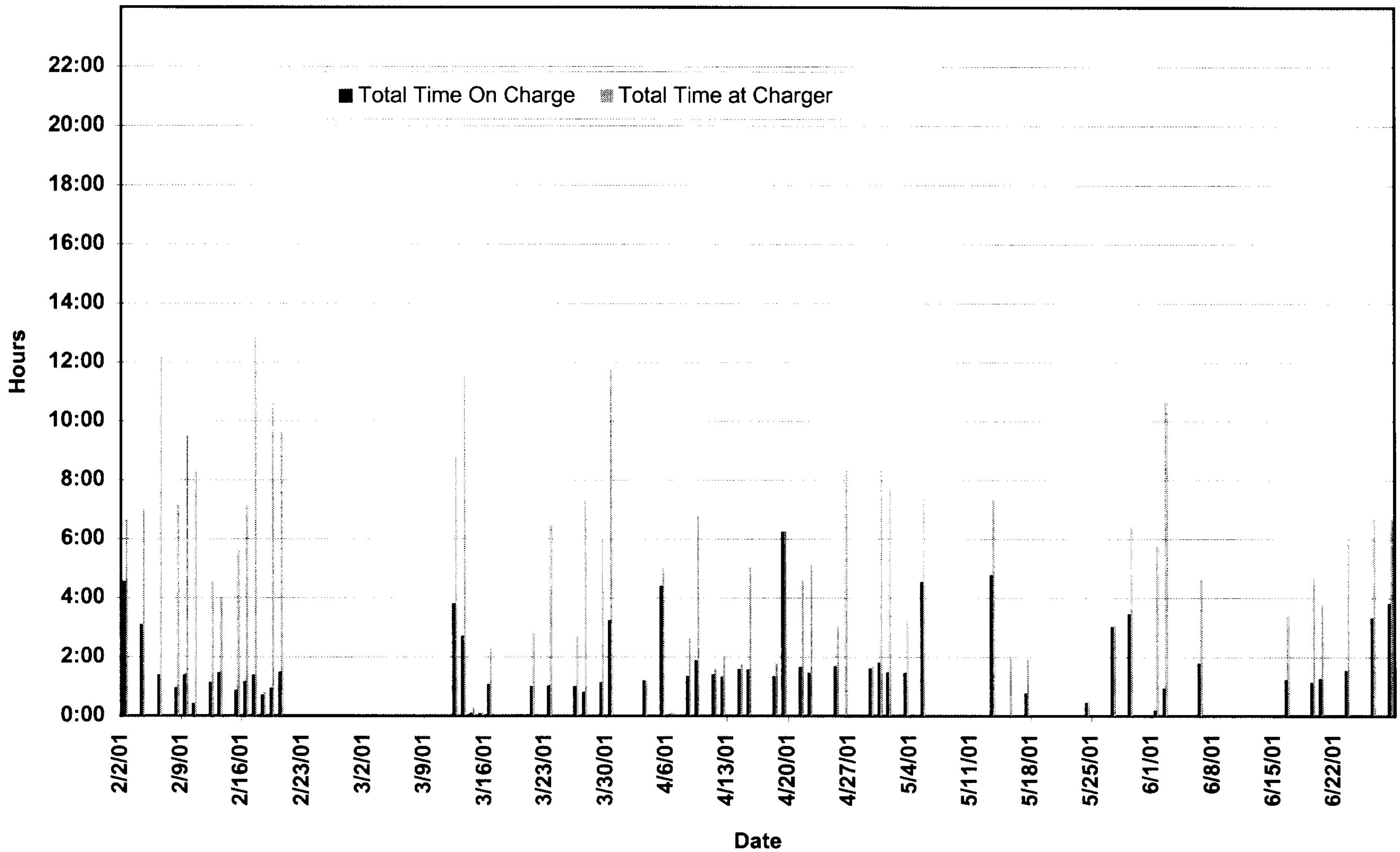
Total Chage Time vs Total Time at Charger - Vehicle BTE-06

Charge Time includes any equalize time)



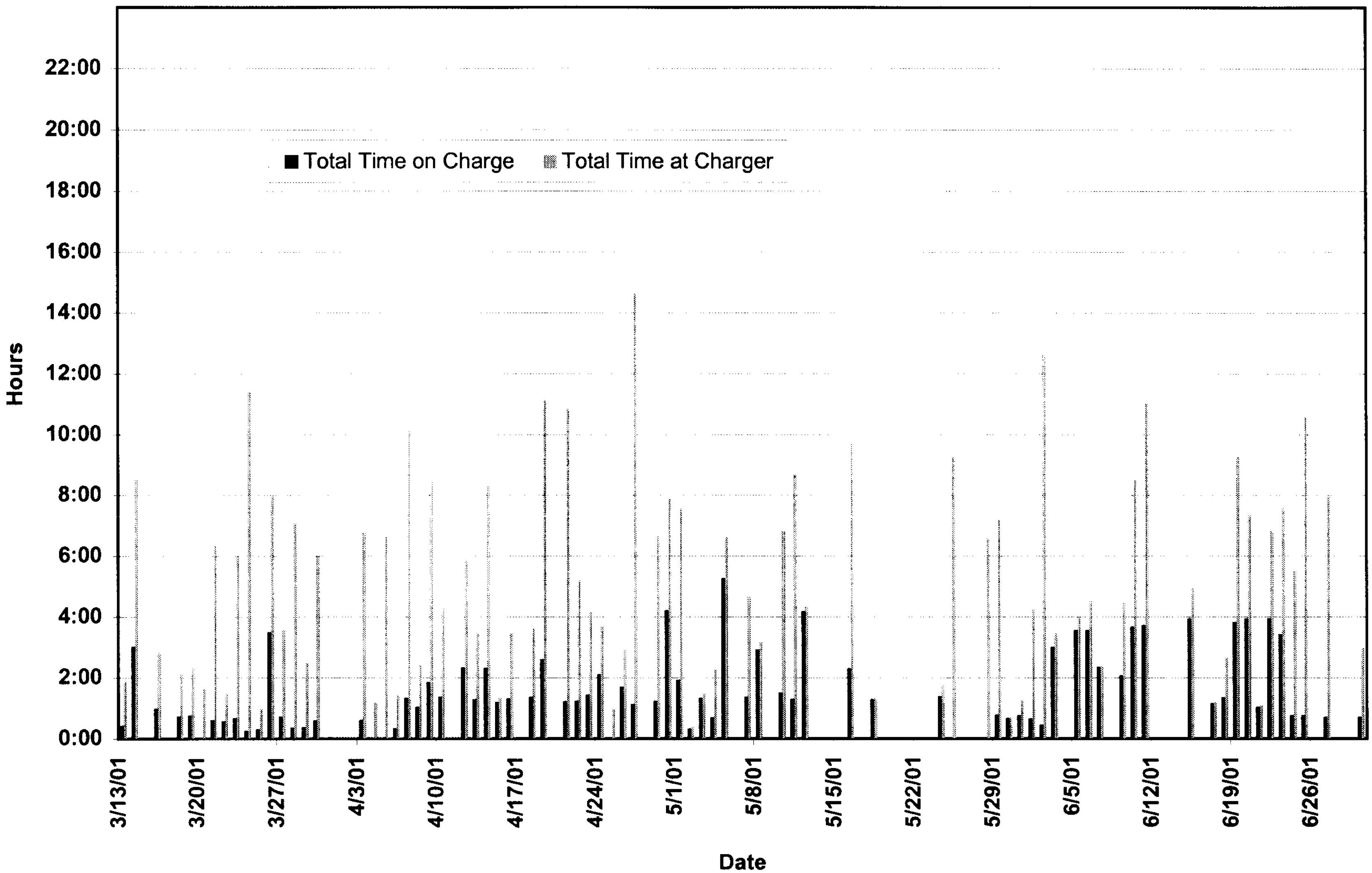
Total Charge Time vs Total Time at Charger - Vehicle BTE-07

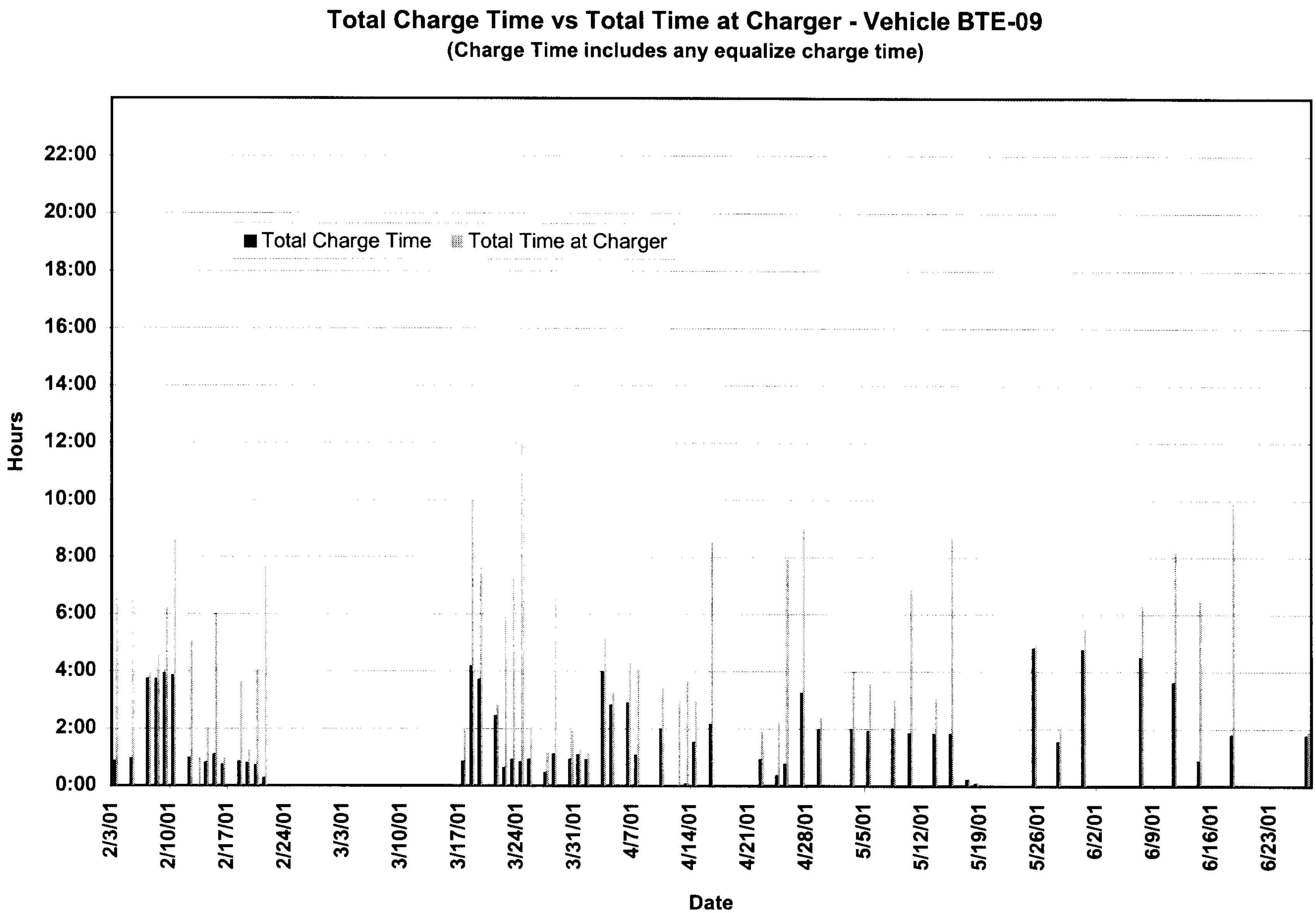
(Charge Time includes any equalize charge time)



Total Charge Time vs Total Time at Charger - Vehicle BTE-08

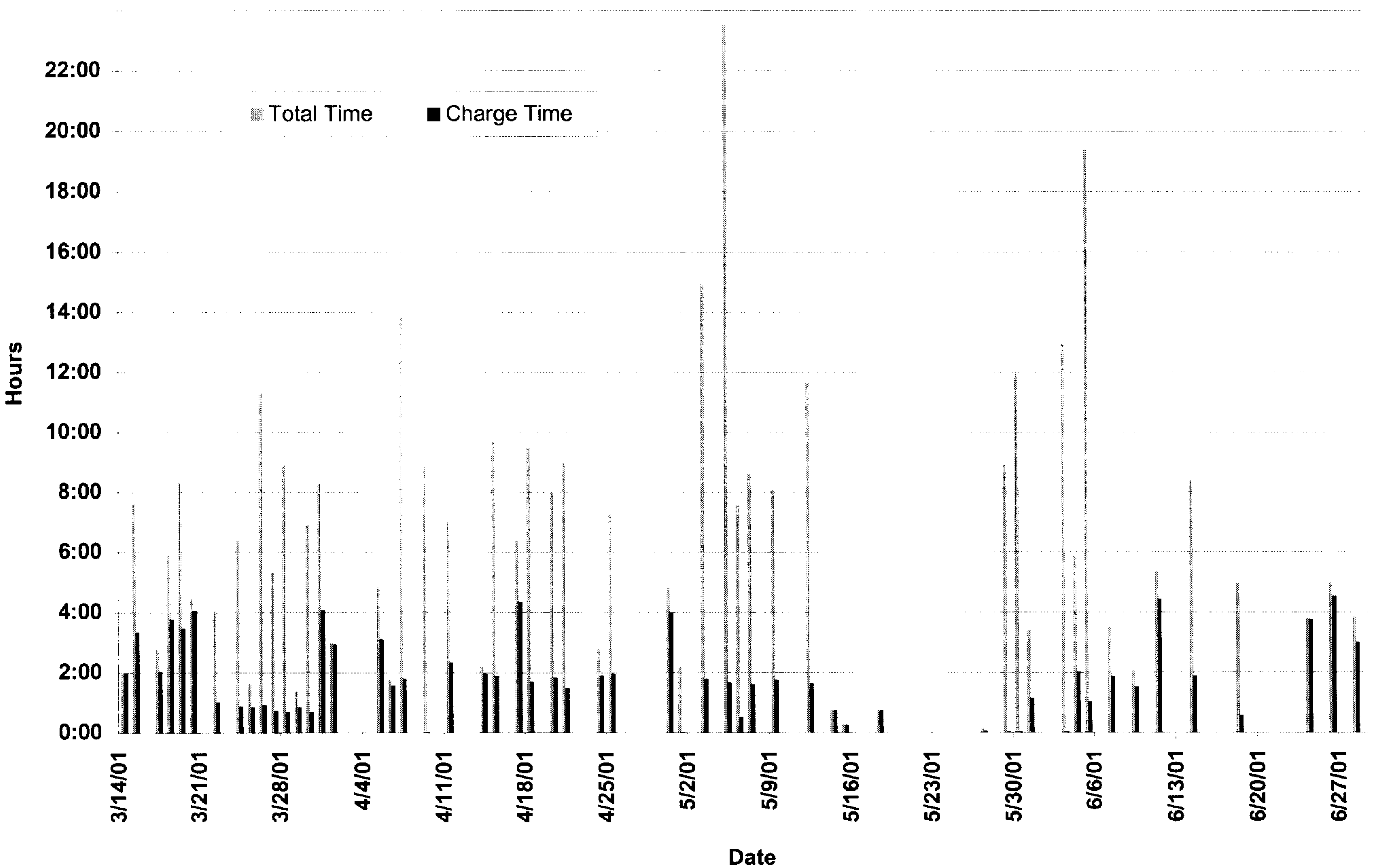
(Charge Time includes any equalize charge time)

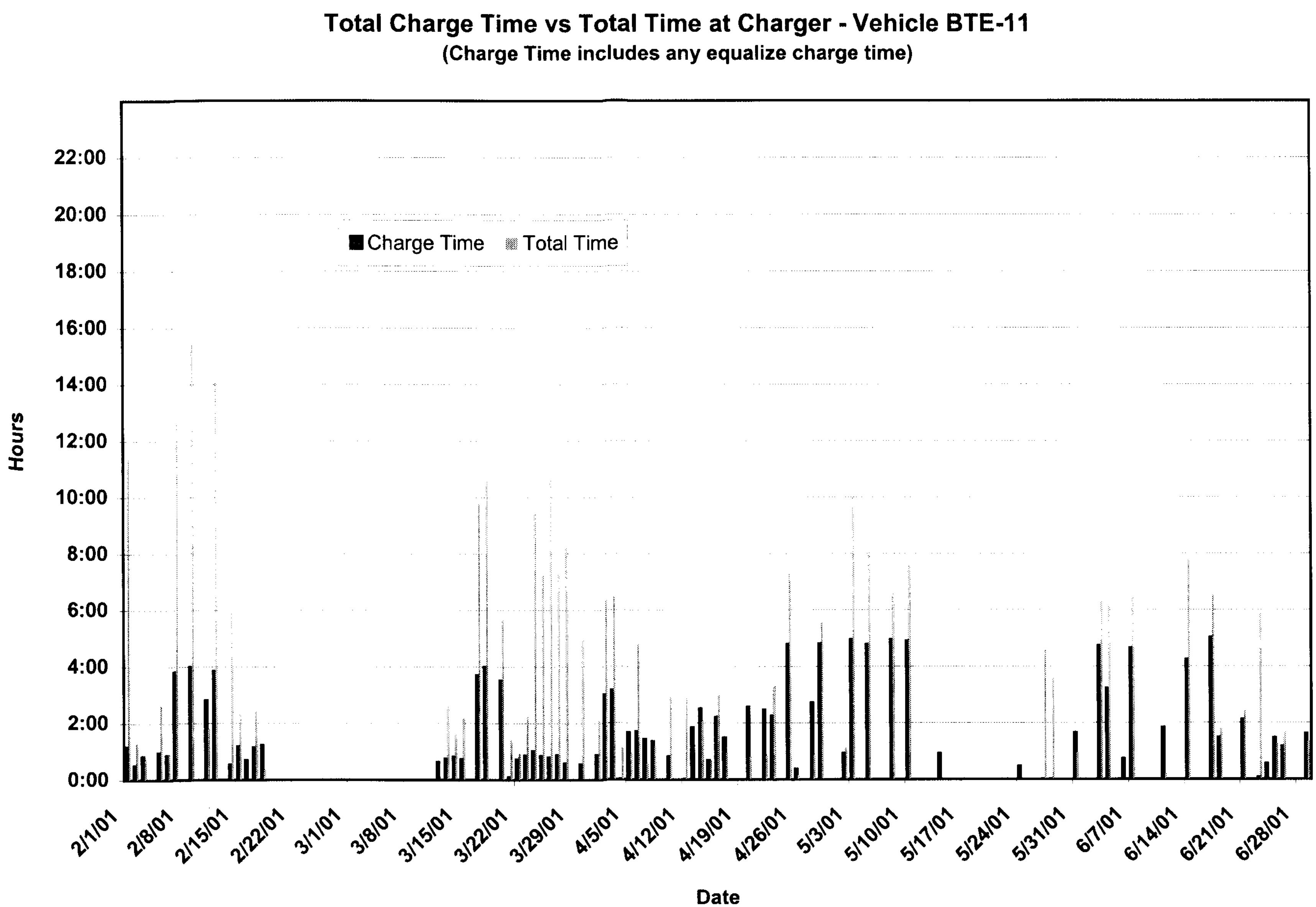




Total Charge Time vs Total Time at Charger - Vehicle BTE-09
(Charge Time includes any equalize charge time)
Total Charge Time
Total Time at Charger
Hours
22:00
20:00
18:00
16:00
14:00
12:00
10:00
8:00
6:00
4:00
2:00
0:00
2/3/01
2/10/01
2/17/01
2/24/01
3/3/01
3/10/01
3/17/01
3/24/01
3/31/01
4/7/01
4/14/01
4/21/01
4/28/01
5/5/01
5/12/01
5/19/01
5/26/01
6/2/01
6/9/01
6/16/01
6/23/01
Date

Total Charge Time vs Total Time at Charger - Vehicle BTE-10
(Charge Time includes any equalize charge time)





Total Charge Time vs Total Time at Charger - Vehicle BTE-11
(Charge Time includes any equalize charge time)
Charge Time
Total Time
Hours
22:00
20:00
18:00
16:00
14:00
12:00
10:00
8:00
6:00
4:00
2:00
0:00
2/1/01
2/8/01
2/15/01
2/22/01
3/1/01
3/8/01
3/15/01
3/22/01
3/29/01
4/5/01
4/12/01
4/19/01
4/26/01
5/3/01
5/10/01
5/17/01
5/24/01
5/31/01
6/7/01
6/14/01
6/21/01
6/28/01
Date

Total Charge Time vs Total Time at Charger - Vehicle BTE-12
(Charge Time includes any equalize charge time)