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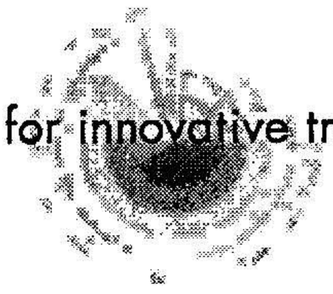
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CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION
INSTITUTE OF TRANSPORTATION STUDIES
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Travel Times on Changeable Message Signs
Volume III – Travel Time

Ali Mortazavi et. al, Senior Development Engineer

CCIT Research Report
UCB-ITS-CWP-2009-3



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Travel Times on Changeable Message Signs
Volume III – Travel Time

Ali Mortazavi, Ph.D., Senior Development Engineer
Kossi Adjaka, Zhen Sun, Research Assistants

CCIT Research Report
UCB-ITS-CWP-2009-3

This work was performed by the California Center for Innovative Transportation, a research group at the University of California, Berkeley, in cooperation with the State of California Business, Transportation, and Housing Agency's Department of Transportation, and the United States Department of Transportation's Federal Highway Administration.

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September 2009

Executive Summary

Real time traffic information on Changeable Message Signs (CMS) has gained popularity in urban areas where congestion and incidents frequently affect vehicle travel. CMS have been used to broadcast information about corridor downstream delays, traffic incidents and estimated travel times. Displaying accurate travel times on CMS helps commuters assess traffic, alleviates driver's stress, and allows drivers to make better route decisions. Knowing the driving times to popular destinations, travelers may be able to map their driving to the less congested route or chose a different form of transportation. Moreover, signs are the most effective means to communicate real-time, relevant information to motorists. Unlike a radio broadcast, signs target drivers passing a given location. Hence, the message is highly likely to be of interest to those drivers.

For the past four years, CCIT has helped Caltrans implement and deploy an automated system nicknamed MITTENS (Messaging Infrastructure for Travel Time Estimates to a Network of Signs) to display travel times on CMS in the Bay Area. MITTENS relies on MTC's 511 for travel time predictions. These predictions are based on real-time traffic data collected by toll tag readers (FasTrak program), by Caltrans' embedded loop traffic detectors, and by speed radar data. Predictions are updated every minute and are reported on the signs accordingly.

Task Order 1009 is the continuation of Task Order 13 in which CCIT could successfully deploy the first version of MITTENS in the Bay area. MITTENS 1.0, was a successful step in delivering travel time messages to a "network of signs" in the Bay Area.

After deploying the first version, new requirements to enhance the functionality of the system emerged. As s result, a new version of the software, MITTENS 2.0, was developed during this project. The new system is flexible in using different data sources other than 511 data to calculate travel time. In addition, MITTENS 2.0 is able to handle smart message display by dynamically generating highway travel times, transit times, and destinations. Furthermore, it is capable of comparing transit travel time and highway travel time. This feature enables the system to display the transit travel time when there is an advantage in using trains during peak hours. The objective was to provide comparative information for commuters and encourage motorists to use transit system in the rush hours. The evaluation study on the transit sings showed positive effect of commuter behavior.

For this version, the administrator Graphical User Interface (GUI) was deployed and CCIT continued enhancing the GUI. The new enhancements consisted of adding features to define different templates for the CMS display. The CCIT team also provided on-going support and incrementally enhancing functionality of MITTENS.

The travel time system is fully operational in the Bay Area and covers more than 30 signs. In addition, the system is successfully displaying comparison of transit trip and highway driving time for Millbrae and Redwood City stations. The system received the California Transportation Foundation TRANNY award for the best traffic operation project and was nominated for Best of ITS Awards for best innovative practice.

CCIT also upgraded MITTENS to allow deployment in other Caltrans districts. We also conducted a feasibility study on disseminating travel time information on other districts, i.e. D3, D5 and D10.

This report consists of the following documents:

Volume I – MITTENS Documentation:

- MITTENS Manual. This section provides detail information on:
    a. System Overview
    b. Operating Manual
    c. User Interface
    d. System Architecture and Database
- Deployment of MITTENS in District 10

Volume II – Evaluation of Transit Signs:

- Evaluation of Displaying Transit Information on Changeable Message Signs

Volume III – Travel Time Studies:

- Travel time study along US-101 and CA-154 in District 5
- Data analysis for travel time estimation on US-50 and I-80 in District 3

PROJECT FACT SHEET

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Section I

Travel Time Study along CA-154 and US-101 (from Los Olivos to Santa Barbara)

Final Report – September, 2009

Prepared by:

Ali Mortazavi

Zhen Sun

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For:

CALIFORNIA DEPARTMENT OF TRANSPORTATION

california center for innovative transportation
UNIVERSITY OF CALIFORNIA, BERKELEY

Table of Contents

1. Introduction 4
2. Problem Statement 8
3. Research Approach 8
3.1. Technical Specifications of the License Plate Recognition (LPR) Cameras 9
3.2. Camera Installation and Set-up 10
3.3. Roadside Vehicle Identification and Data Recording Process 12
3.4. System Limitations and Constraints 13
3.5. License Plate Number Data Collection Procedure 14
3.5.1. CA-154 data collection 14
3.5.2. US-101 data collection 15
3.6. Data Analysis Process 20
4. RESULTS 21
4.1. Detection rate and matching rate of the deployed LPR cameras 21
4.2. License Plates Matching and Travel Times Calculation 24
4.3. Travel Time Data Processing/Outlier Removal 26
4.4. Travel Time Comparison and Variability Analysis 29
4.4.1. Metrics for the travel time variation analysis 29
4.4.2. Travel time variation analysis for Route US-101 and CA-154. 31
4.4.3. Travel time variation analysis for the two segments of US-101 33
4.5. Travel Time Comparison between CA-154 and US-101 37
5. CONCLUSIONS 42
REFERENCES 43
A. A step by step analysis using the "modified one-way ANOVA test" 45
A.1 Within-day travel time variation analysis 45
A.2 Day-to-day travel time variation analysis 46
B. Daily detection rates and matching rates on CA154 48
C. Travel Time Distribution (Figures are not indexed) 53
C.1 CA-154 From Los Olivos to Santa Barbara Travel Time Distribution 53
C.2 CA-154 From Los Olivos to Cachuma Travel Time Distribution 64
C.3 CA-154 From Cachuma to Santa Barbara Travel Time Distribution 76
C.4 US-101 From Los Olivos to Santa Barbara Travel Time Distribution 89
C.5 US-101 From Los Olivos to Ellwood Travel Time Distribution 95
C.6 US-101 From Ellwood to Santa Barbara Travel Time Distribution 115
C.7 US-101 From Los Olivos to Gaviota Travel Time Distribution 141
C.8 US-101 From Gaviota to Ellwood Travel Time Distribution 151
C.9 US-101 From Ellwood to Goleta Travel Time Distribution 159
C.10 US-101 From Goleta to Santa Barbara Travel Time Distribution 164

Tables and Figures

Table 1: Summary of data collection phases for CA-154 14
Table 2: Summary of data collection phases for US-101 17
Table 3: Data Summary 26
Table 4: With-in-day travel time variation analysis 31
Table 5: Day-to-day travel time variation analysis 32
Table 6: With-in-day travel time variation analysis 33
Table 7: Day-to-day travel time variation analysis 36
Table 8: Multiple comparison results for Segment 1 37
Table 9: Day-to-day travel time variation analysis for Segment 1 37

Figure 1: Two links connecting Los Olives to Santa Barbara 9
Figure 2: LPR Camera Model # P372P 10
Figure 3: DC Converter and Interface box 11
Figure 4: Camera and Solar Panel 12
Figure 5: Vehicle identification and data recording process 13
Figure 6: Camera location for Phase I, CA-154 15
Figure 7: Camera location for Phase II, CA-154 15
Figure 8: Section 1 on US-101 16
Figure 9: Section 2 on US-101 17
Figure 10: Locations of cameras for phase I, US- 101 18
Figure 11: Locations of cameras for Phase II, US- 101 18
Figure 12: Camera locations for Phase III, US- 101 19
Figure 13: Camera location for Phase IV, US- 101 19
Figure 14: Camera location for Phase V, US- 101 20
Figure 15: Camera location for Phase VI, US- 101 20
Figure 16: Data Collection and Analysis Process 21
Figure 17: CA-154: Hourly Volume averaged across 4 days 23
Figure 18: Performance of LPR Camera averaged across 4 days 23
Figure 19: Principe of the Modified SSA 25
Figure 20: Raw Individual Travel Times 28
Figure 21: Processed Travel Times 28
Figure 22: Travel time on June 20th on US101 Northbound 32
Figure 23: Travel time on June 20th on Segment 1 34
Figure 24: Travel time on June 20th on Segment 2 34
Figure 25: Travel time on June 30th on Segment 2 35
Figure 26: Travel time on July 24th on Segment 2 36
Figure 27: CA154 Northbound comparison 38
Figure 28: CA154 Southbound comparison 39
Figure 29: US101 Northbound comparison 39
Figure 30: US101 Southbound comparison 40
Figure 31: Northbound weekdays comparison 40
Figure 32: Southbound weekdays comparison 41
Figure 33: Northbound weekends comparison 41
Figure 34: Southbound weekends comparison 42
Figure 35: CA-154: Hourly Volume on 05/09/08 49

Figure 36: CA-154: Performance of LPR Camera on 05/09/08 49
Figure 37: CA-154: Hourly Volume on 05/10/08 50
Figure 38: CA-154: Performance of LPR Camera on 05/10/08 50
Figure 39: CA-154: Hourly Volume on 05/11/08 51
Figure 40: CA-154: Performance of LPR Camera on 05/11/08 51
Figure 41: CA-154: Hourly Volume on 05/12/08 52
Figure 42: CA-154: Performance of LPR Camera on 05/12/08 52

1. Introduction

Advanced Traveler Information System (ATIS) is a key component in managing transportation growth and providing valuable traffic information to travelers. Real-time traffic information enables drivers to know what is ahead on their trip, and in some cases to divert their route and reduce traffic.

One of the main pieces of ATIS content is undoubtedly travel time estimation. Estimated travel times between selected locations are found to be one of the most practical information drivers can use. Travel times on defined itineraries represent information that is easy for the traveling public to understand and process.

Real-time traveler information on Changeable Message Signs (CMS) has gained popularity especially in urban areas. A network of signs is capable of disseminating a variety of information for different purposes. Displaying accurate travel times on CMS helps commuters assess traffic, alleviates driver's stress, and allows drivers to make better route decisions.

Several studies have shown that users value the reliability of a transportation system more than other features *(1)(2)(3).*Travel time variability is a major factor in applications such as travel time display by Changeable Message Signs (CMS) on freeways, and road performance measure. However, few studies were dedicated to travel time variability because of limited data availability *(4).*

Providing travel times is important in rural areas that host many travelers/tourists. Congestion can intensify specifically when the high volume of travelers confronts road construction or inclined weather condition. In addition, dissemination of travel time information can help travelers with their route choices when safety is a major concern. In scenarios which travelers have alternative rural shortcut options with low safety standards (i.e. winding geometry), displaying the comparison of travel times — between the major route and the shortcut(s) — can inform travelers that diverting to the shortcuts cannot save travel time significantly. This type of information would educate travelers about their rout choices aiming to encourage more travelers to use safer route alternatives.

As a part of Task Order (T.O.) 1009, The California Center for Innovative Transportation (CCIT) envisions bringing travel time information to Caltrans District 5 (D5) along with other districts (i.e. D4, D10 and D3). The targeted areas in D5 are two stretches of US-101 and CA-154 between Los Olivos and Santa Barbara. This task is framed as a pilot project to assess collecting and disseminating travel time information for the two routes in D5.

To evaluate the feasibility of providing driving times along the aforementioned corridors, CCIT collected traffic data using three *(3)* license plate recognition cameras and analyzed travel time variability. The purpose of this report is majorly to analyze travel time variability on the two stretches of CA-154 and US-101 corridors. Daily and day-to-day travel time variability are assessed.

This report is structured as follows: Section 2 states the problem of the study; Section 3 describes the research approach, including details about the technical specification of the LPR cameras as well as roadside data collection and analysis procedure; the results are shown in Section 4, which defines the metrics for license plate matching, travel time data processing and travel time variability analysis. The

results of travel time variability and travel time comparison are shown in this section, followed by concluding remarks in section 5.

2. Problem Statement

The two links (US-101 and CA-154) between Los Olivos and Santa Barbara (see) are often used interchangeably depending on driver-perceived traffic conditions.CA-154 is a two-lane local highway that creates a diagonal link between US-101 near Los Olivos and the western portion of Santa Barbara (). It is used as an alternative to US-101, although it is discouraging because of its rural nature and safety issues. The safety issues are as follows:

- Winding nature of the corridor
- Need for slowing travel speed

US-101 is a 4-lane national divided highway that composes the two perpendicular sides of the triangle. Caltrans is planning to provide travel time information to drivers so they could make an educated decision about which link to choose. The goal is to encourage travelers to take US-101 — instead of CA-154 (the shorter route) — due to safety issues. However, there are no traffic detections on those roadway stretches to estimate travel time. In this regard, CCIT started assessing cost effective traffic data collection technologies that fit within the requirement of the project.

The key issue is how often either US-101 or CA-154 experience traffic that leads to significant change in travel time. Before disseminating travel time information to the travelers, the typical patterns of travel times on US-101 and CA-154 should be identified and assessed to have a clear picture on the route selection problem.

3. Research Approach

This project aims to:

- Assess using license plate recognition (LPR) cameras as an alternative technology to collect travel time specifically in areas with no traffic sensor coverage
- Analyze travel time variability along CA-154 and US-101 to assess feasibility of displaying driving time along the two corridors in District 5

The main objective of this project is to assess the feasibility of disseminating driving times for US-101 and CA-154. As the first step, traffic data was collected along US-101 and CA-154 using three LPR cameras to compare and analyze travel time variability for the two corridors before initiating any travel time dissemination task. Travel time data were estimated along the two corridors by matching license plate numbers.

This study also creates a good opportunity for CCIT and Caltrans to assess LPR system performance as a mean of traffic data collection.

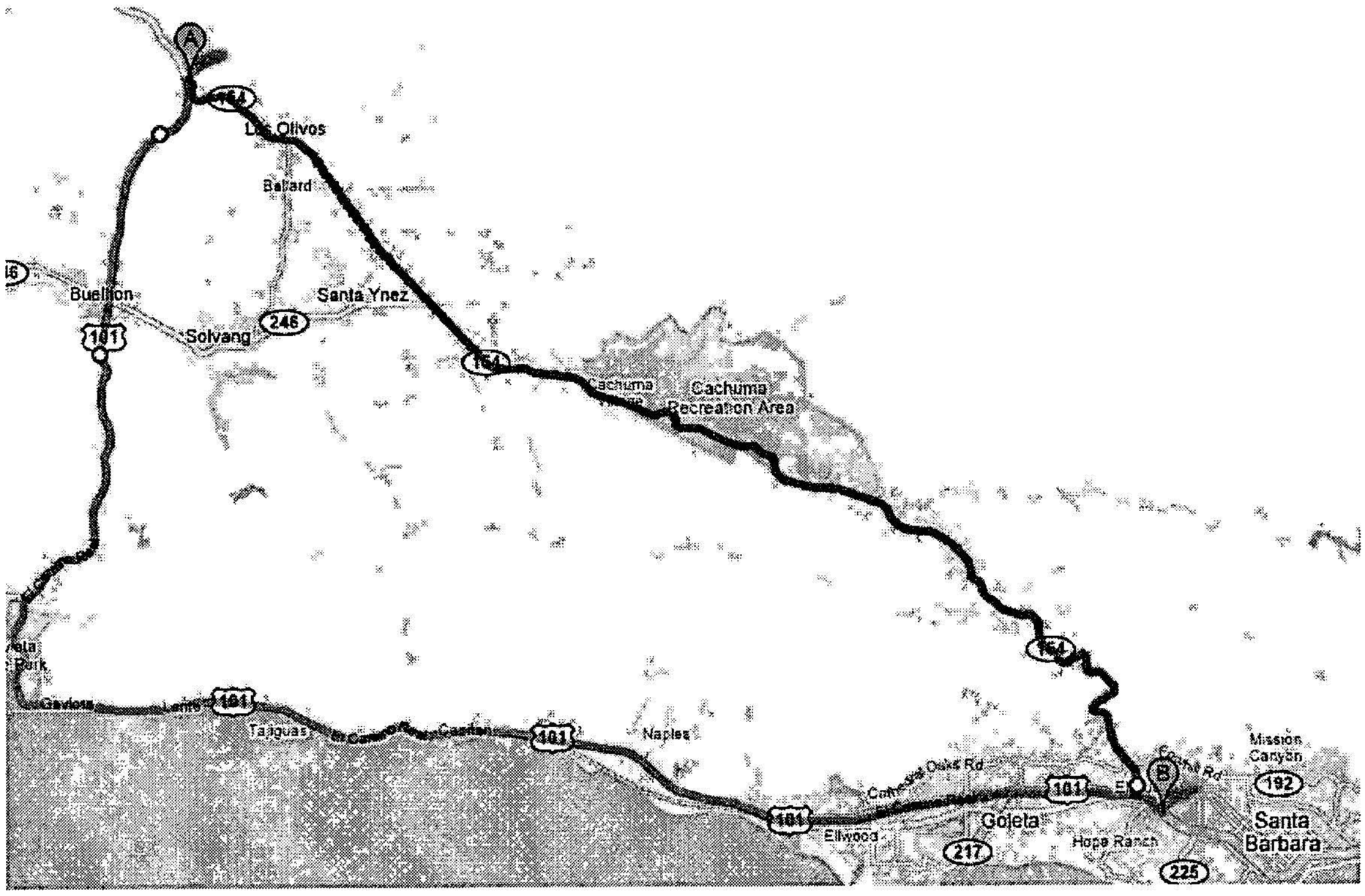


Figure 1: Two links connecting Los Olives to Santa Barbara

3.1. Technical Specifications of the License Plate Recognition (LPR) Cameras

Technical specifications of the LPR cameras (Figure 2) are as follows:

Manufacturer	Pips Technology
Model	# P372P
Dimensions	13.2" (336 mm) long, 4.85" (123 mm) diameter, including hood
Weight	<5.5 lbs. (2.5 kg.) including hood
Power	Typically less than 20W, 12-18V DC
Mechanics	Rugged alloy housing, metal sun hood. Sealed end caps provide totally sealed enclosure. Casing is nitrogen purged and waterproof to IP67 standard
Illumination	High-power IR pulsed LED illuminator with triple-flash (patented) technology. Illuminator flash table runs locally and autonomously on power up and can be set via web interface. Effective range – up to 50 feet (15m). Class 1M Eye Safety per BS EN 60825-1:1994 (including Amendments to 2:2001)

Standard Configuration	PIPS Cardet™ OCR generating time-stamped VRN ASCII string output.
	Local 8 MB flash local memory for program storage
	Patented real-time video plate finder (internal trigger)
	Software JPEG compression
Optics	Clear IR-transmissive window. 35, 25, 12, 8, and 6 mm lenses available to meet variety of focal length requirements

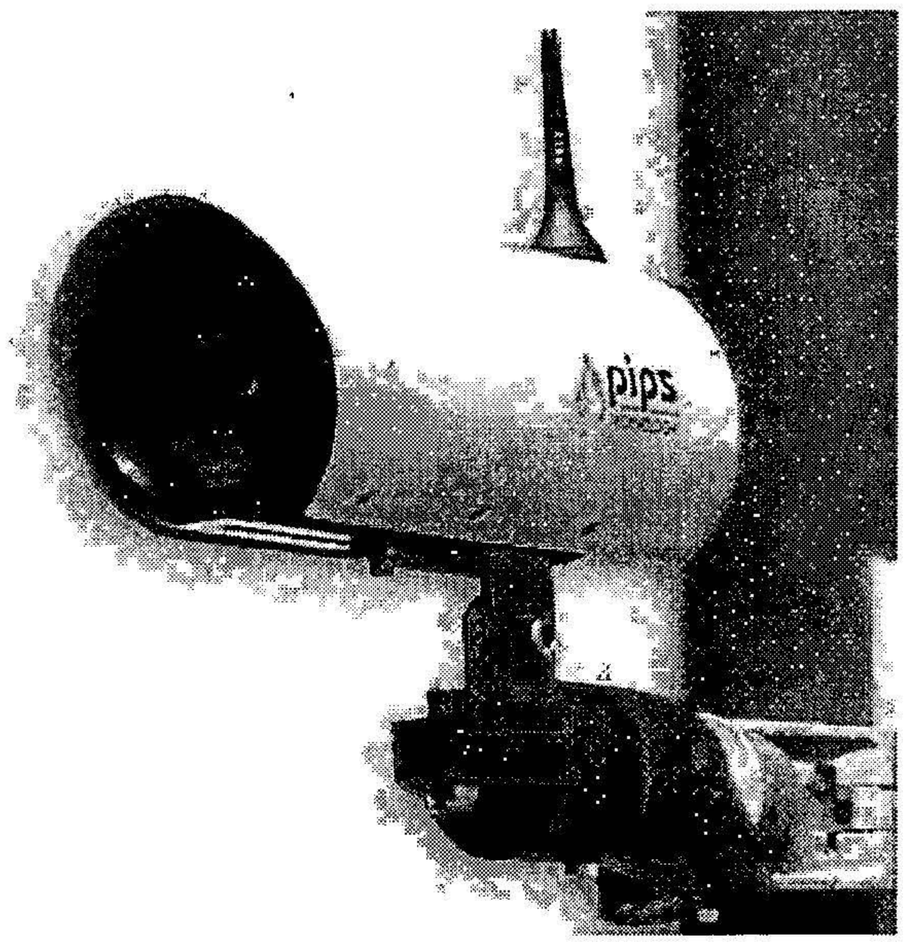


Figure 2: LPR Camera Model # P372P

3.2. Camera Installation and Set-up

The license plate recognition system consists of two major elements:

- Camera
- Interface box

Interface box (Figure 3) is used for power connection to camera, data transfer and software updates. The data can be transferred by connecting a laptop to the cameras via a crossover Ethernet cable. It is specially designed for field installations and can provide wiring terminations, lightening protection, and other valuable features.

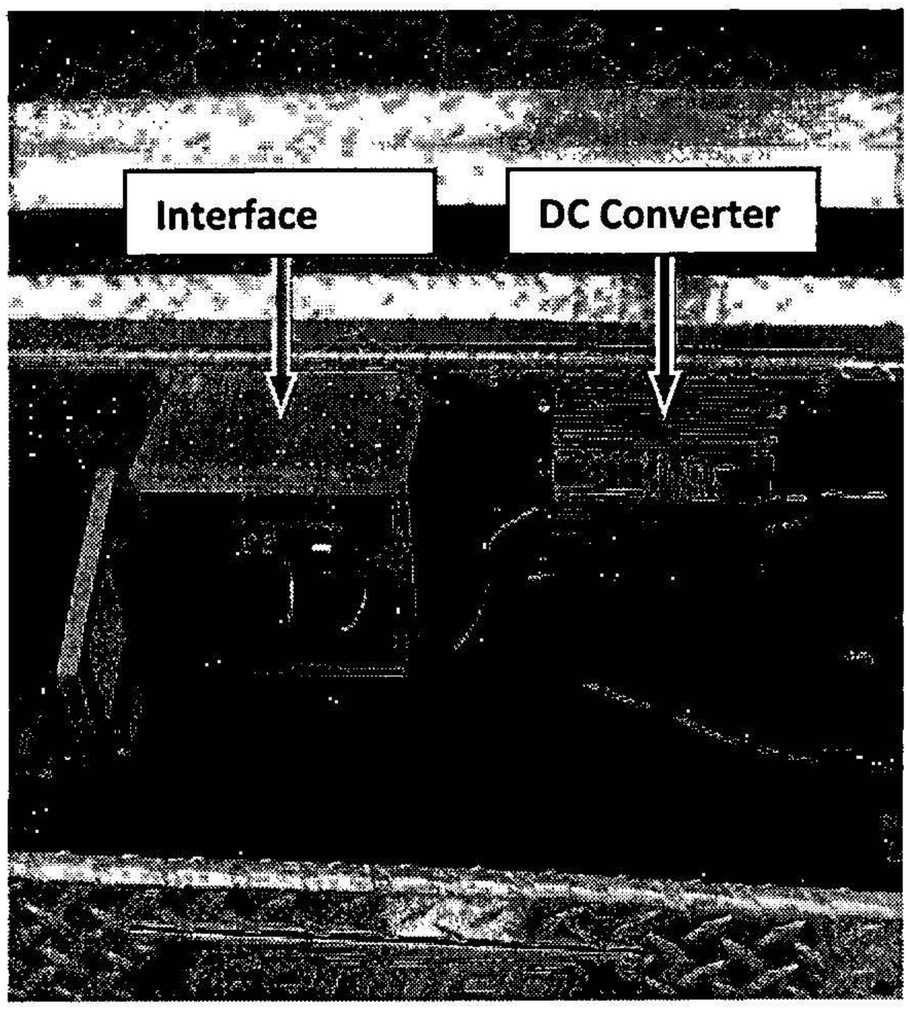


Figure 3: DC Converter and Interface box

The cameras were mounted on top of arrow-board trailers (Figure 4). The trailers were equipped with solar panels. Considering limited access to power sources along the two corridors, trailers were suitable candidates as mounting platforms for the LPR cameras. Several factors were taken into account for selecting the trailers:

- **Height.** Trailers provided enough elevation for the cameras to clearly view license plate numbers.
- **Security.** Trailers were equipped with secured boxes; the cameras were also mounted on top of the trailers to minimize the risk of being vandalized.
- **Power source.** The existing solar panels installed on the trailers were used to power up the cameras.
- **Mobility.** This feature enabled the team to easily move and set up the cameras along the sites.

A DC converter (Figure 3) was used to adjust the solar panel output power with the cameras' operating voltage.

All the preparations and modifications on the trailers to mount the cameras were conducted in Caltrans District 5.

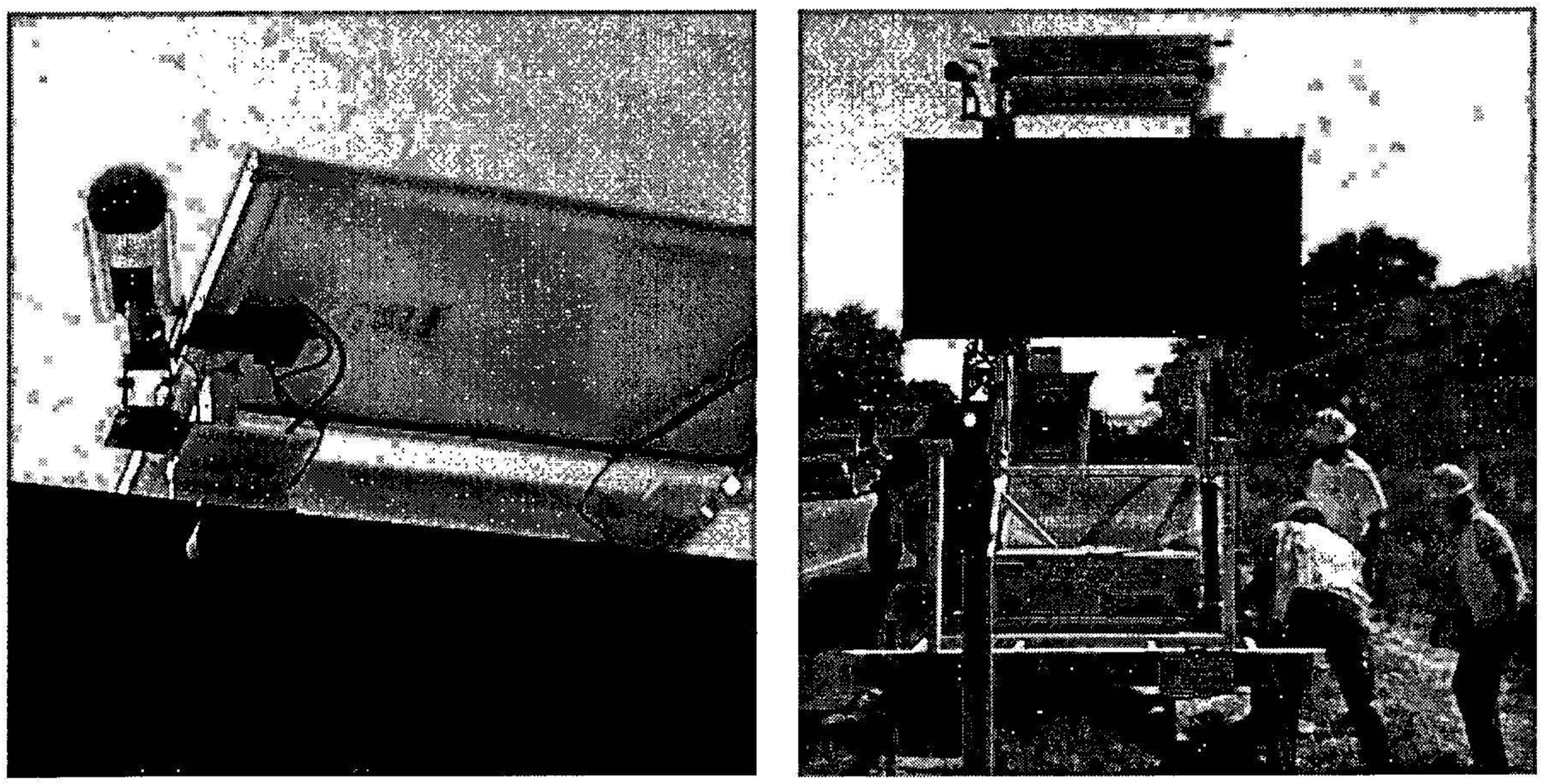


Figure 4: Camera and Solar Panel

3.3. Roadside Vehicle Identification and Data Recording Process

Figure 5 displays roadside vehicle identification and data recording process. The camera works as follows:

1. Presence of a vehicle is detected which consequently triggers LPR camera operation (vehicle detection)
2. LPR camera captures the digital image of the license plate (plate capture)
3. The camera reads the number on the plate using Optical Character Recognition (OCR) module
4. The license plate number is time stamped and stored in the memory storage card of the camera. (As an optional feature, the data can also be broadcasted to another access point real-time.)

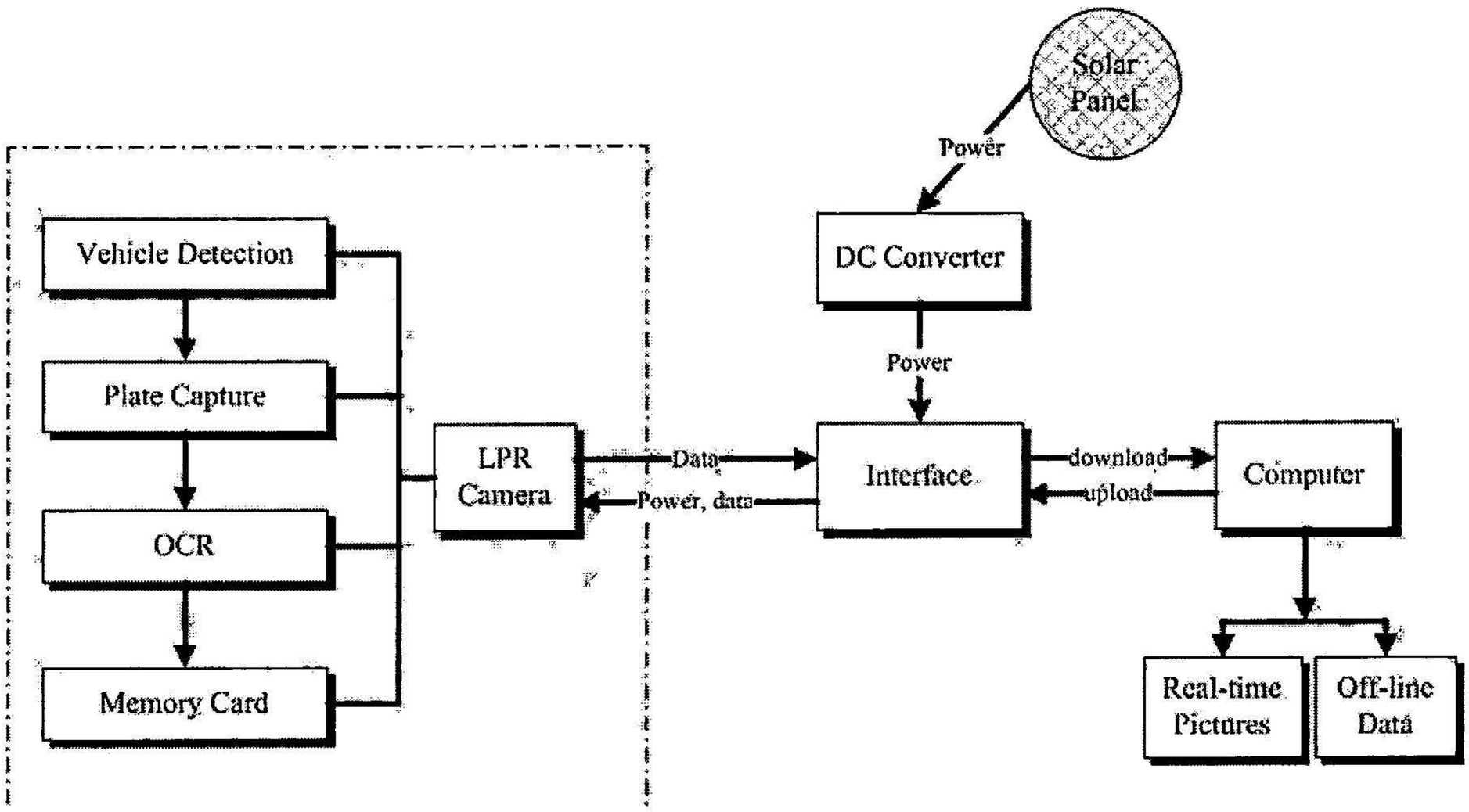


Figure 5: Vehicle identification and data recording process

License plate data are recorded as a text file. Each recorded field consists of 7 elements. An example of a recorded field is as follows:

0920,1757416: 0920,1757411,1, 3NCL458,97

The first two columns are the date and time when the license plate is captured; while the following two columns are the date and time when the vehicle is first detected (there is one decimal for second in the recorded time). Usually there are about 0.5 second time difference between detection and capturing. The sixth column is the license plate number recognized by the camera, which we will use for plate matching in the data analysis. In the above example, the data show a vehicle with license plate number 3NCL458 was detected at 17:57:41.1 (5:57:41.1 PM) on Sep 20th, and was captured at 17:57:41.6 (5:57:41.6 PM).

3.4. System Limitations and Constraints

There were some constraints associated with this pilot project that needs to be addressed. These constraints directly — or indirectly —affected the deployment plan decisions and are as follows:

1. **Lane coverage**. The cameras can only cover 5 feet of the road. This means that they are able to collect data from only one lane. Therefore, cameras fail to capture plate numbers of vehicles driving far left or right of the covered lane. This constraint has an adverse effect on license plate matching rate and consequently the penetration rate.
2. **Real-time communication**. As previously mentioned, due to limited access to communication infrastructure, the proposed data collection system was not able to broadcast the collected data

real-time. The time-stamped plate numbers were archived in the camera memory and transferred off-line to a computer's hard drive for future analysis.

3. **Memory.** Since the capacity of LPR camera storage card was limited, the field team had to frequently (every three days) download the recorded data and clean up the memory.
4. **Number of cameras**. Due to budget limit for equipment purchases, the team could purchase only 3 cameras — sufficient for covering 3 data collection stations.
5. **Front license plate problem.** Displaying front license plate is not mandatory in California. Hence, camera set up aiming for front plates may recognize less number of license plates comparing to a camera set up capturing rear plates. What's more, front plates are usually closer to the ground and thus are not as clean as the rear plates. In the first round of data collection along CA-154 the cameras aimed to collect the front plate numbers. Considering all the factors, in order to increase the capture rate and recognition accuracy, the project team revised the set-up accordingly to collect rear plate numbers.

3.5. License Plate Number Data Collection Procedure

The quality of the collected data is dependent on different parameters, i.e. the number of lanes (only one lane can be covered for this project) and number of exits/interchanges. Therefore, choosing longer segments may degrade the quality of the collected data.

To increase the penetration rate, the corridors were divided into shorter segments. Each segment is defined by a combination of two LPR cameras.

3.5.1. CA-154 data collection

There is no major exit on CA-154. The penetration rate is also higher for the two-lane CA-154 corridor (comparing to US-101). Therefore, there was no need to break the corridor into smaller sections for improving the data quality. The data collection for this corridor includes only two phases (including data collection for NB and SB). Table 1demonstrates data collection phases for CA-154.

Table 1: Summary of data collection phases for CA-154

Phase	Section	Direction	Duration	PM Locations of cameras
Phase I	CA-154	SB	7 Days	See Figure 6
Phase II	CA-154	NB	4 Days	See Figure 7

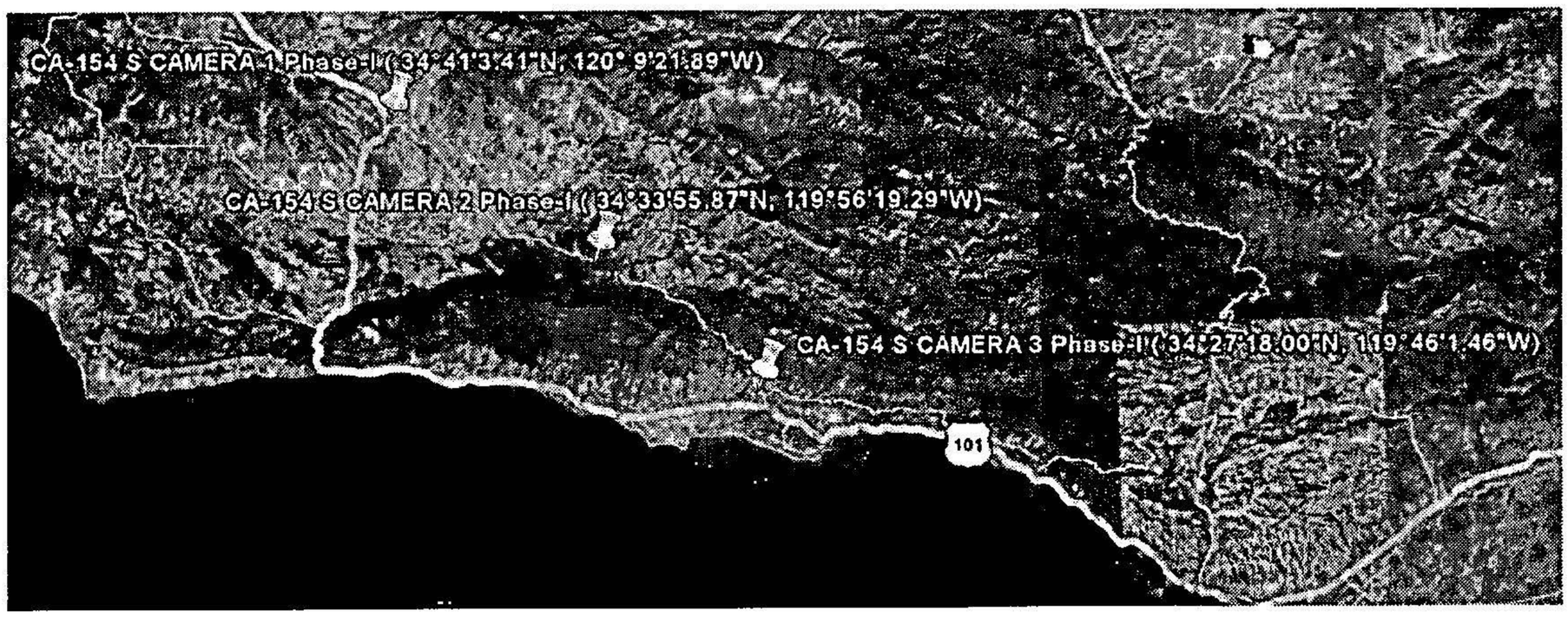


Figure 6: Camera location for Phase I, CA-154



Figure 7: Camera location for Phase II, CA-154

3.5.2. US-101 data collection

Due to limited number of purchased cameras, the data collection was conducted in different stages for US-101 corridor. US-101 is long and includes couples of on ramp/off ramps between Goleta and Santa Barbara. Therefore, we divided the stretch of US-101 into two sections:

1. From Los Olivos to Ellwood (Section 1). This 2-lane 38-mile stretch of US-101 has no major exit or ramp. (Figure 8)

2. From Ellwood to west of Santa Barbara (Section 2). This segment is shorter (8.5 miles) and has at least 5 major intersections. (Figure 9)



Figure 8: Section 1 on US-101



Figure 9: Section 2 on US-101

The data collection in US-101 will be conducted in 6 separated phases (which includes data collection for south bound and north bound stretches). Table 2provides more information about the proposed data collection phases. It should be noted that Phase III and Phase VI consists of data collection from the whole US-101 corridor stretch (NB and SB).

Table 2: Summary of data collection phases for US-101

Phase	Section	Direction	Duration	Locations of cameras
Phase I	1	SB	8 Days	See Figure 10
Phase II	2	SB	13 Days	See Figure 11
Phase III	Whole corridor stretch	SB	3 Days	See Figure 12
Phase IV	1	NB	20 Days	See Figure 13
Phase V	2	NB	12 Days	See Figure 14
Phase VI	Whole corridor stretch	NB	9 Days	See Figure 15

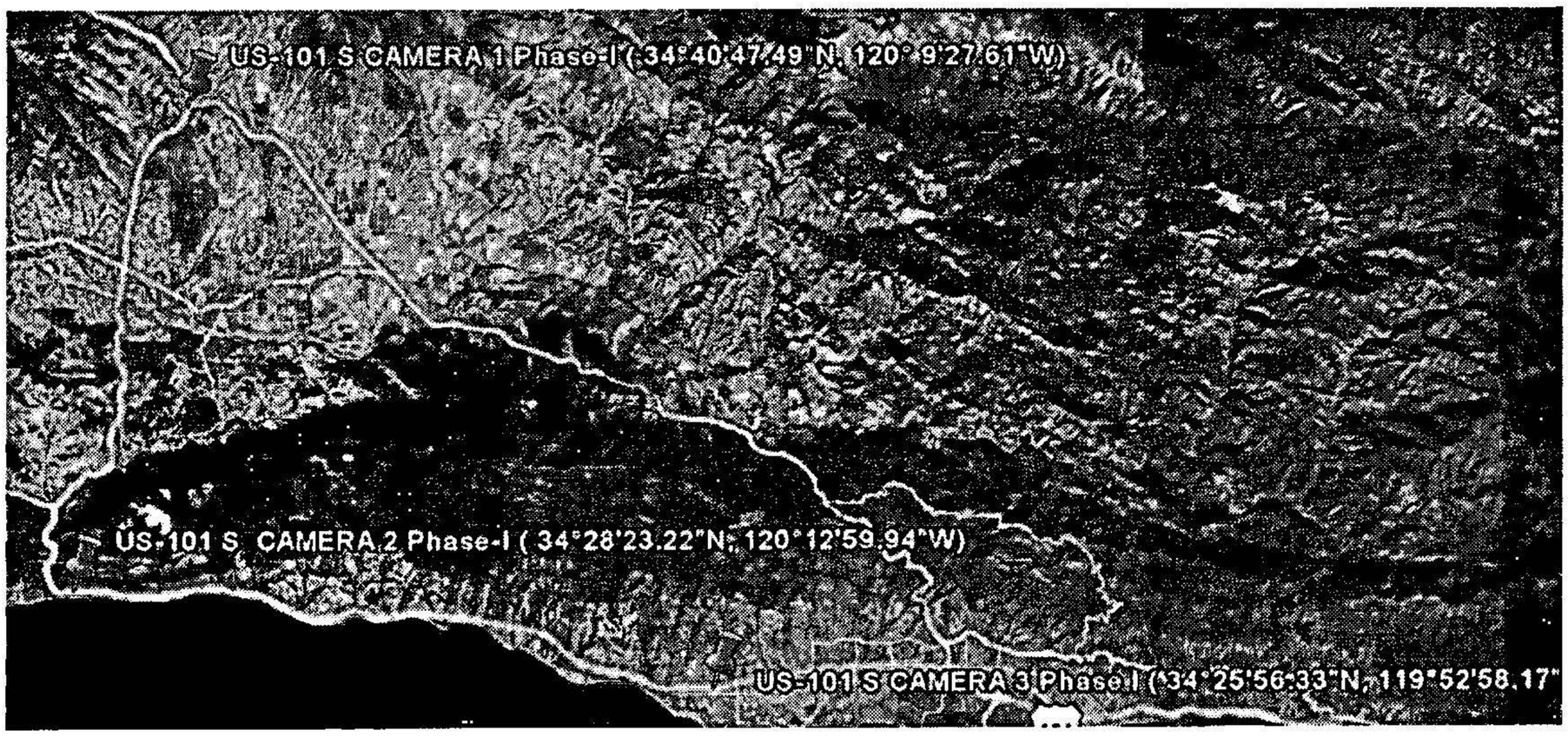


Figure 10: Locations of cameras for phase I, US- 101

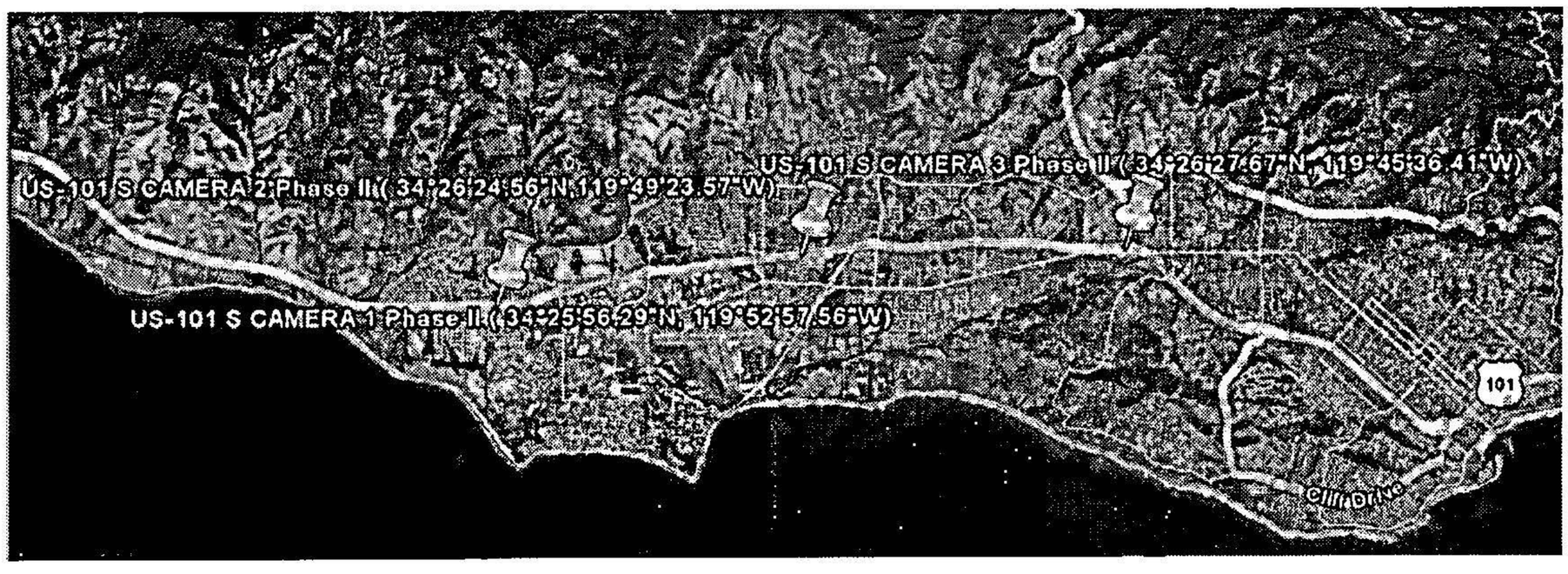


Figure 11: Locations of cameras for Phase II, US- 101

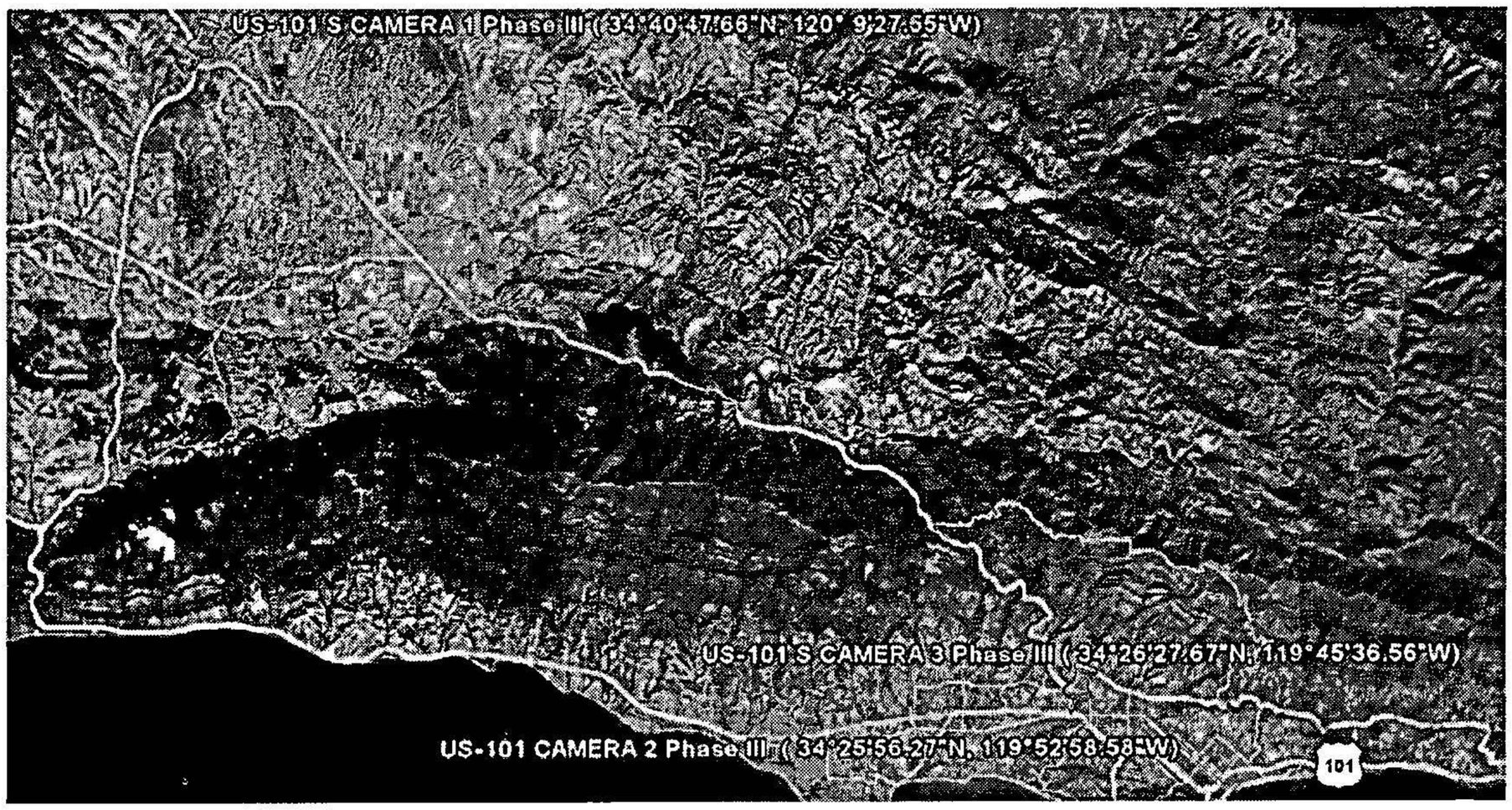


Figure 12: Camera locations for Phase III, US- 101



Figure 13: Camera location for Phase IV, US- 101

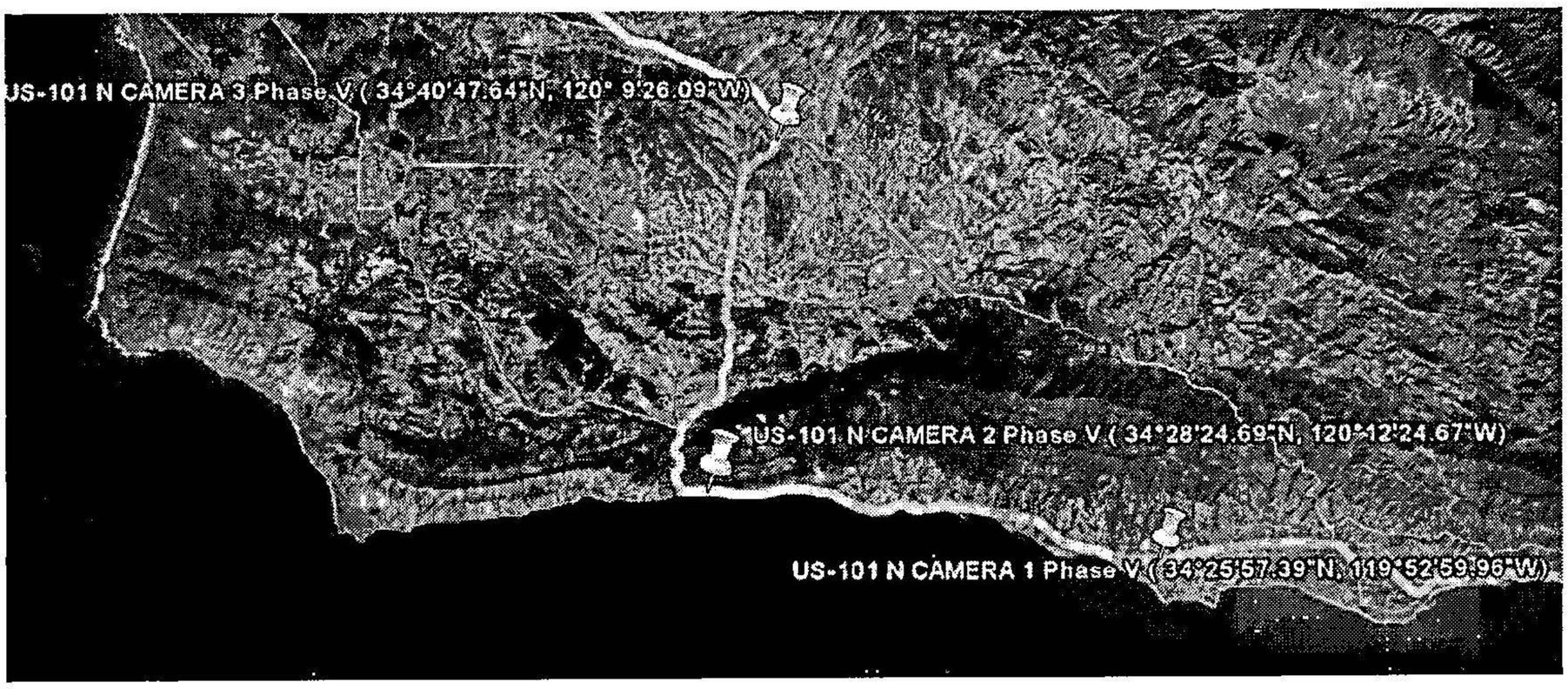


Figure 14: Camera location for Phase V, US- 101



Figure 15: Camera location for Phase VI, US- 101

3.6. Data Analysis Process

After storing the camera data into the laptop, over a separate process, segment travel times were calculated by matching the license plate numbers. The estimated travel time were used for the variability analysis.

The overall procedure for travel time variability analysis consists of two phases: the first phase is license plates matching and individual travel times estimation; the second phase includes travel time data

filtering and variability analysis. Figure 16 shows the procedure of data acquisition and travel time variability analysis.

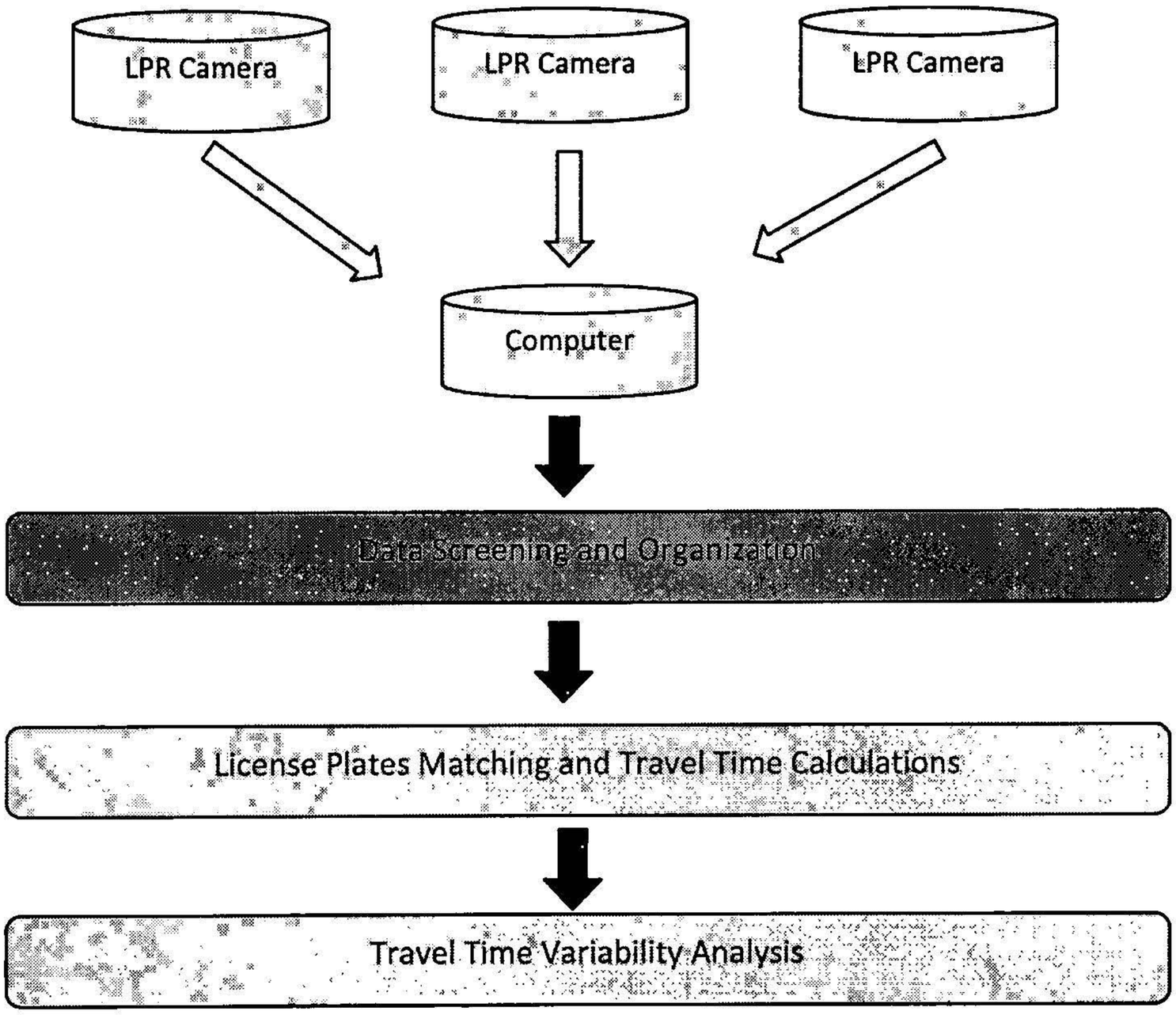


Figure 16: Data Collection and Analysis Process

4. Results

For this study, data was collected from April 2008 to August 2008. However, data was not available for every day of that period because of frequent interruptions in downloading data from cameras and moving LPR cameras along data collection sites.

4.1. Detection rate and matching rate of the deployed LPR cameras

To assess the detection rate of the LPR cameras, traffic volume count was performed with a pneumatic tube on CA-154 during Phase 2 of the data collection. Vehicles traveling Northbound were counted on CA-154 near the location of the second (middle) camera.

In this study, performance or rate of detection of an LPR camera during a time interval *t* is defined as the number of vehicles detected by the LPR camera divided by the total volume of vehicles at the camera's location during *t*. Assuming that the volume of vehicles detected by the tube is the total volume of vehicles, the performance is given by the following equation:

$$detection\ rate = 100 \times \frac{number\ of\ vehicles\ detected\ by\ LPR\ camera}{number\ of\ vehicles\ detected\ by\ tube}$$

On the other hand, the matching rate during a time interval t is defined as the number of matched vehicles detected by the camera 1 (upstream camera) and at camera 2, divided by the number of vehicles detected the camera 2 during the same time interval. The matching rate is given by the following equation:

$$matching\ rate = 100 \times \frac{number\ of\ matched\ vehicles}{number\ of\ vehicles\ detected\ by\ LPR\ camera}$$

Figure 17shows the average hourly volumes of vehicles counted by the tube, the number of vehicles detected by the LPR camera 2, and the number of matched vehicles from camera 1 and camera 2. Figure 18represents the average hourly detection rates and matching rates. Performance of the LPR camera ranges mostly from 60% to 70% between 7am and 9pm. During the times where traffic volume is low (9pm to 7am), the detection rate is lower but still maintains an average rate of over 40%(note that the camera set-up in this period was aiming at the front plates of vehicles, which might partly account for the low capture rate. Please refer to 3.4for further explanation).The detection rate during 9pm to 7am period also has more variations compared with daytime performance. The matching rate, on the other hand, is more evenly distributed across day-time and night, with a range of 54% to 61%, due to the fact that there is only one lane for each direction on CA-154 and few major ramps along this stretch. This range can also be used as approximate upper bounds for the matching rates of the LPR cameras. Please refer to Appendix B for more detailed daily performance figures.

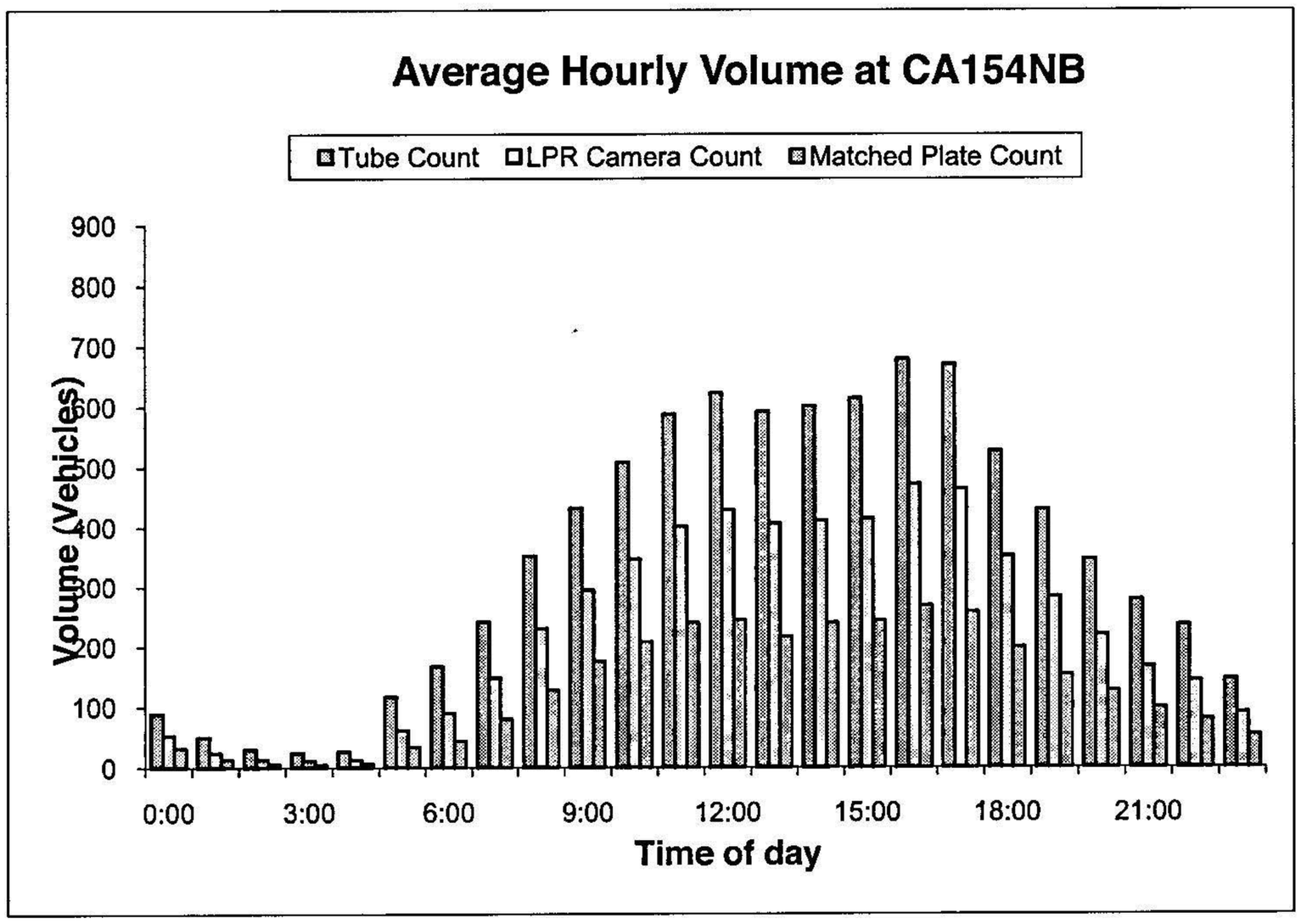


Figure 17: CA-154: Hourly Volume averaged across 4 days

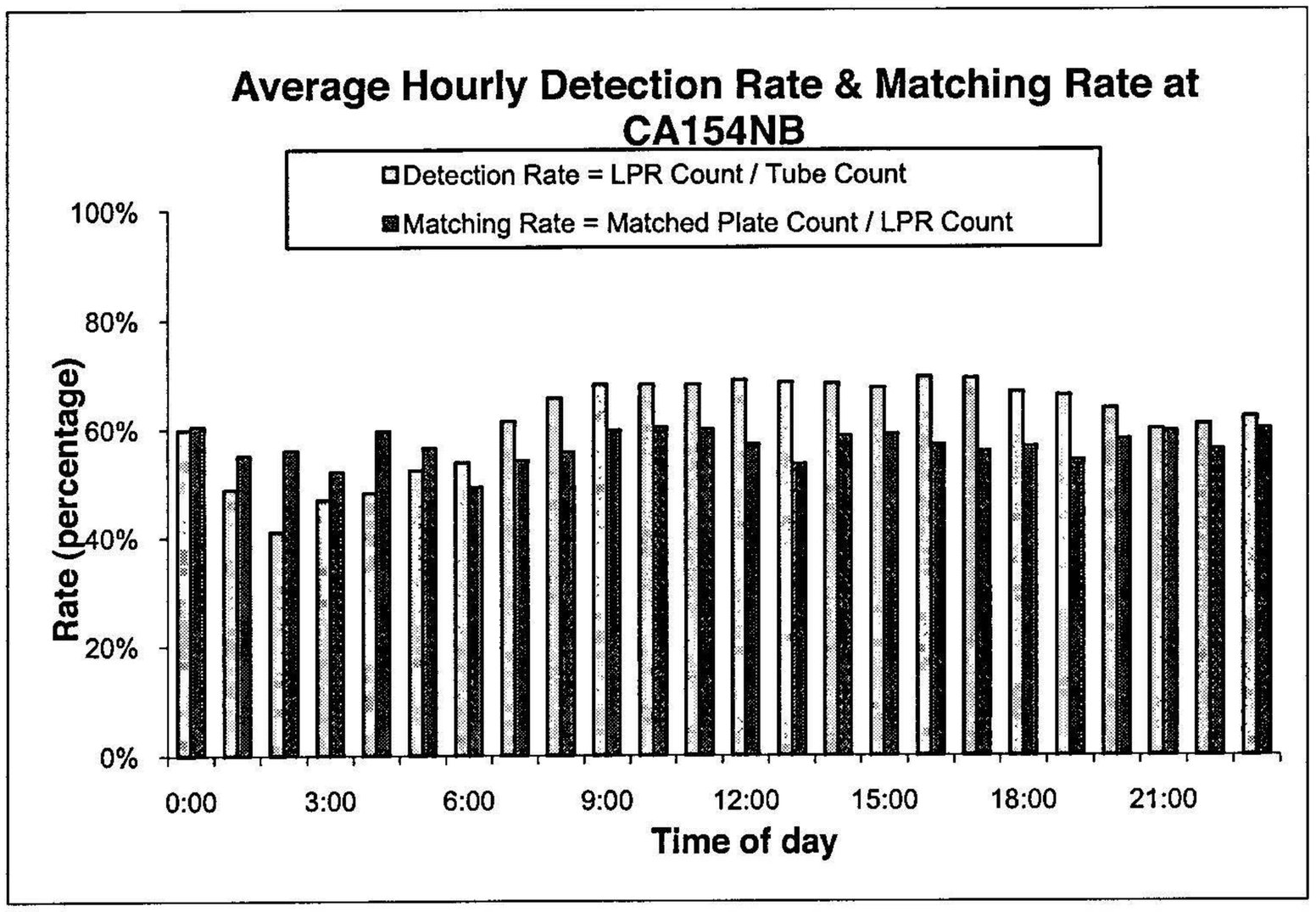


Figure 18: Performance of LPR Camera averaged across 4 days

4.2. License Plates Matching and Travel Times Calculation

We used a matching algorithm to match the License plate numbers for travel time estimations. Matching algorithm is a procedure that attempts to find an item within a list of entries. The procedure used in the present study is a variant of the modified Sequential Search Algorithm (SSA) as presented by B. Hellinga(5).

Let camera1 and camera2 located respectively at the upstream and at the downstream on a given direction of a corridor. A vehicle detected by camera1 may not be detected by camera2 because of exits between the two locations and the fact that the vehicle may change lane before arriving at the second camera. Data collected consist of license plates with timestamps. Let L1 a list that contents all logs coming from camera1 in chronological order, and L2 a list summarizing records from camera2 in chronological order also.

The modified SSA used in this paper attempt to find a "match" for each record of L2 within a dynamic range of timestamps in list L1. In order to make the search more efficient, two reference travel times were defined: the minimum travel time need by any vehicle to cross the segment (TTmin) and the maximum travel time for the trip (TTmax). TTmin is assumed to be the travel time corresponding to a speed of 90mph, and TTmax is the resulting travel time when a vehicle travels at 10mph. For a record having a time stamp t in list L2, the algorithm searches the matching between t-TTmax and t-TTmin (

Figure 19). The procedure as defined reduces the computational time. When the "match" is found, the travel time is calculated by the difference between the departure time and the arrival. Table 3 shows the summary of license plates matched for different segments and routes. Here "matching rate" is defined as the ratio of matched logs over the average recorded logs from camera1 and camera2. For CA-154, the matching rate varies between 14% and 58%. The low rates are for the vehicle match between Los Olivos and Santa Barbara, which has longer distance. On US-101, the average rate of matching license plates is

15% from Los Olivos to Ellwood, and 28% for individual segments of that stretch. The two segments, Ellwood to Goleta and Goleta to Santa Barbara have shown matching rates below 10%, which is reasonable because there are more ramps on this stretch. According to previous experiments, the LPR camera picks up 60%-70% of the through traffic randomly at all traffic states. Therefore, as long as we can get sufficient matched logs, they can represent the real traffic even with a low matching rate.

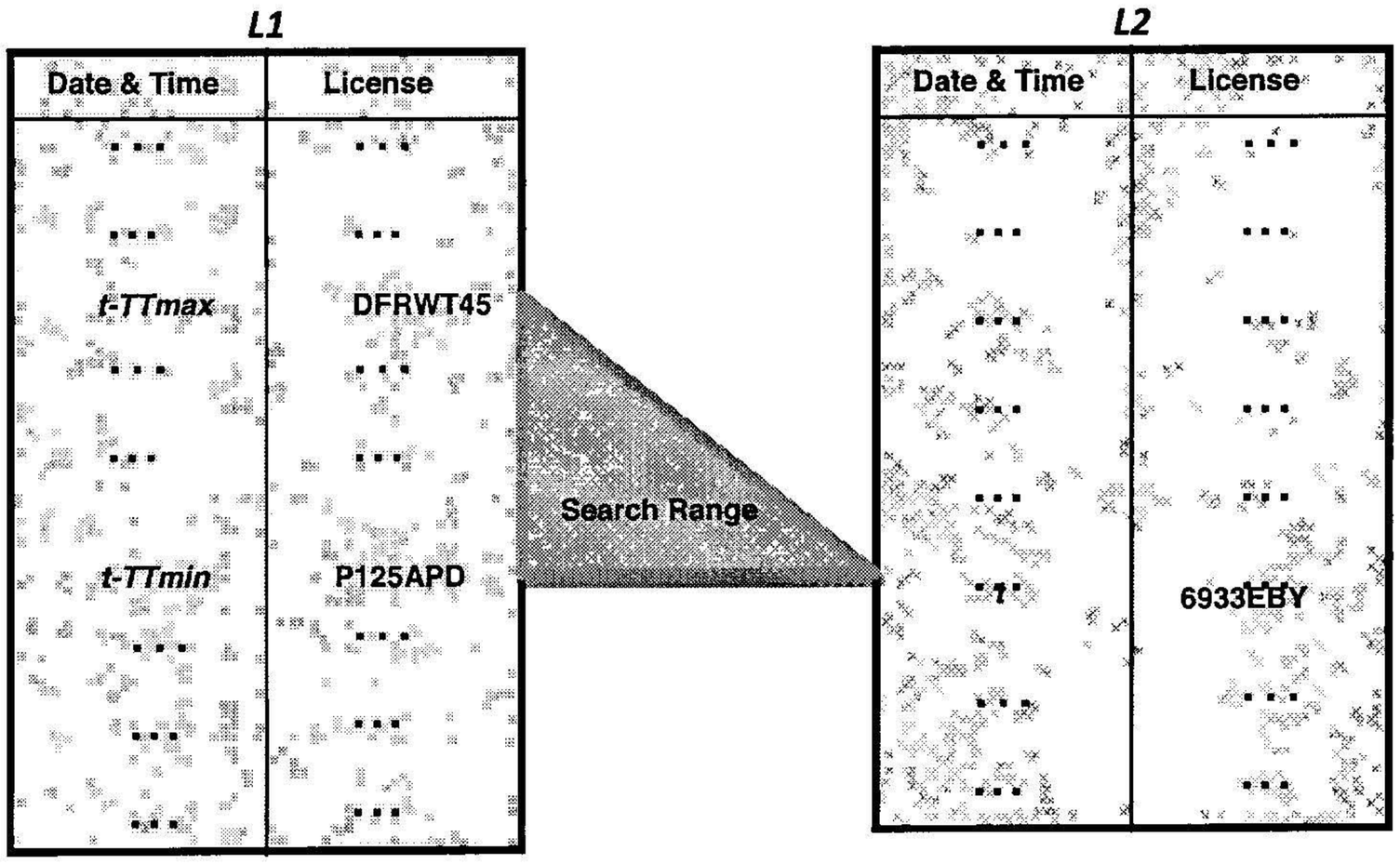


Figure 19: Principe of the Modified SSA

Table 3: Data Summary

	From	To	Length (miles)	Direction	Camera Logs		Matching Licenses	
					Origin	Destination	Total	(%)
CA-154	Los Olivos	Cachuma	16	NB	26 327	26 389	5 525	21
				SB	41 485	41 614	6 653	16
	Cachuma	Santa Barbara	15	NB	27 567	26 327	15 629	58
				SB	41 614	47 462	19 920	45
	Los Olivos	Santa Barbara	31	NB	27 567	26 389	4 370	16
				SB	41485	47 462	6 241	14
US-101	Los Olivos	Gaviota	19	SB	54 952	53 225	16 607	31
	Gaviota	Ellwood	19	SB	53 225	42 158	11 888	25
	Ellwood	Goleta	3.5	NB	26 355	27 757	1 219	5
				SB	54 760	55 063	6 782	12
	Goleta	Santa Barbara	5	NB	27 371	26 355	528	2
				SB	55 063	54 026	2 503	5
	Los Olivos	Ellwood	38	NB	110 904	120 585	17 006	15
				SB	80 036	69 125	12 256	16
	Ellwood	Santa Barbara	8.5	NB	76 545	100 548	2 228	2
				SB	81 727	81 497	4 263	5
	Los Olivos	Santa Barbara	46.5	NB	25 084	27 471	979	4
				SB	49 174	80 752	1 023	3

4.3. Travel Time Data Processing/Outlier Removal

Individual travel times obtained from the matching algorithm were plotted against departure times to check whether or not the data contain outliers. Figure 20 is an example of row individual travel time distributions on CA-154 Northbound on May, 09 2008 (Row travel time distribution for all segments and days are shown in Appendices.). Figure 20 also suggests that the raw travel time data content outliers.

To have a clear picture of travel time variation trend, the row data were filtered using the Median Absolute Deviation (MAD). MAD is a statistical measure of dispersion that detects outliers in a set of

univariate sample. MAD is more resistant to outliers than other statistical measures of dispersion. Let $(x_i)_{i=1,2,\ldots,n}$ a set of variables. The MAD is defined as:

$$MAD = median(\|x_{i-\tilde{x}}\|)$$

$$\overline{z_i} = 0.6745 \times \frac{x_{i-\tilde{x}}}{MAD}$$

Where

$\tilde{x}$ =*median* $(x_i))_{i=1,2,\ldots,n}$

$\overline{z_i}$ =*modified z-score*

0.6745 is chosen because the data are assumed to be normally distributed, under which $\sigma = \frac{MAD}{0.6745}$. Thus, the modified z-score $\overline{z_i}$ approximately follows a standard normal distribution. Outliers are identified by comparing the modified z-score to a cut point. If $\|\overline{z_i}\|$>2.58 then x_i is flagged as an outlier (corresponding to a significance level of less than 1%). The outliers can be caused by incorrect matching, but are presumed to be mainly caused by drivers who leave the routes temporarily and return some time later (i.e. Solvang, which is a popular place for visitors and locates between Los Olivos and Santa Barbara). In this paper, $(x_i)_{i=1,2,\ldots,n}$ represents individual travel time for every 30 minutes interval of a day.

Raw travel time data was filtered for all segments or routes. Figure 20 and Figure 21 are examples of raw travel time data and processed travel times on CA-154 Northbound on May,10 2008 (Raw and processed travel time distribution for all segments and days are shown in Appendices). Figure 21 shows that CA-154 didn't experience any evident congestion on that day.

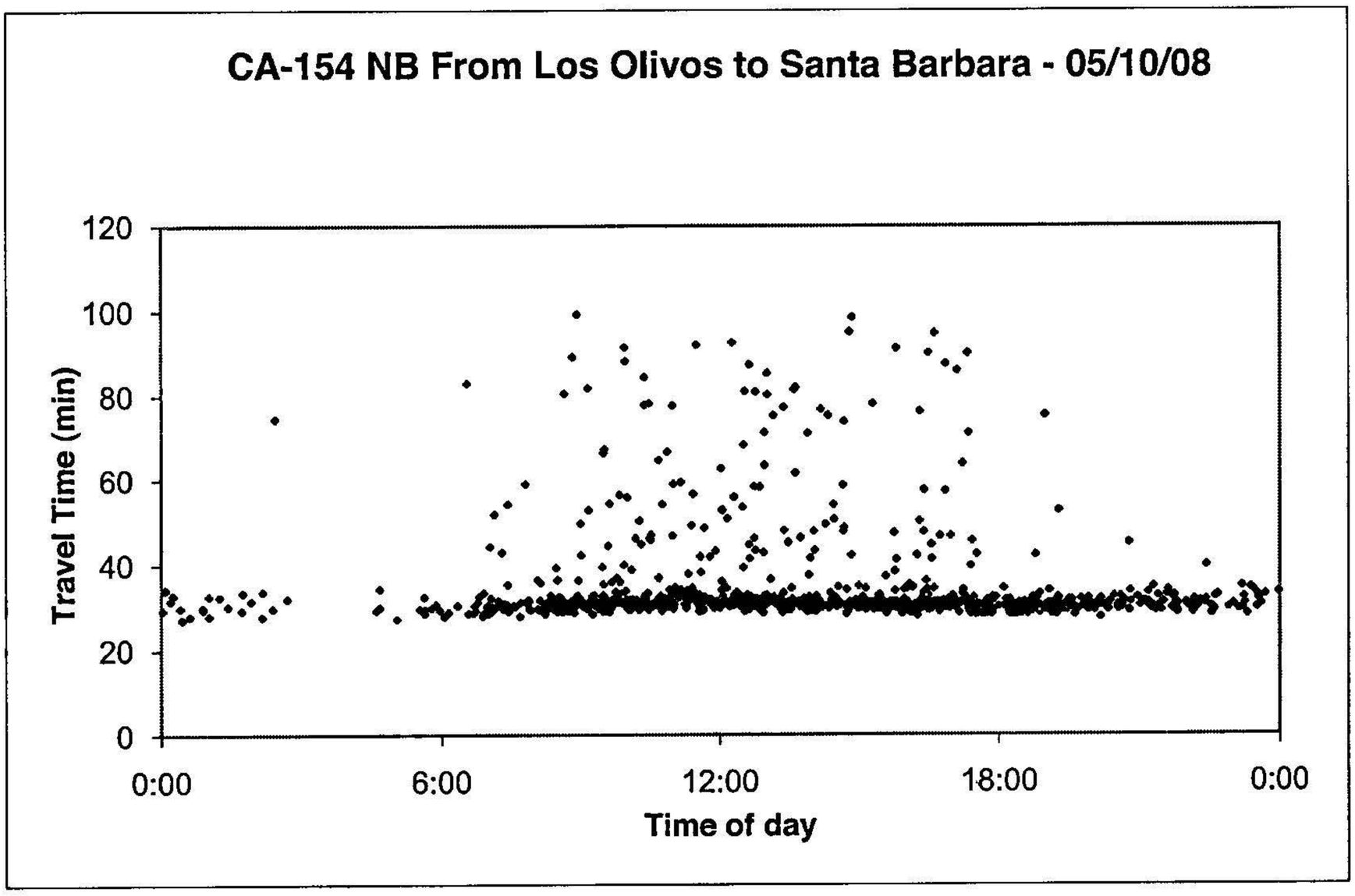


Figure 20: Raw Individual Travel Times

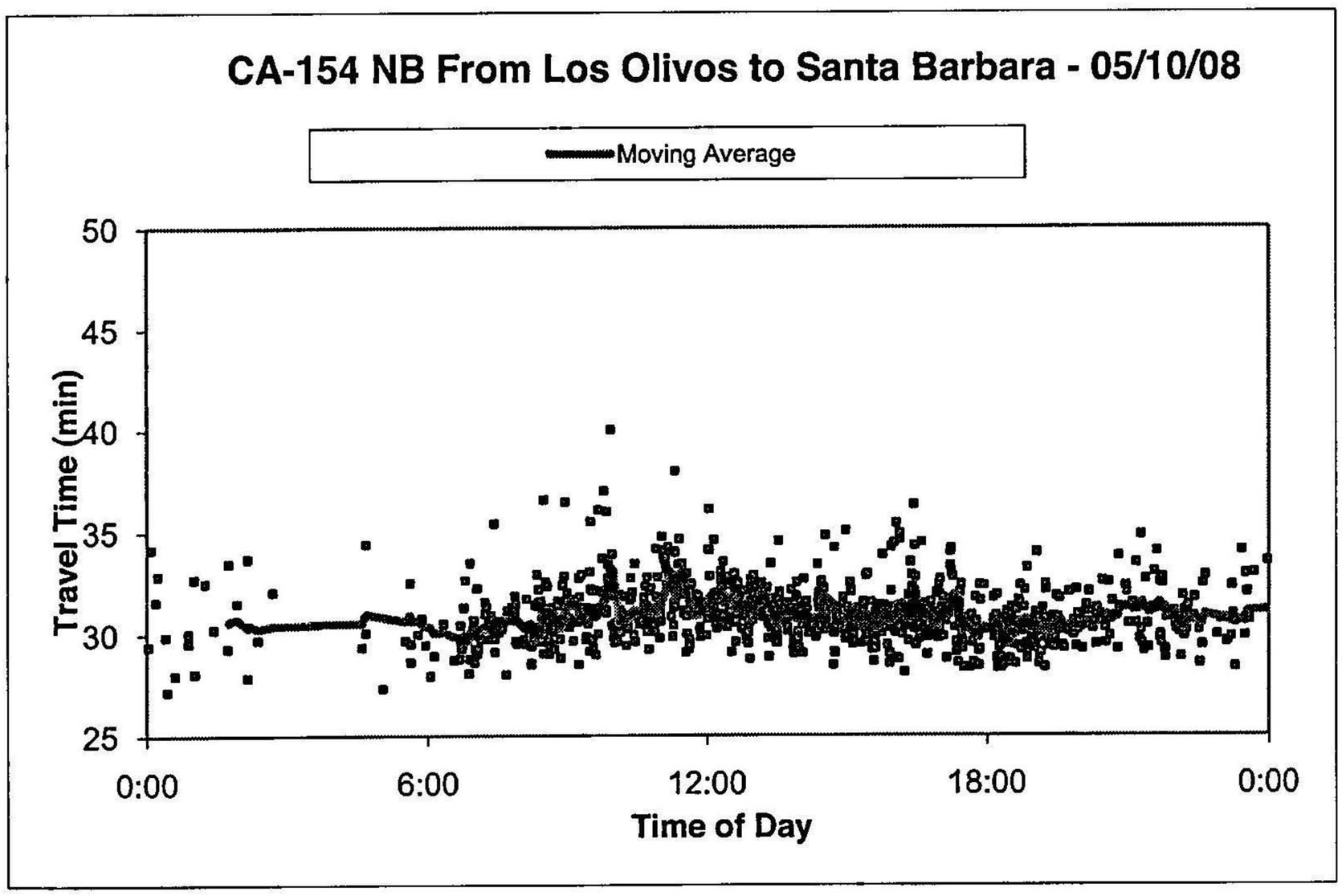


Figure 21: Processed Travel Times

4.4. Travel Time Comparison and Variability Analysis

Travel time variability is caused either by change in traffic demand, an incident in the traffic streams or different driving behaviors. *(6)* and *(7)* defined travel time variability as an aggregate of three components: day-to-day variability, within-day variability, and vehicle-to-vehicle variability. Day-to-day variability shows how travel time varies for trips departing at the same time widow over many days. A smaller day-to-day variation means that traffic pattern is recurrent on the study segment or route. With-in-day variability measures how travel time fluctuates for the same trip departing at different time intervals of a single day. One of the major causes of within-day travel time variation is peak hours' congestion. Vehicle-to-vehicle travel time variability measures the difference in travel times for a short period of time. It is related to vehicle type and driver's aggressiveness. However, we only consider the day-to-day variation and with-in-day variation as they are more related to the research objective.

Travel times are grouped into 3-hour intervals for each day to account for different periods: early morning (6:00-9:00); morning (9:00-12:00); early afternoon (12:00-15:00); afternoon (15:00-18:00); evening (18:00-21:00). Travel times between 9:00pm and 6:00am are discarded because the routes are very lightly traveled at night. Based on the previous processed data, there is no prolonged congestion that extends to the next day. Therefore, travel times in different time intervals of the same day and in different days are assumed to be independent. In this regard, day-to-day variation analysis is to test whether there is variation among travel times in different days over the same time interval; with-in-day variation analysis, on the other hand, is to test whether there is variation among travel times in different time intervals over the same day.

We implemented "modified one-way ANOVA test" for the travel time variability analysis, to incorporate the statistical properties with an engineering meaning. Firstly, some traffic knowledge was needed to be taken into account for the statistical test. For example, for CA-154 between Los Olivos and Santa Barbara, the trip length is about 35 mile and speed limit is 55 mph. However, if drivers travel at around 55 mph to 60 mph in a free flow state, the average travel time may differ up to 3 minutes, with average travel time of about 35 min to 38 min. Variation within this range should be considered insignificant since no drivers need help from CMS if they know the average travel time only varies up to 3 minutes on this 35 mile long stretch. In light of this, we decide to use 3 minutes as the threshold for this stretch and the NULL hypothesis in our test would be "mean travel times among different groups differ by less than 3 minutes on CA154 between Los Olivos and Santa Barbara" (instead of that "mean travel times among different groups are equal"). In a similar way, we set the threshold of 4 minutes for route US101, which has a longer length of about 46 mile.

The metrics for the proposed method will be described below. A step-by-step analysis using travel time data for US101 from Ellwood to Los Olivos will be described in the appendix.

4.4.1. Metrics for the travel time variation analysis

Step 1: Conduct a one-way ANOVA test for all the groups of data. The NULL hypothesis for ANOVA test is that "the means (averages) from different groups are equal".

Step 2: Examine the ANOVA test results from step 1. If the NULL hypothesis turns out to be true, the analysis for these groups of data stops and we claim that we failed to reject the hypothesis ("mean travel time among these groups are equal"). While if the NULL hypothesis is rejected, multiple comparisons will be conducted using Bonferroni t-test.

Step 3: Conduct multiple comparisons with Bonferroni t-test to test the modified NULL hypothesis that "travel times among different groups differ by less than t minutes", in which "t" is the threshold we set for different routes and segments. We can do multiple comparisons for certain groups after the ANOVA test. Multiple comparisons mainly aim to find out the estimated difference between any two groups, and thereafter, which groups have the largest difference. Therefore, what we need to do is to test the hypothesis that "the difference between any two groups' means is less than t min." If test result from any two groups rejects the hypothesis, the proposed NULL hypothesis "mean travel times among different time intervals differ by less than t minutes" is rejected; otherwise we do not have sufficient evidence to reject the NULL hypothesis and claim there is no significant variation among different groups of travel time.

Here we will briefly introduce Bonferroni Method. The idea is very simple. If k null hypotheses are to be tested, a desired overall type I error rate of at most α can be guaranteed by testing each null hypothesis at level α/k. An equivalent derivation of Bonferroni Method is, if k confidence intervals are each formed to have confidence level 100(1-α/k)%, they all hold simultaneously with confidence level at least 100(1-α)%.A detailed description of step 3 is as follows:

Take any two groups i_1 and i_2, the confidence interval for the difference of mean of group i_1 and i_2 is:

$$\text{Sample mean difference} \pm t_{value} \times S_p \times \sqrt{\frac{1}{j_1}+\frac{1}{j_2}}$$

Where:

j_1, j_2: the count of data in group i_1 and i_2;

S_p: the square root of the mean square for error within groups (which can be derived from the ANOVA test results in Step 1).

t_{value}: degree of freedom, equals to degree of freedom within groups in ANOVA test; probability level for the t-value equals to α/k; where k is the total number of pair-wise comparisons: $\frac{n(n-1)}{2}$.

The proposed NULL hypothesis that "mean travel times among different time intervals differ by less than t minutes" is equivalent to:

$$\text{Absolute value of sample mean difference} < t_{value} \times S_p \times \sqrt{\frac{1}{j_1}+\frac{1}{j_2}} + t.$$

Theoretically, we need to do this test for all k pairs, but practically, we only need to consider those pairs that have very large mean difference and/or very large counts. These pairs can be easily picked out by glance or a simple computer algorithm when we have too many pairs (not needed in our study). If the above inequity for two groups of data holds, the NULL hypothesis that "mean travel time between the two time intervals is less than t minute" is true. This method involves little computation besides the

ANOVA test (which can be done by software like Excel), and is flexible in terms of the threshold time difference we'd like to test.

4.4.2. Travel time variation analysis for Route US-101 and CA-154.

Firstly we conduct with-in-day travel time variation analysis for the two routes using the proposed "modified one-way ANOVA test". Threshold for the two routes are set to be 4 minutes and 3 minutes respectively as described before. The results are summarized below:

Table 4: With-in-day travel time variation analysis

Route	*Days tested*	*Days null hypothesis holds*	*Days null hypothesis gets rejected*
CA-154 Southbound (Los Olivos-Santa Barbara)	7	7	0
CA-154 Northbound (Santa Barbara-Los Olivos)	4	4	0
US-101 Southbound* (Los Olivos-Santa Barbara)	5	4	1
US-101 Northbound* (Santa Barbara-Los Olivos)	10	8	2

*for route US-101, due to its longer length and more lanes and ramps, we could not get enough matched data only from cameras located at the two ends of the routes. Thus we utilized the matched data for the same day from segment Los Olivos-Ellwood and Ellwood-Santa Barbara; and aggregated them into 5 minute average and added the two travel times up to represent the travel time on the whole route.

The results show little with-in-day travel time variation on the two routes except a few days. Moderate to significant congestion occurred on those days that NULL hypothesis was rejected. However there is no evidence that the congestion is recurrent. Given the congestion only occurred on some isolated days, it is highly possible that it is caused by accidents or short-term work-zone activity. One day that Null hypothesis got rejected on US-101 Northbound is June 20th, 2008, on which day a significant congestion due to road construction was observed in the afternoon lasting for about 3 hours. Vehicle travel times on this day are shown in Figure 22.

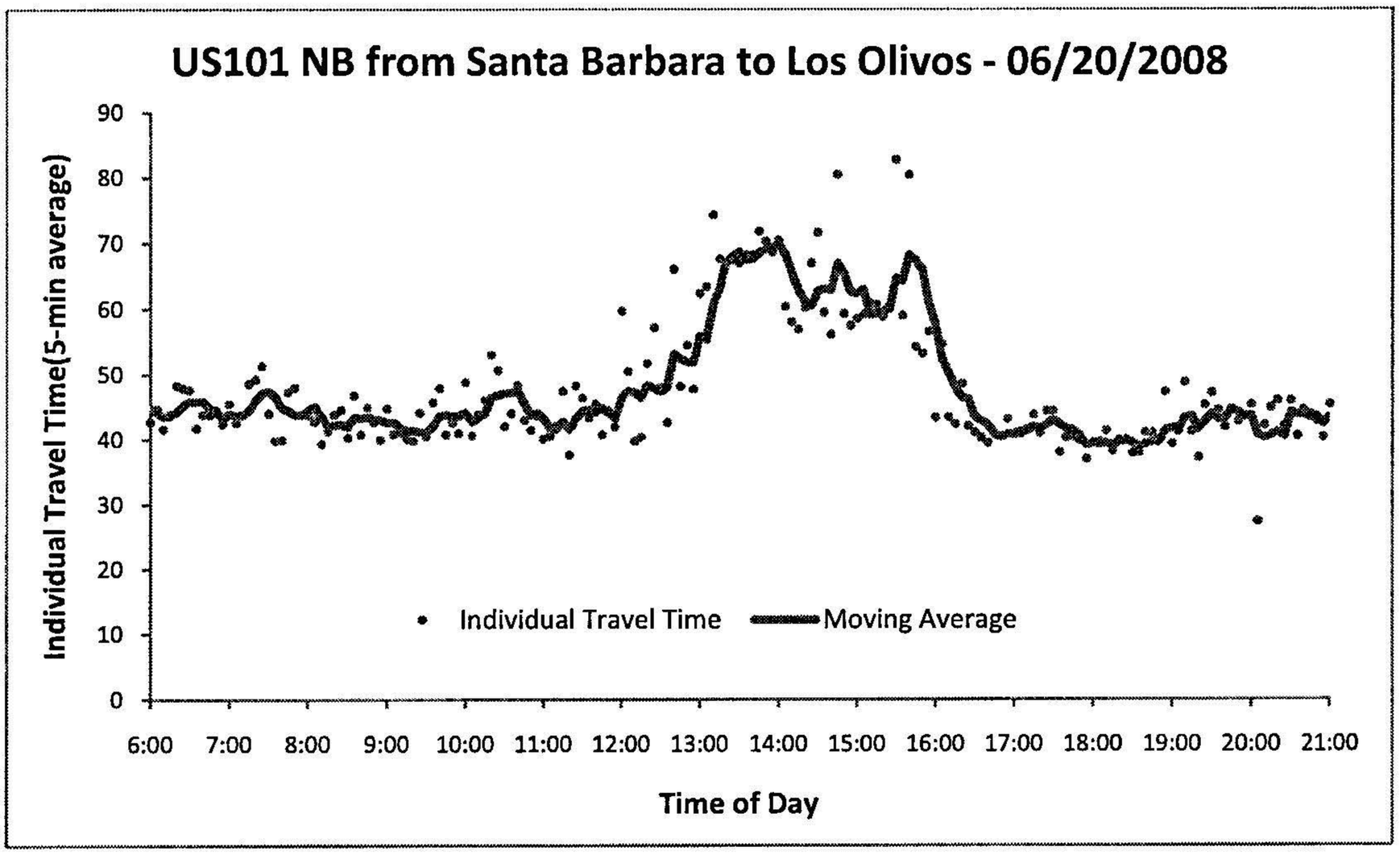


Figure 22: Travel time on June 20th on US101 Northbound

Day-to-day travel time variation analysis is conducted next and the results are shown in Table 5. (As described before, we divided every day into five 3-hour time intervals to capture the different traffic states during the day.)

Table 5: Day-to-day travel time variation analysis

Route	*Intervals tested*	*Intervals null hypothesis holds*	*Intervals null hypothesis gets rejected*
CA-154 Southbound (Los Olivos-Santa Barbara)	5	5	0
CA-154 Northbound (Santa Barbara-Los Olivos)	5	5	0
US-101 Southbound* (Los Olivos-Santa Barbara)	5	5	0
US-101 Northbound* (Santa Barbara-Los Olivos)	5	3	2

* see notes for Table 4.

The results show little day-to-day travel time variation on CA-154 and on US-101 Southbound. However, US-101 Northbound shows significant day-to-day variation. The time intervals that have significant travel time variation are 12:00-15:00 and 15:00-18:00.

Both the with-in-day and day-to-day travel time variation analysis reveals that traffic on US-101 has more fluctuations than on route CA-154. In light of this, we will focus on US-101 in the future variation analysis to give more insights into which segment of this route caused the variations.

4.4.3. Travel time variation analysis for the two segments of US-101

US-101 is long and includes couples of on/off ramps between Ellwood and Santa Barbara. Therefore, we divided the stretch of US-101 into two segments:

1. Segment 1: from Los Olivos to Ellwood. This 2-lane 38-mile stretch of US-101 has no major exit or ramp. (see Figure 8)

2. Segment 2: from Ellwood to west of Santa Barbara. This segment is shorter (8.5 miles) and has at least 5 intersections. (see Figure 9)

Considering the different length of the two segments (Segment 1 is more than 4 times as long as Segment 2), we use 3 minute and 1 minute as the thresholds for Segment 1 and Segment 2 respectively, i.e. the NULL hypothesis for Segment 1 would be "mean travel time on this segment among different groups differ by less than 3 minute." On the other hand, the NULL hypothesis for Segment 2 is "mean travel time on this segment among different groups differ by less than 1 minute." Results for with-in-day travel time analysis for the two segments are shown in Table 1 (note that the data were recorded in different phases as illustrated before, thus the days we have for the two segments are different).

Table 6: With-in-day travel time variation analysis

Segment	*Days tested*	*Days null hypothesis holds*	*Days null hypothesis gets rejected*
Segment 1 Southbound (Los Olivos-Ellwood)	8	8	0
Segment 1 Northbound (Ellwood-Los Olivos)	20	19	1
Segment 2 Southbound (Ellwood-Santa Barbara)	13	11	2
Segment 2 Northbound (Santa Barbara-Ellwood)	12	11	1

The results show there is little with-in-day travel time variation on the two segments on most days except a few days on Segment 2. The day that Segment 1 northbound gets rejected is again June 20th, 2008. However, it shows little variation on Segment 2 on this day, which implies that the congestion on this day only occurred between Ellwood and Los Olivos. Vehicle travel times on the two segments are shown in Figure 23 and Figure 24. It's clear from the two figures that congestion only occurred in Segment 1.

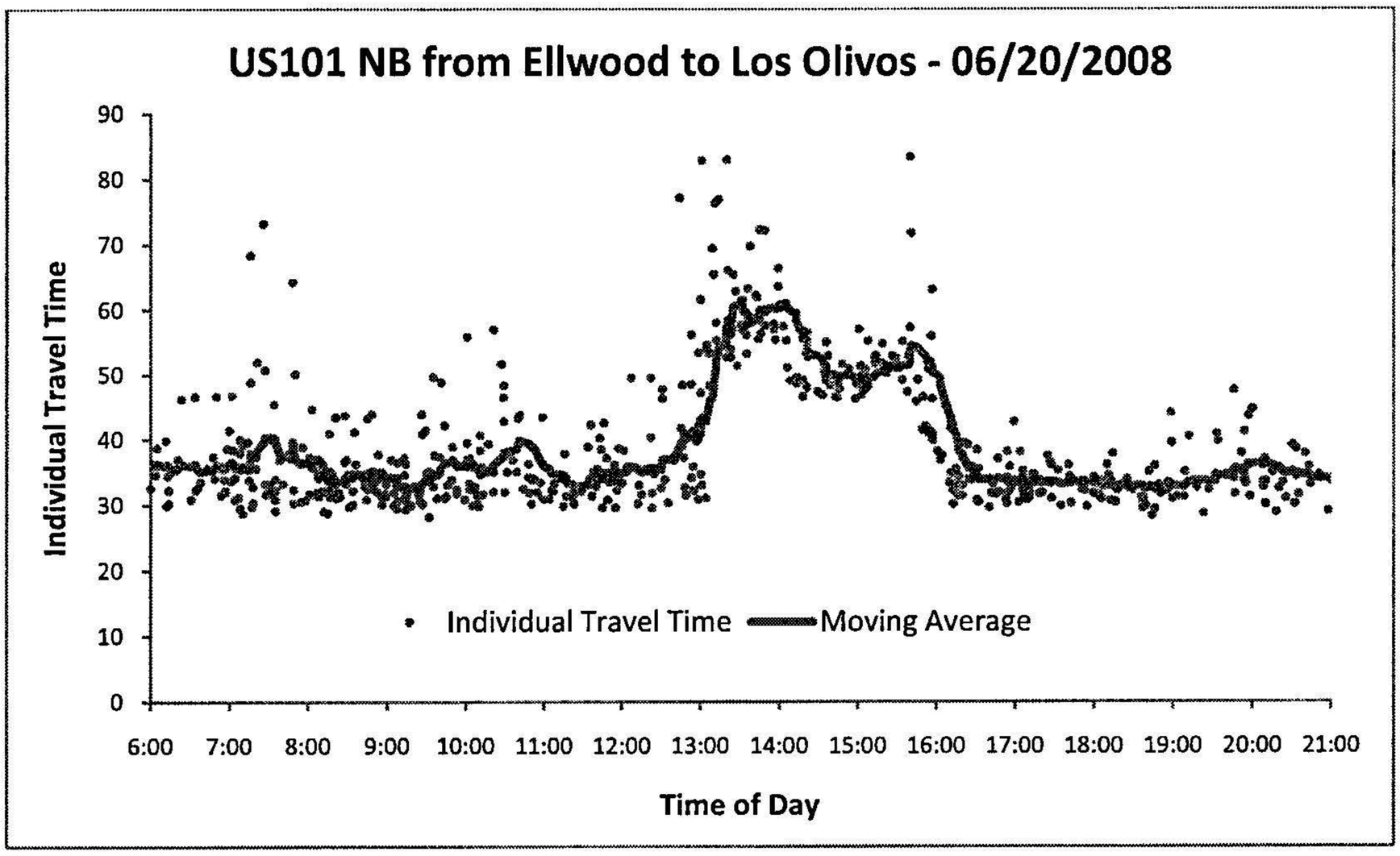


Figure 23: Travel time on June 20th on Segment 1

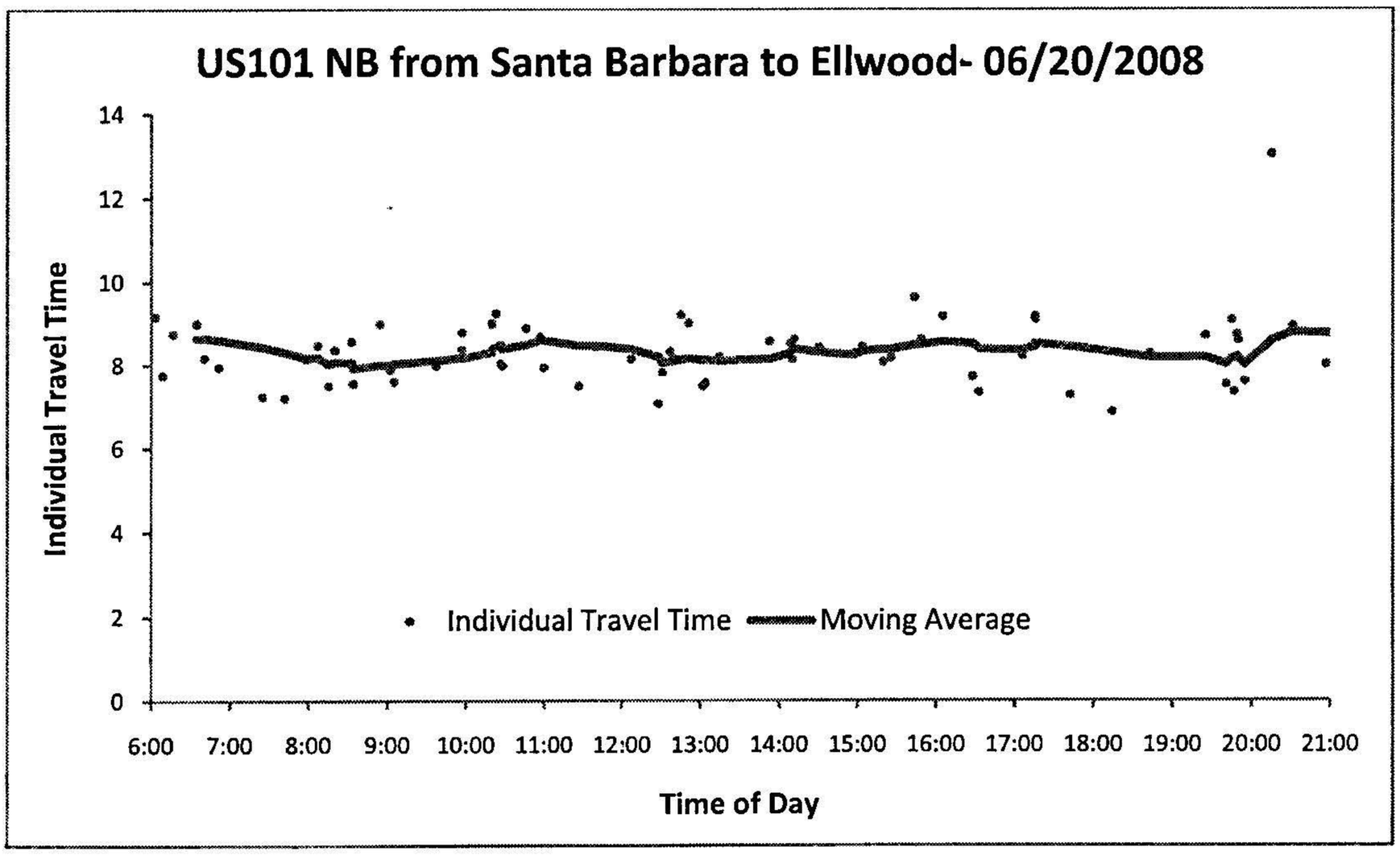


Figure 24: Travel time on June 20th on Segment 2

There are more days on Segment 2 that have significant travel time variation. Those days are: June 27th, June 30th, and July 24th, all of which are weekdays. Further investigation of the data shows that all congestions occur in the afternoon, though they are not restricted to any specific time period. Travel

times on June 30th and July 24th are shown in Figure 25andFigure 26 for illustration purpose. Without a clear pattern of recurrent congestion and without the knowledge of what happened on those days, we can only conclude that traffic on this segment is less predictable and more vulnerable to congestion.

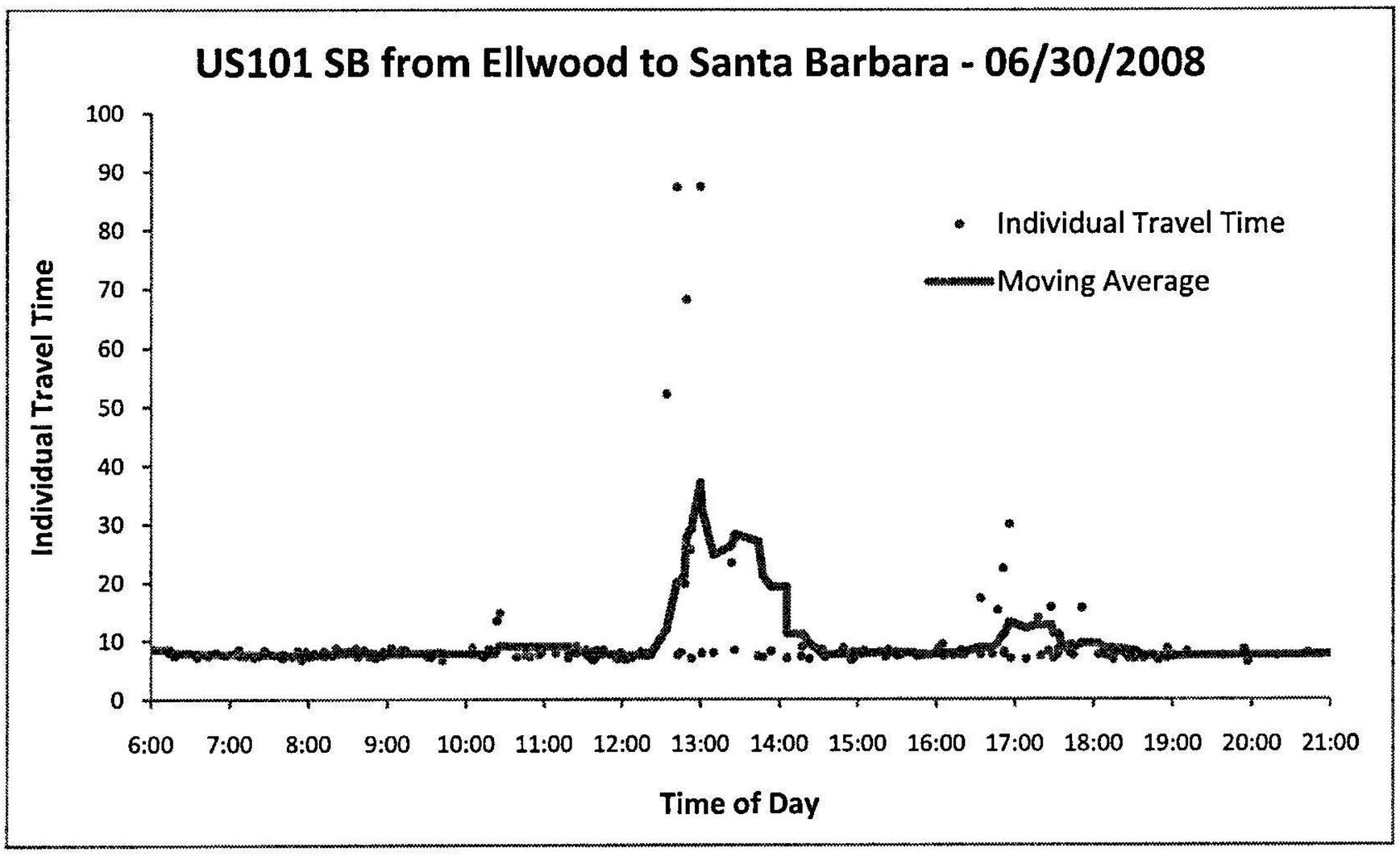


Figure 25: Travel time on June 30th on Segment 2

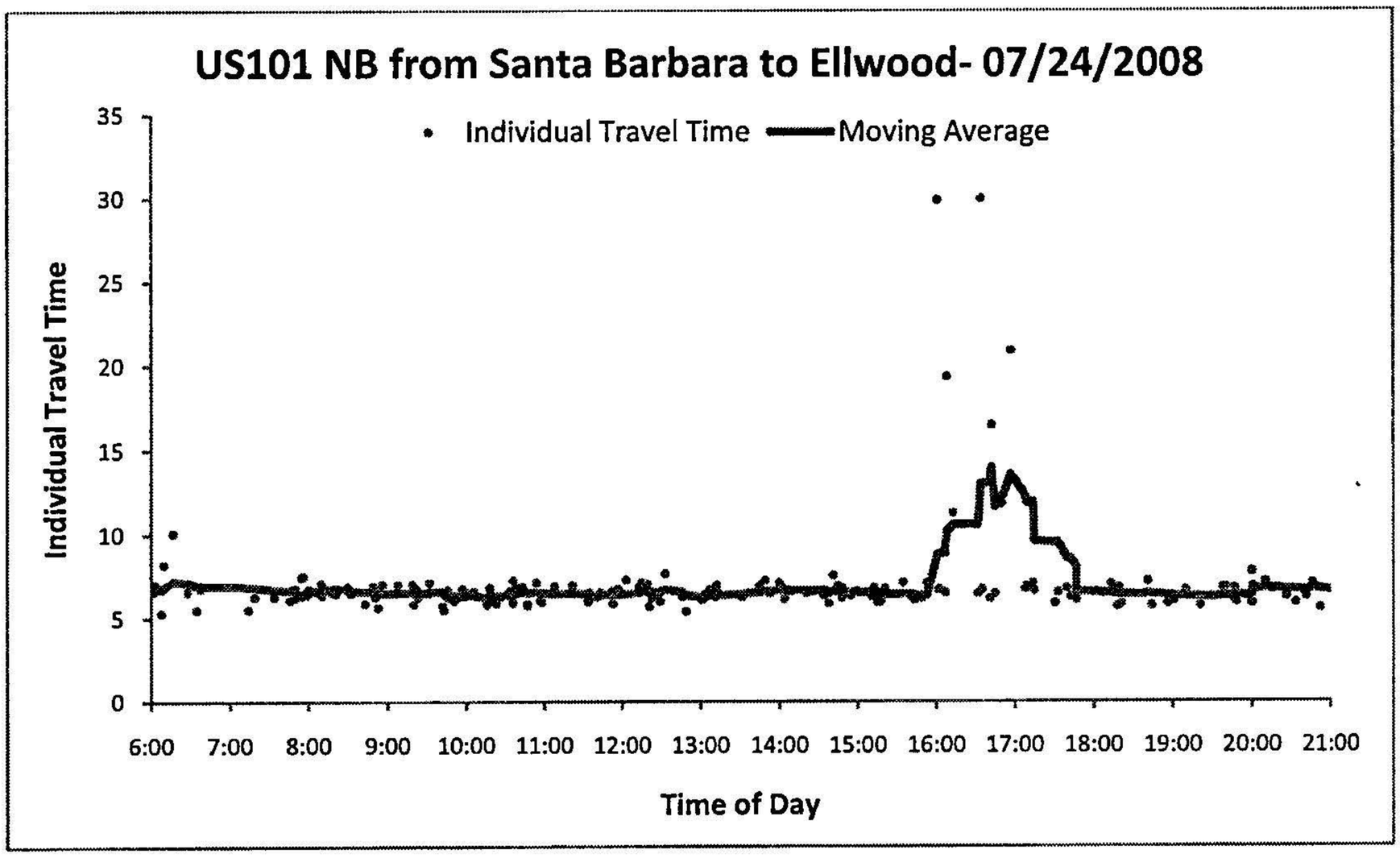


Figure 26: Travel time on July 24th on Segment 2

Day-to-day travel time variation analysis is conducted next and the results are shown in Table 7. Considering June 20th on Segment 1 might be caused by accident or other special events and thus are not representative of the normal traffic states of this segment, we exclude this day in the day-to-day travel time variation analysis.

Table 7: Day-to-day travel time variation analysis

Segment	*Intervals tested*	*Intervals null hypothesis holds*	*Intervals null hypothesis gets rejected*
Segment 1 Southbound (Los Olivos-Ellwood)	5	5	0
Segment 1 Northbound (Ellwood-Los Olivos)	5	2	3
Segment 2 Southbound (Ellwood-Santa Barbara)	5	2	3
Segment 2 Northbound (Santa Barbara-Ellwood)	5	1	4

The results show there is little day-to-day travel time variation on Segment 1 Southbound from Los Olivos to Ellwood. However, Segment 2 of US-101 has significant day-to-day variation, as well as Segment 1 Northbound. Further investigation of the data from Segment 1 Northbound shows that all the variations that cause the test to reject the Null hypothesis are due to the travel time difference between weekdays and weekends. There was no exception. A detailed multiple comparisons are shown in Table 8. In light of this, we separate weekdays and weekends for this segment and conduct the

"modified one-way ANOVA test" for weekdays and weekends separately. The results are in Table 9 (June 20th is still excluded). Therefore, we can conclude there is no significant day-to-day travel time variation on this segment among weekdays or among weekends; however, travel times show evident difference between weekdays and weekends. This finding will be confirmed again in section 4.5.

Table 8: Multiple comparison results for Segment 1

Time Interval	Test results	Multiple comparison: pairs that get rejected	
		large mean	small mean
6:00-9:00	Rejected	Jun 18 (wed)	Sep 20 (Sat)
		Jun 19 (Thu)	Sep 20 (Sat)
9:00-12:00	Rejected	Jun 4 (wed)	Sep 21 (Sun)
		Jun 11 (wed)	Sep 21 (Sun)
		Jun 16 (Mon)	Sep 21 (Sun)
12:00-15:00	Rejected	Jun 18 (wed)	Sep 21 (Sun)
		Jun 19 (Thu)	Sep 20 (Sat)
		Jun 19 (Thu)	Sep 21 (Sun)
15:00-18:00	Holds	-----	
18:00-21:00	Holds	-----	

Table 9: Day-to-day travel time variation analysis for Segment 1

Day type	*Total days*	*Intervals tested*	*Intervals null hypothesis holds*	*Intervals null hypothesis gets rejected*
weekdays	11	5	5	0
weekends	8	5	5	0

On the other hand, a multiple comparison for Segment 2 did not find a similar pattern. Many pairs between weekdays get rejected in the multiple comparisons too, though high travel times usually occur on weekdays only. Thus the only conclusion we can come to is this segment is more vulnerable to congestion on weekdays than on weekends. However, during weekdays, there can still be significant day-to-day travel time variation. The travel time is variable. This conclusion is reasonable given the segment's adjacency to Santa Barbara and high number of ramps and intersections.

4.5. Travel Time Comparison between CA-154 and US-101

In this part, we will compare the average travel time between the two routes on both weekdays and weekends. Travel times are averaged across days for northbound and southbound traffic separately (Figure 27- Figure 34). After reviewing all the figures, we can conclude that:

1. Travel times on CA-154 show little variation between weekdays and weekends; and across different time of day (Figure 27 and Figure 28). There is no evident recurrent peak hour on this route and travel time is between 30 to 35 minutes for both directions all the time.
2. There is usually an early afternoon rush (around 11:00-14:00) and an afternoon rush (around 16:00-18:00) on US-101, especially on weekdays (Figure 29 and Figure 30). The noon rush

between 11:00-14:00 on southbound traffic during weekdays is considerable (Figure 30). On weekdays, the travel time on US101 southbound during rush hour (about 57 minutes) is 15 minutes more on average than the free flow travel time (about 42 minutes).

3. Travel times on US-101 during weekdays are usually slightly longer than during weekends, indicating more traffic on weekdays (Figure 29 and Figure 30). This confirmed the analysis in section 4.4.3.

4. The comparison results show that travel time on US101 is usually 10 minutes or more than on CA-154 and is more prone to traffic fluctuations (Figure 31 - Figure 34).For example, during the peak hours, travelling on US-101 may take almost twice as long as on CA-154 (Figure 32).

All the above findings indicate that taking US-101 provides no time advantage over route CA-154.

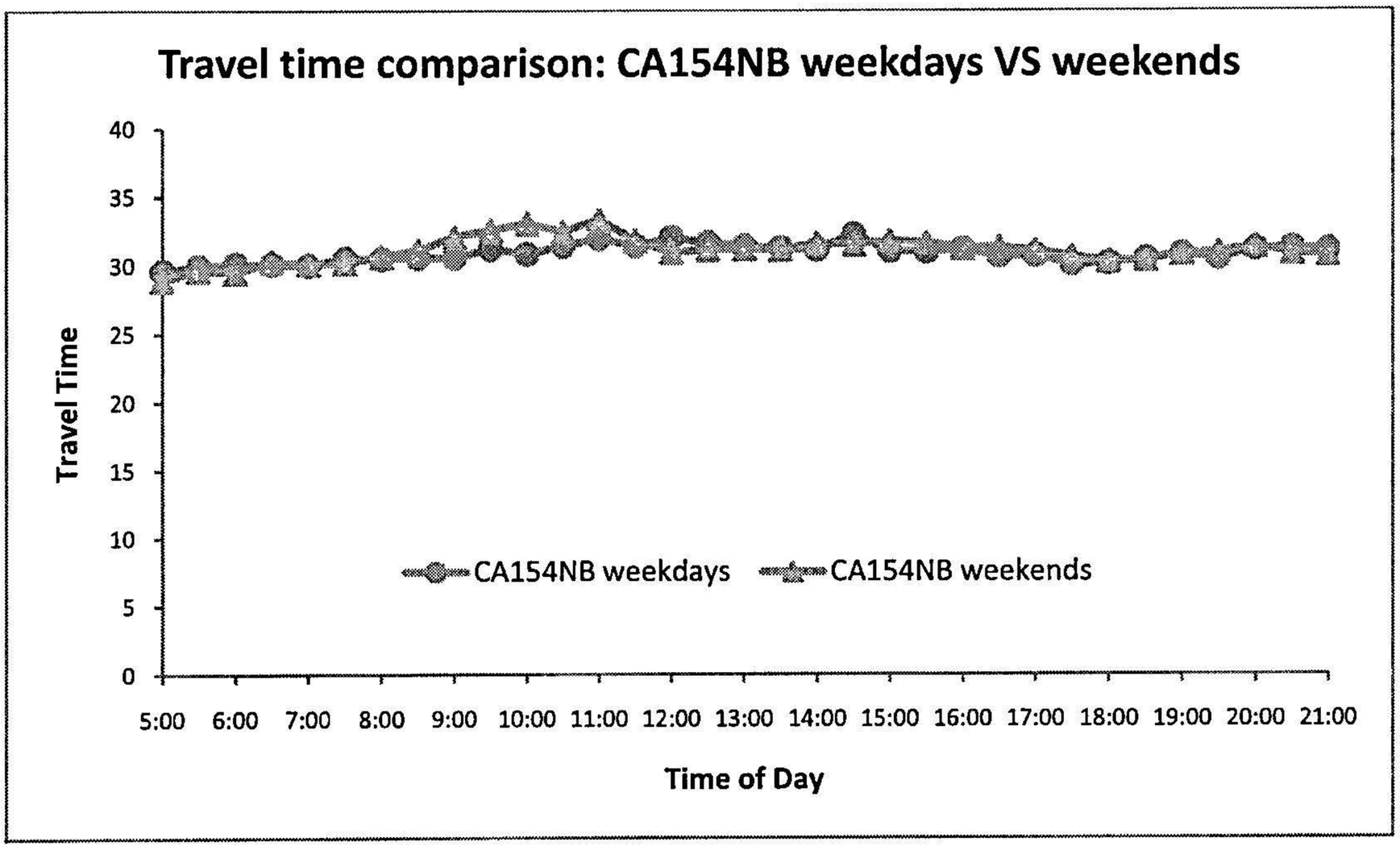


Figure 27: CA154 Northbound comparison

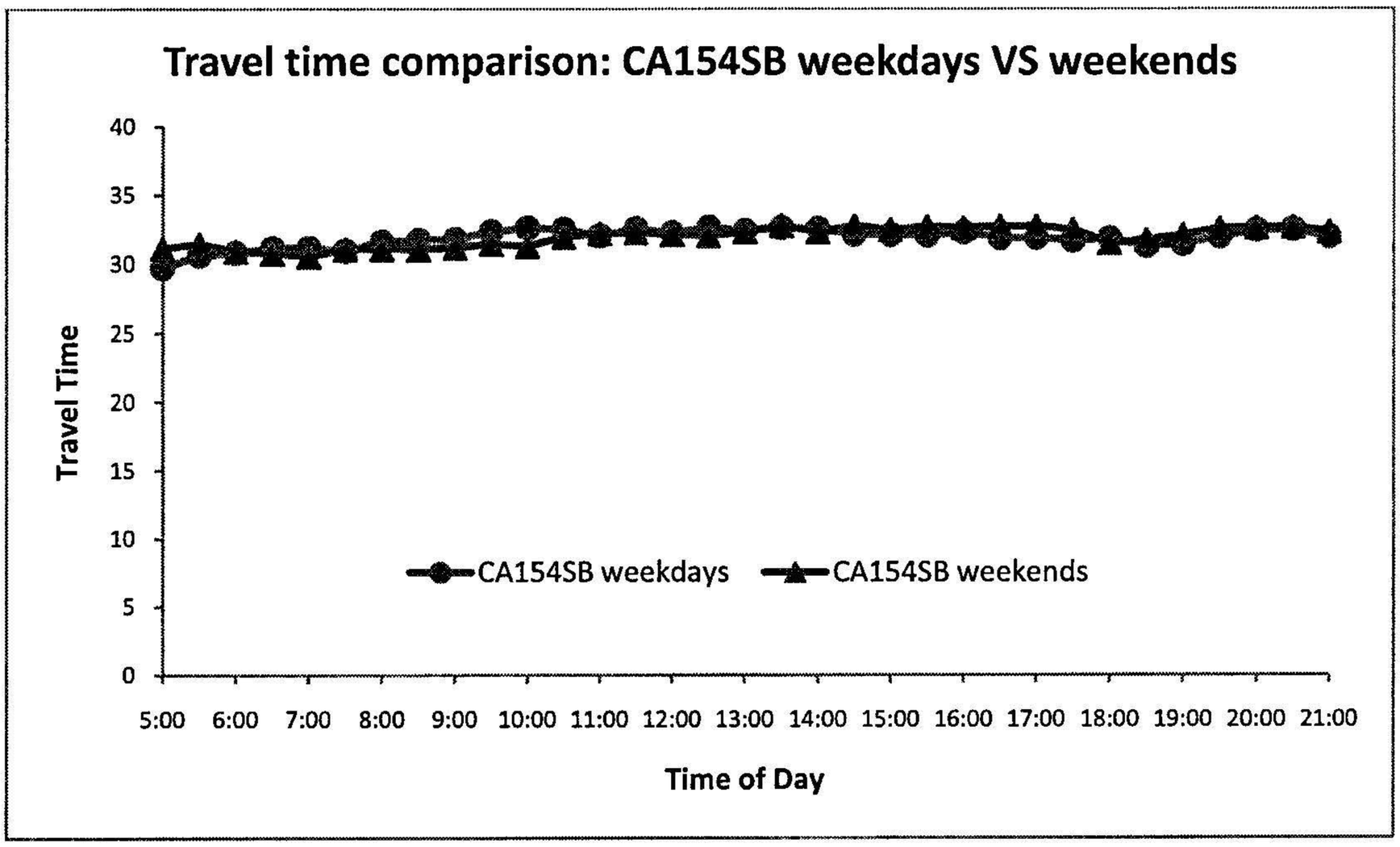


Figure 28: CA154 Southbound comparison

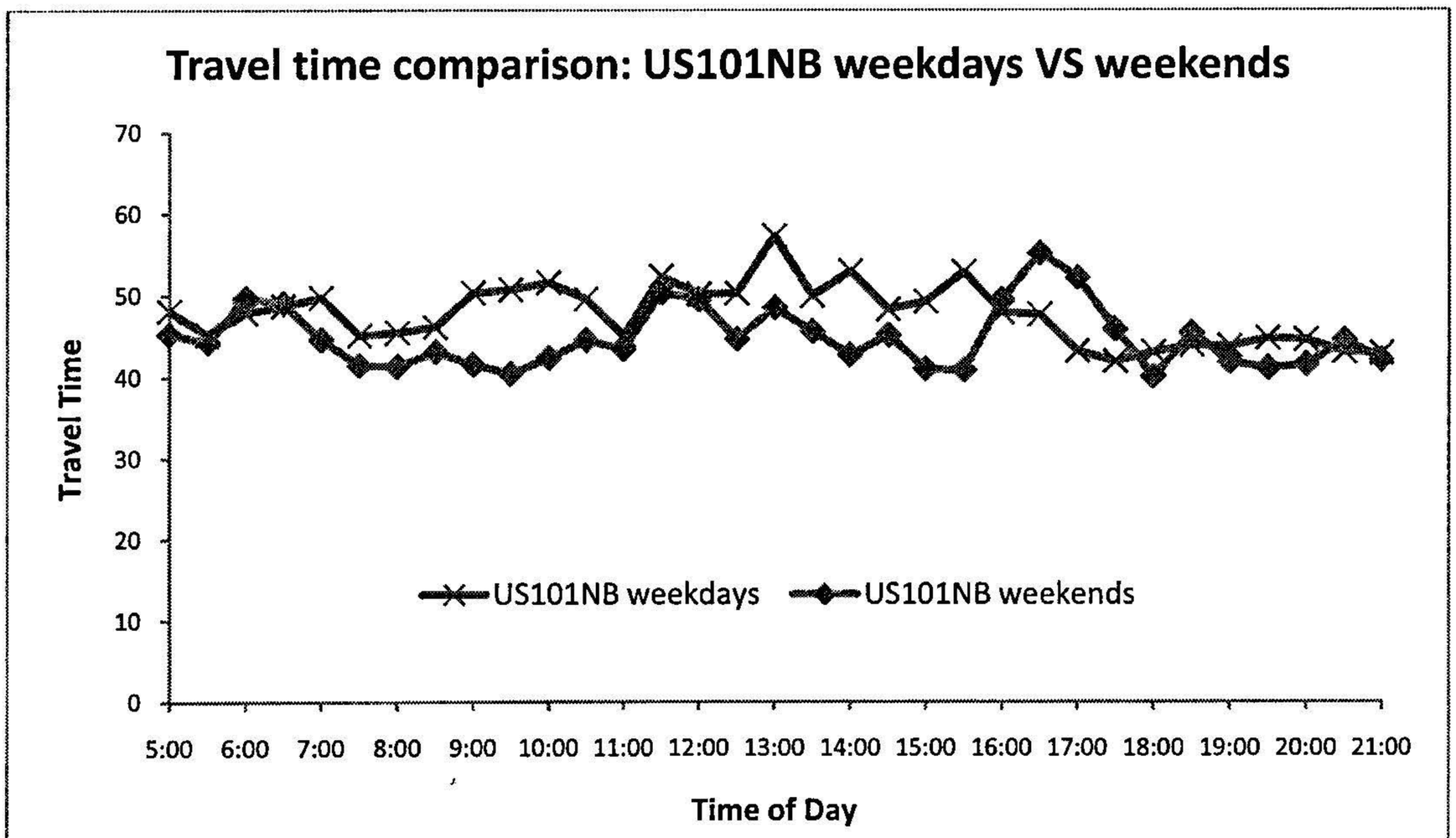


Figure 29: US101 Northbound comparison

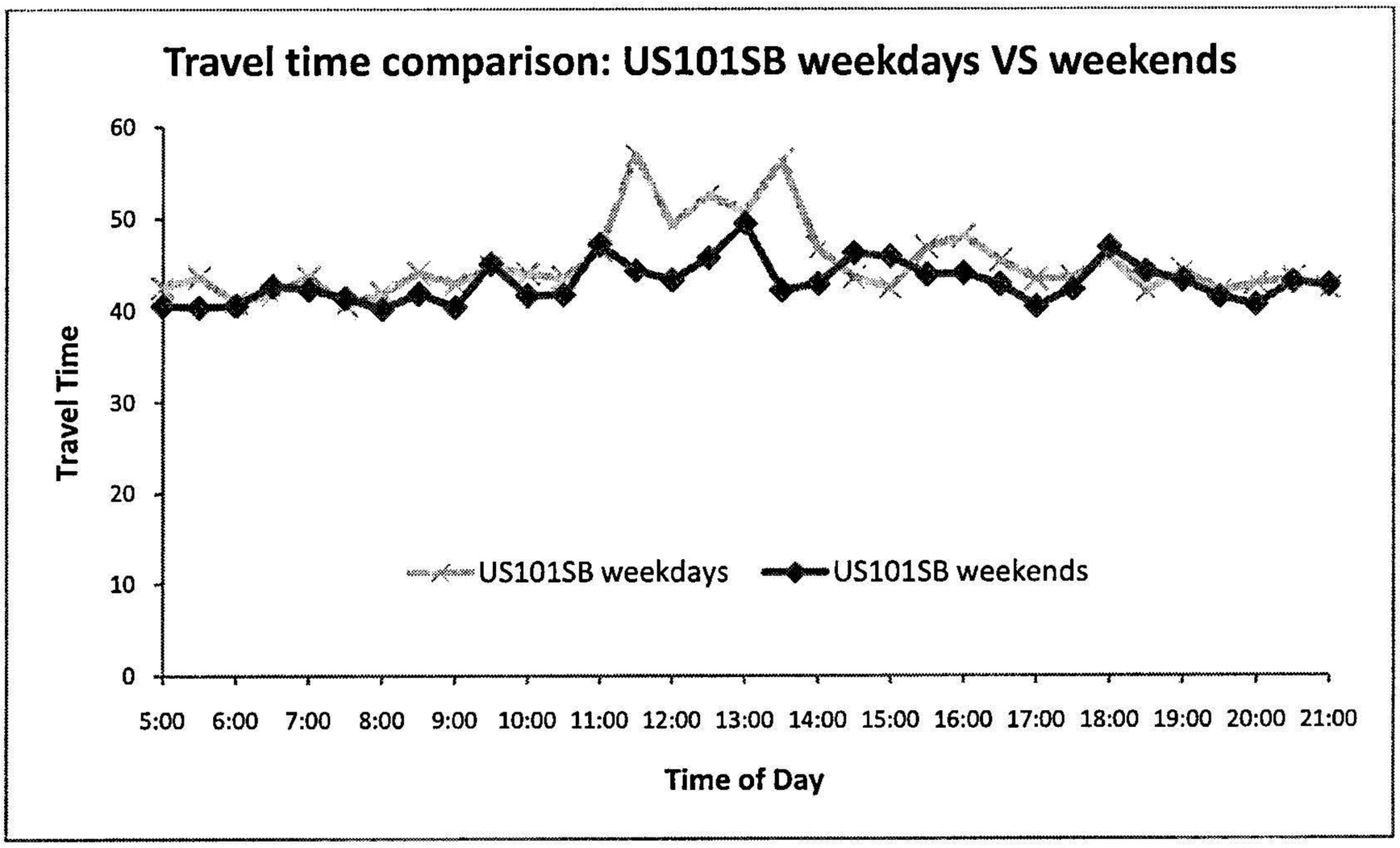


Figure 30: US101 Southbound comparison

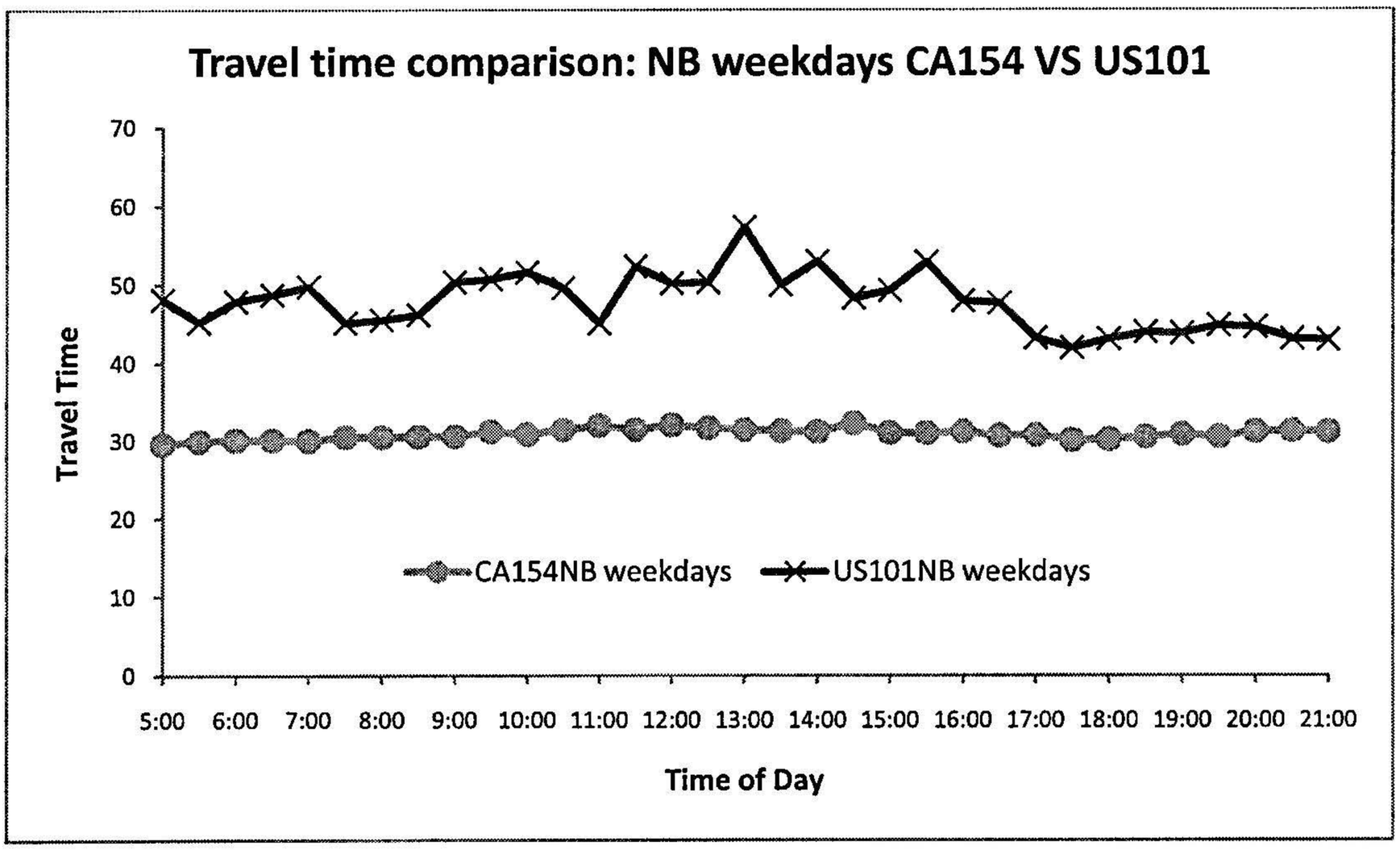


Figure 31: Northbound weekdays comparison

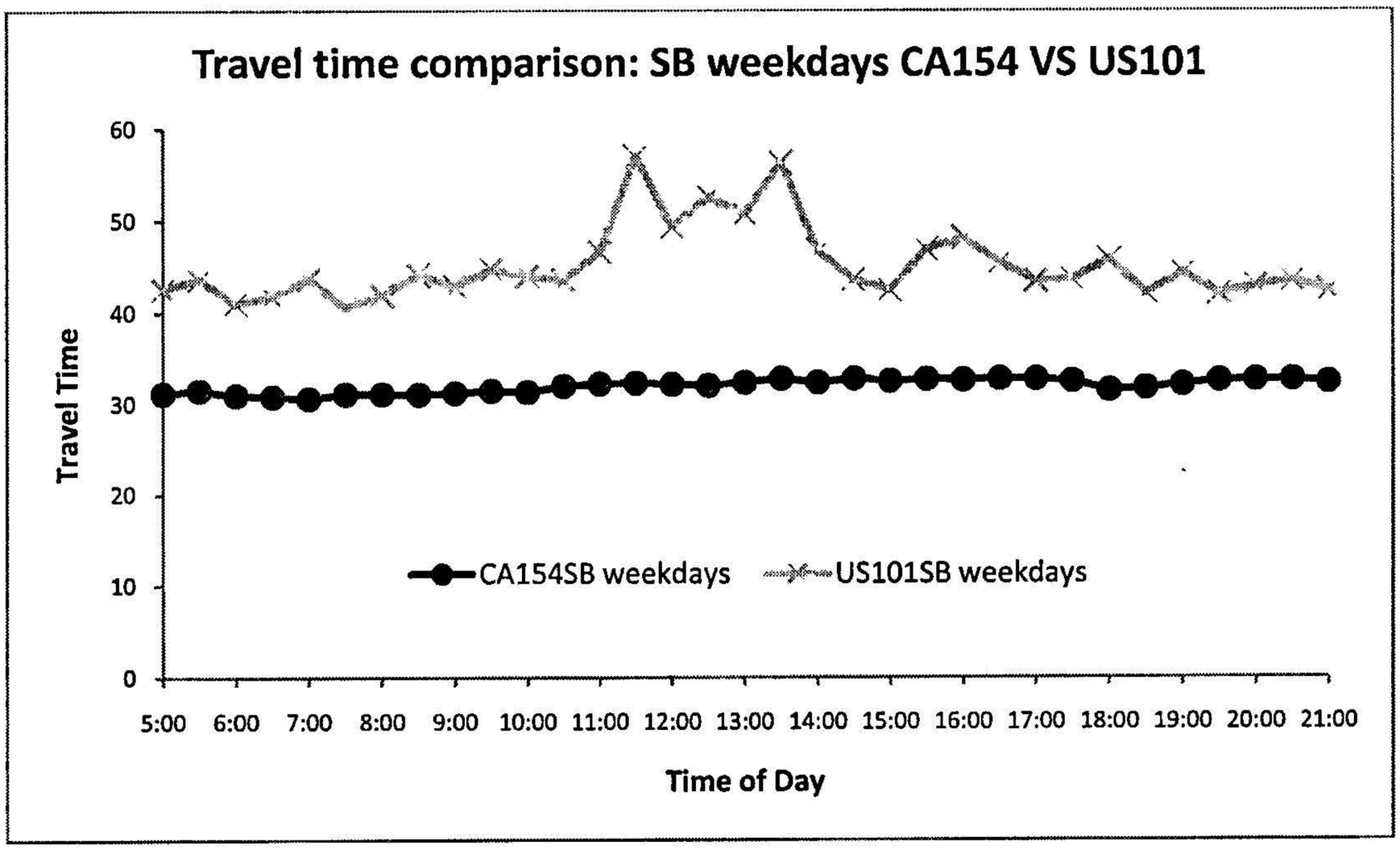


Figure 32: Southbound weekdays comparison

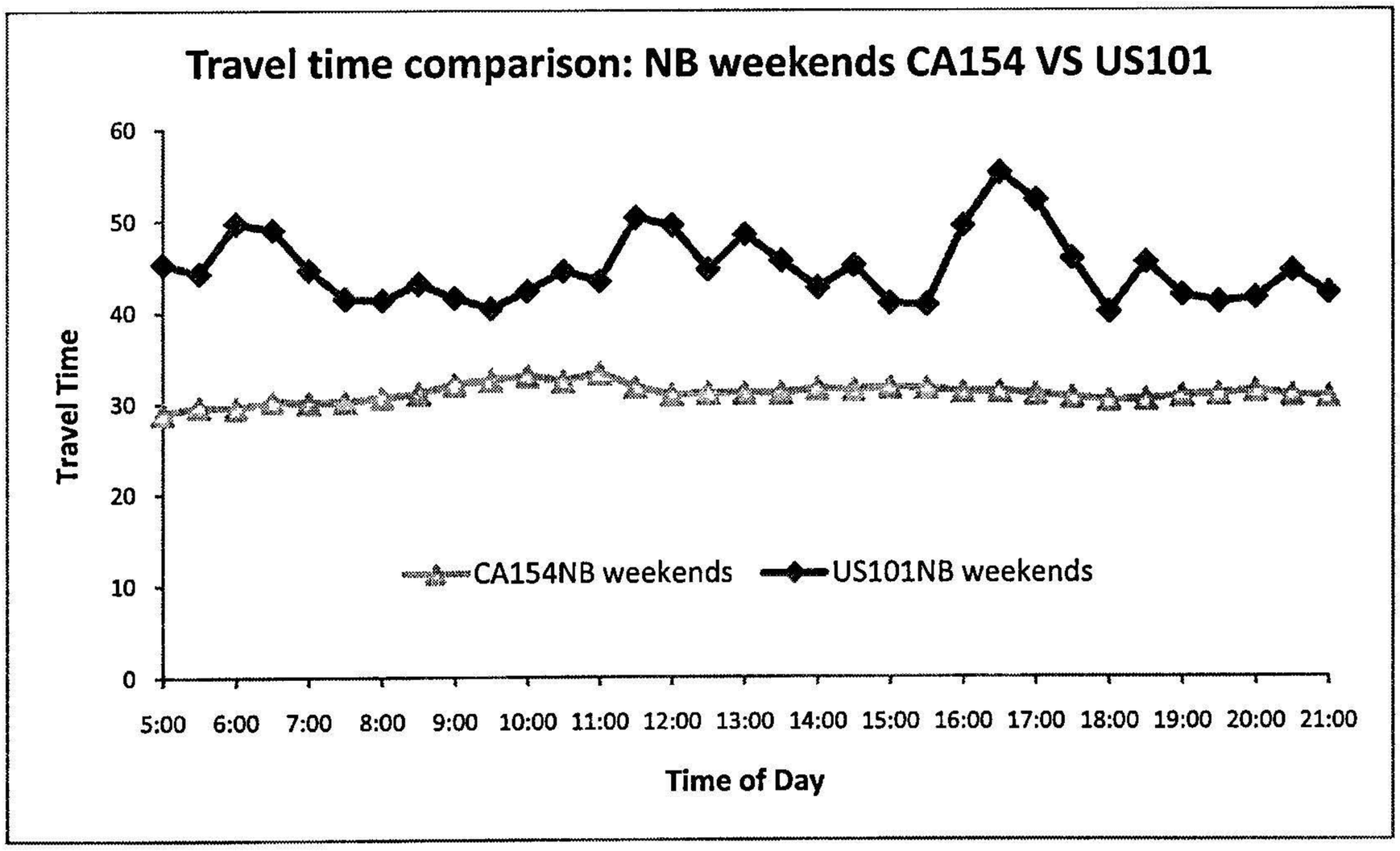


Figure 33: Northbound weekends comparison

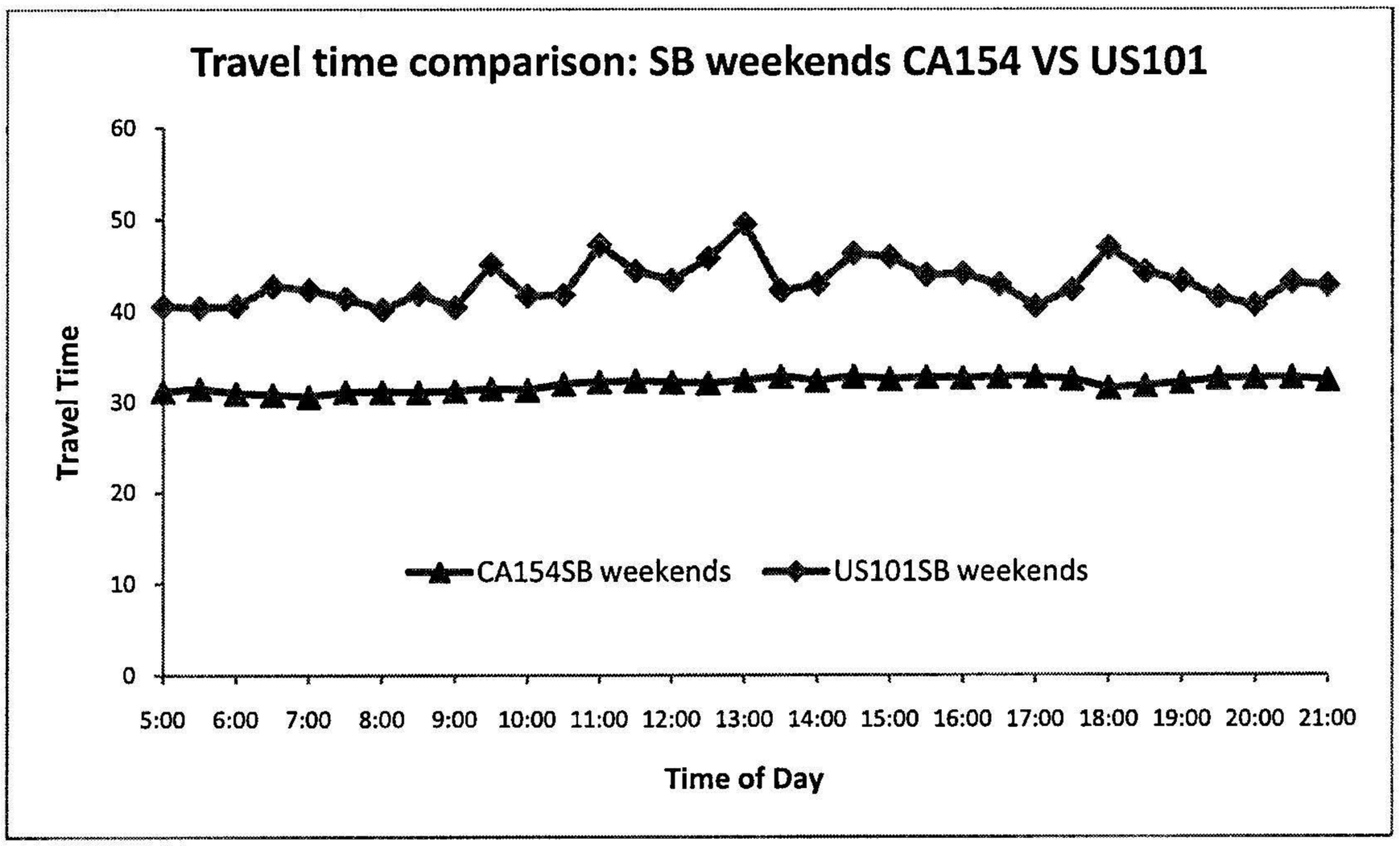


Figure 34: Southbound weekends comparison

5. CONCLUSIONS

In this study, travel time data were collected and analyzed along CA-154 and US-101 corridors from Los Olivos to Santa Barbara. The travel time was estimated by matching plate numbers collected from license plate recognition cameras.

The study shows that LPR cameras can be effectively leverage for travel time estimations. LPR cameras are capable of transferring data through cellular network, which makes them a feasible option in rural areas where cellular coverage is available. During the data collection task, the project team could successfully relocate the cameras along various data collection sites. The team could quickly set up and calibrate the cameras installed on arrow board trailers. This feature confirms that LPR cameras can be efficiently used as portable devices to estimate delays in work zones.

The matching rate data indicate that increasing the number of installed cameras can directly improve the data quality. However, it will drastically increase the equipment costs, which is a drawback for the system.

The collected data demonstrated that corridor CA-154 has an average travel time of about 35 minutes for the Northbound and 32 minutes for the Southbound. On the other hand, corridor US-101 has an average travel time of about 42-43 min for both the Northbound and Southbound. It seems it would not be effective for Caltrans to persuade drivers to use US-101 instead of CA-154 if only based on travel time.

Travel time variability analysis was performed for these two alternative routes. A "modified one-way ANOVA test" was used to assess possible with-in-day and day-to-day travel time fluctuations on different segments of the CA-154 and US-101. The results suggest that there is no significant with-in-day or day-to-day variation of travel time on CA-154 Southbound (from Los Olivos to Santa Barbara).

However, some with-in-day travel time variations were revealed on the Northbound. Further analysis indicates there is moderate early afternoon peak hour congestion on this segment, which may need extra investigation. There is no significant with-in-day or day-to-day travel time variation on US-101 segment Los Olivos-Ellwood. On the other hand, segment Ellwood-Santa Barbara on US-101 corridor has shown some important day-to-day fluctuations in its travel time, though no significant with-in-day travel time variation was found. The findings imply that traffic on this segment is less predictable from day to day and may need more attention in future study. Based on variability analysis results, displaying travel time for CA-101 is valuable and informative to the motorists specifically for the drivers traveling between Ellwood and Santa Barbara.

In the next step, leveraging the team's gained experience in evaluating innovative data collection technologies, CCIT can help Caltrans look into alternative solutions and extend the coverage of traffic data in the district.

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4. Li, R., Rose, G., and Sarvi, M. (2006) Using Automatic Vehicle Identification Data to Gain Insight into Travel time Variability and Its Causes. *Journal of Transportation Research Board No.1945*, 24-32.

5. Helinga B., Automated Vehicle identification tag-matching algorithms for estimating vehicle travel times. *Transportation Research Record No, 1774, paper No.01-2207*

6. Noland R. B. and and Polak J.W. (2002) Travel time reliability: A review of theatrical and empirical issues. *Transport Reviews Vol. 22 No. 1, 39-54*

7. Oh, J.-S., and Chung, Y. (2006) Calculation of Travel time Variability from Loop Detector Data. *Journal of Transportation Research Board No.1945*, 12-23.

Appendices

A. A step by step analysis using the "modified one-way ANOVA test"

A.1 Within-day travel time variation analysis

Take the data on Sep 24th on US-101 Northbound from Ellwood to Los Olivos as an example.

Step 1: Conduct a one-way ANOVA test for the 5 groups of data from Sep 24th. Test results are shown below (confidence level is 95%).

Groups	*Count*	*Sum*	*Average*	*Variance*
6:00-9:00	77	2563.5	33.3	14.1
9:00-12:00	137	4806.0	35.1	25.5
12:00-15:00	159	5423.0	34.1	18.6
15:00-18:00	145	4849.0	33.4	8.3
18:00-21:00	67	2189.7	32.7	7.2

ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	356.08	4	89.02	5.65	0.00018	2.39
Within Groups	9138.56	580	15.76			
Total	9494.64	584				

F>F_{crt}, meaning hypothesis that "mean travel times among different time intervals in this day are equal" is rejected at confidence level 95%. However, direct ANOVA test for the proposed NULL hypothesis that "mean travel times among different time intervals differ by less than 3 minutes in this day" is not obvious.

Step 2: Conduct multiple comparisons with Bonferroni t-test.

Take any two groups i_1, and i_2, the confidence interval for the difference of mean of group i_1 and i_2 is:

$$\text{Sample mean difference} \pm t_{value} \times S_p \times \sqrt{\frac{1}{j_1}+\frac{1}{j_2}}$$

Where:

j_1, j_2: the count of data in group i_1 and i_2;

S_p: the square root of the mean square for error within groups (which can be derived from the ANOVA test results in Step 1), in this case $S_p = \sqrt{15.76} = 3.97$.

t_{value}: degree of freedom, equals to degree of freedom within groups in ANOVA test; which is 580 in this case; probability level for the t-value equals to α/k; where k is the total number of pair-wise comparisons: $\frac{n(n-1)}{2} = 10$.

The proposed NULL hypothesis that "mean travel times among different time intervals differ by less than 3 minutes" is equivalent to:

$$\text{Absolute value of sample mean difference} < t_{value} \times S_p \times \sqrt{\frac{1}{j_1} + \frac{1}{j_2}} + 3.$$

Theoretically, we need to do this test for all k pairs, but practically, we only need to consider those pairs that have very large mean difference and/or very large counts. In this case, for example, first we can test "9:00-12:00", which has the largest mean travel time, 35.1 min, with "18:00-21:00", which has the smallest mean travel time, 32.7 min. The test results are shown below:

Sample mean difference = 2.4;

$$t_{value} \times S_p \times \sqrt{\frac{1}{j_1} + \frac{1}{j_2}} + 3 = t\left(\frac{0.05}{10}, 580\right) \times 3.97 \times \sqrt{\frac{1}{137} + \frac{1}{67}} + 3 = 1.7 + 3 = 4.7;$$

2.4<1.7+3=4.7, thus the NULL hypothesis is true, that is, we failed to reject the hypothesis that "mean travel time between the two time intervals is less than 3 minute". Also noting that 2.4>1.7, meaning that the conventional hypothesis that "mean travel times in these two time intervals are equal" would be rejected.

We can do the test for all other pairs to verify the test results, which are not necessary in practice. This method involves little computation besides the ANOVA test (which can be done by Excel), and is flexible in terms of the threshold time difference we'd like to test.

A.2 Day-to-day travel time variation analysis

The underlying philosophy for day-to-day variation analysis is the same as the within-day part, only to rearrange the data into groups by different days. Take the afternoon interval (12:00-15:00) for US-101 Southbound from Los Olivos to Ellwood as an example to show the process.

Step 1: Conduct a one-way ANOVA test for the 8 groups (8 different days) of data taken during 12:00-15:00 on each day on US-101 Southbound from Los Olivos to Ellwood. Test results are shown below (confidence level is 95%).

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

May 18th	209	7403.9	35.4	22.6
May 20th	112	4086.5	36.5	31.7
May 21st	109	3859.8	35.4	26.4
May 24th	202	6981.2	34.6	16.9
May 25th	204	7273.9	35.7	41.4
Jun 27th	246	8411.0	34.2	13.6
Jun 28th	300	10524.9	35.1	24.9
Jun 29th	243	8513.7	35.0	18.1

ANOVA: Single Factor

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	573.9	7	81.993	3.486	0.001	2.015
Within Groups	38035.7	1617	23.522			
Total	38609.6	1624				

$F > F_{crit}$, meaning hypothesis that "mean travel times among different days during this time interval are equal" is rejected at confidence level 95%. However, we need to test the proposed NULL hypothesis that "mean travel times among different days during this time interval differ by less than 3 minutes."

Step 2: Conduct multiple comparisons with Bonferroni t-test.

Similarly, the NULL hypothesis that "mean travel times among different days during this time interval differ by less than 3 minutes" is equivalent to:

$$\text{Absolute value of sample mean difference} < \text{t-value} \times S_p \times \sqrt{\frac{1}{j_1} + \frac{1}{j_2}} + 3.$$

For example, consider May 20th, which has the longest travel time, 36.5 min, and Jun 27th, which has the shortest average travel time 34.2 min. The test results are shown below:

Sample mean difference = 2.3;

$$\text{t-value} \times S_p \times \sqrt{\frac{1}{j_1} + \frac{1}{j_2}} + 3 = t(0.05/28, 1617) \times 4.85 \times \sqrt{\frac{1}{112} + \frac{1}{246}} + 3 = 1.73 + 3 = 4.73;$$

2.3<1.73+3=4.73, thus the NULL hypothesis is true, that is, we failed to reject the hypothesis that "mean travel time between the two days is less than 3 minutes". Also note that 2.3>1.73, means that the conventional hypothesis that "mean travel times in these two days are equal" would be rejected. Repeat this multiple comparison for all pairs of days (which are not necessary in practice).

B. Daily detection rates and matching rates on CA154

Figure 17 shows the average hourly volumes of vehicles counted by the tube, the number of vehicles detected by the LPR camera 2, and the number of matched vehicles from camera 1 and camera 2. Figure 18 represents the average hourly detection rates and matching rates. The performance of the LPR camera ranges mostly from 60% to 70% between 7am and 9pm. During the times where traffic volume is low (9pm to 7am), the detection rate is lower but still maintains an average rate of over 40% (note that the camera set-up in this period was aiming at the front plates of vehicles, which might partly account for the low capture rate. Please refer to 3.4 for further explanation). The detection rate during 9pm to 7am also has more variations compared with daytime performance. Please refer to Appendix B for more detailed daily performance figures.

Figure 35, Figure 37, Figure 39, and Figure 41 show the hourly volumes of vehicles counted by the tube, the number of vehicles detected by the LPR camera, and the number of matched vehicles from camera 1 and camera 2. Figure 36, Figure 38, Figure 40, and Figure 42 represent the hourly detection rates and matching rates. The detection rates of the LPR camera range mostly from 60% to 70% between 7am and 9pm. During the times where traffic volume is low (9pm to 7am), the detection rate varies significantly with an estimated minimum of 15% in Figure 40 (note that the camera set-up in this period was aiming at the front plates of vehicles, which might partly account for the low capture rate. Please refer to 3.4 for further explanation). The matching rates are more evenly distributed across day time and night, compared with the detection rates, and are generally smaller than the detection rates during day time.

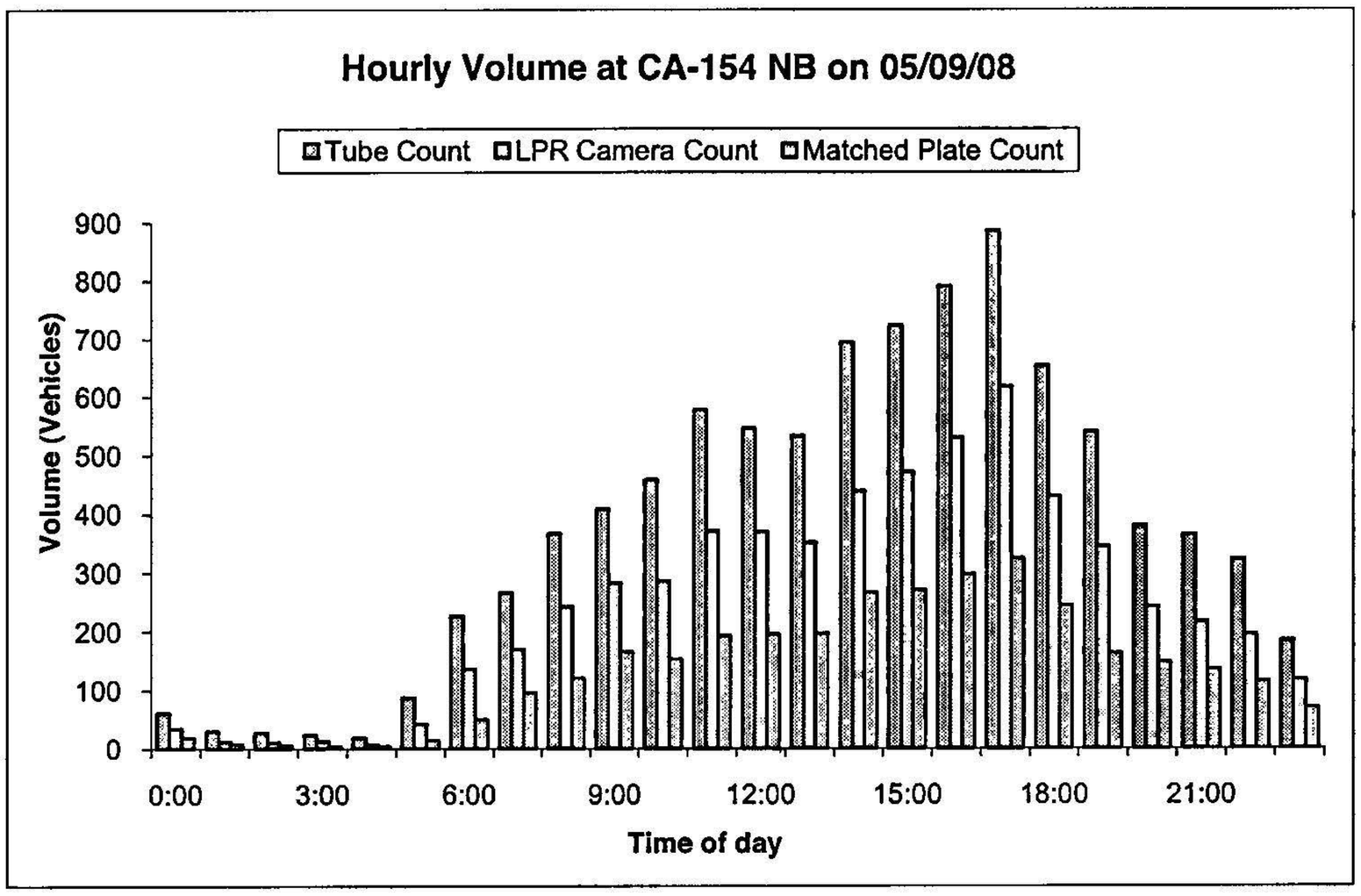


Figure 35: CA-154: Hourly Volume on 05/09/08

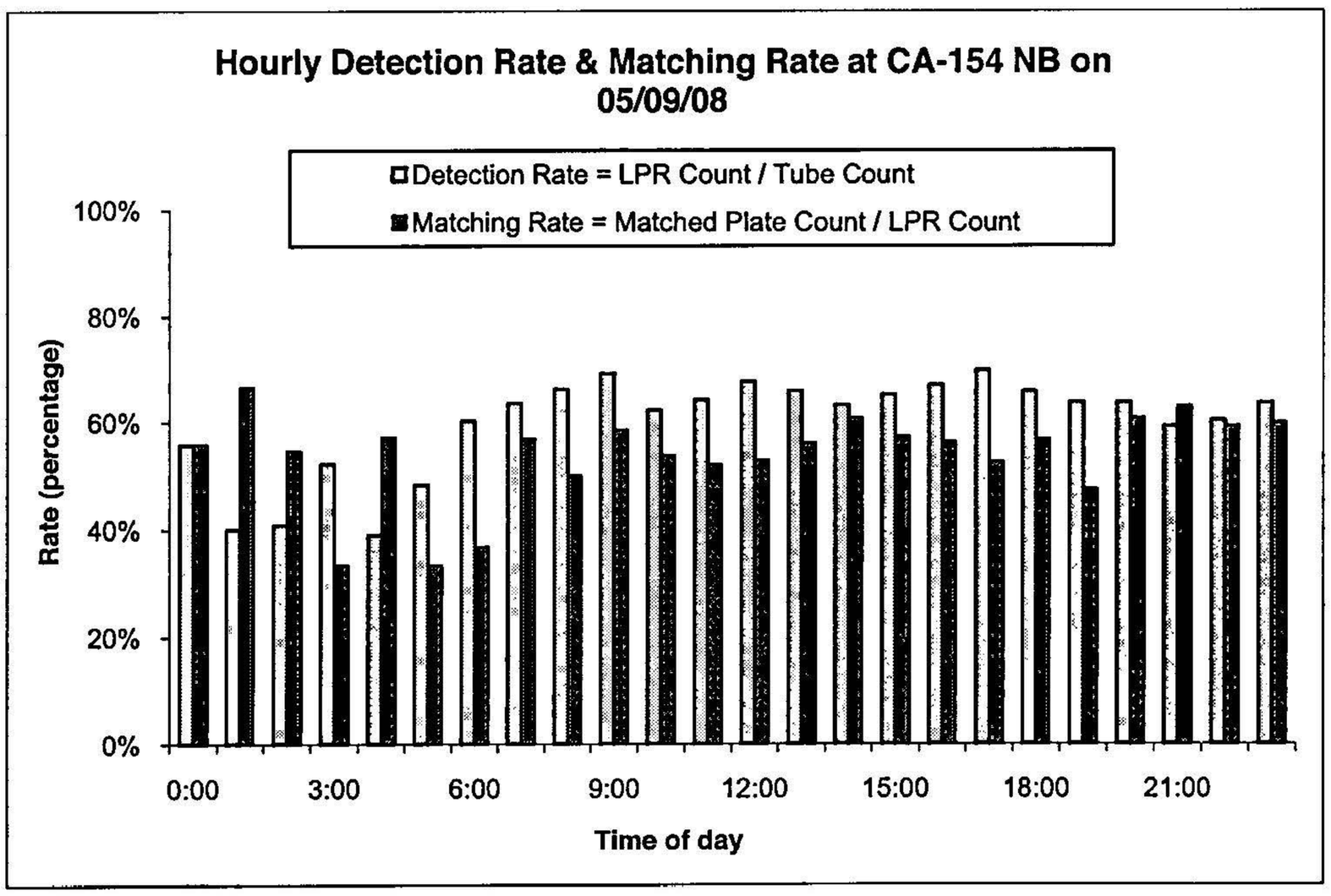


Figure 36: CA-154: Performance of LPR Camera on 05/09/08

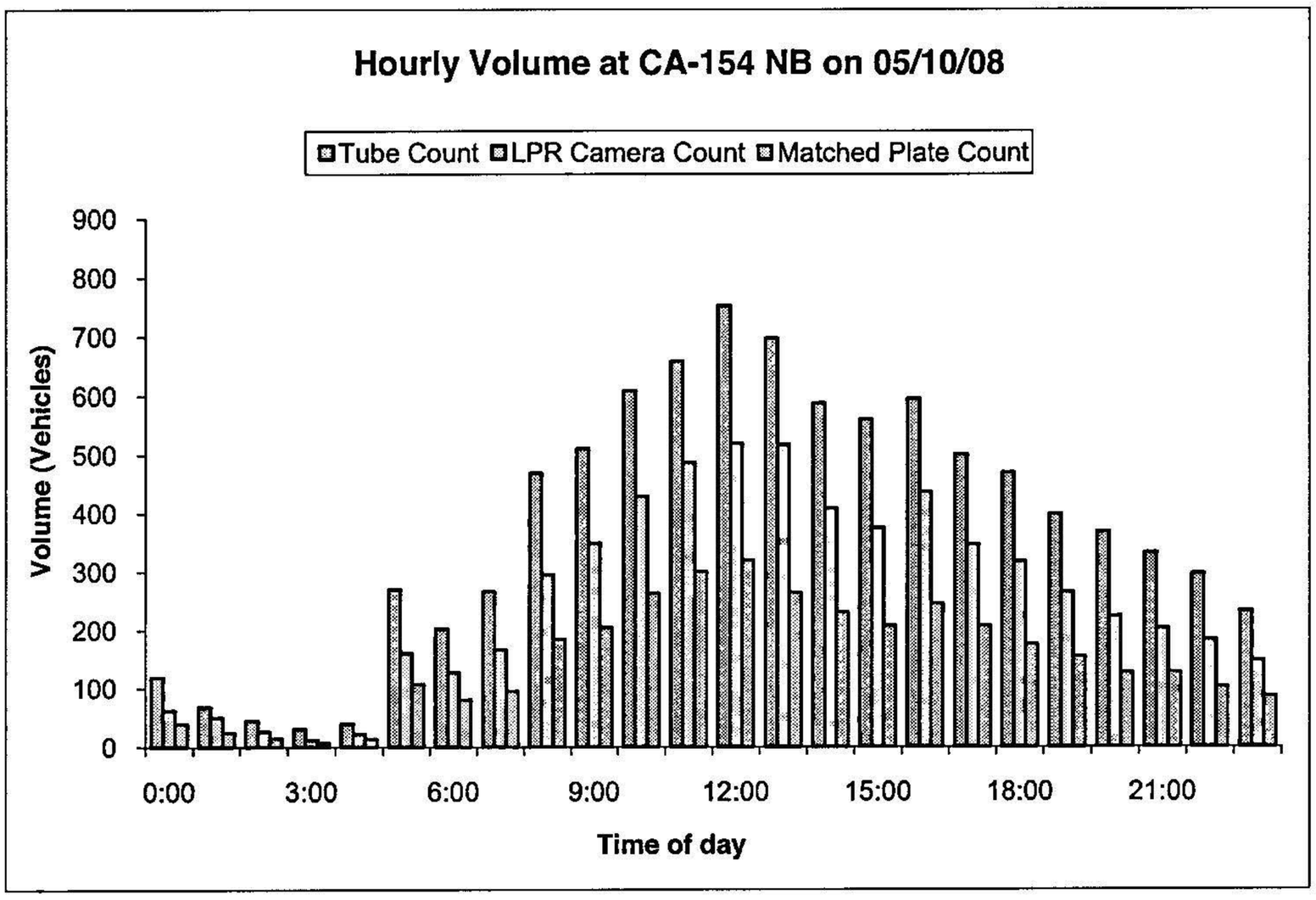


Figure 37: CA-154: Hourly Volume on 05/10/08

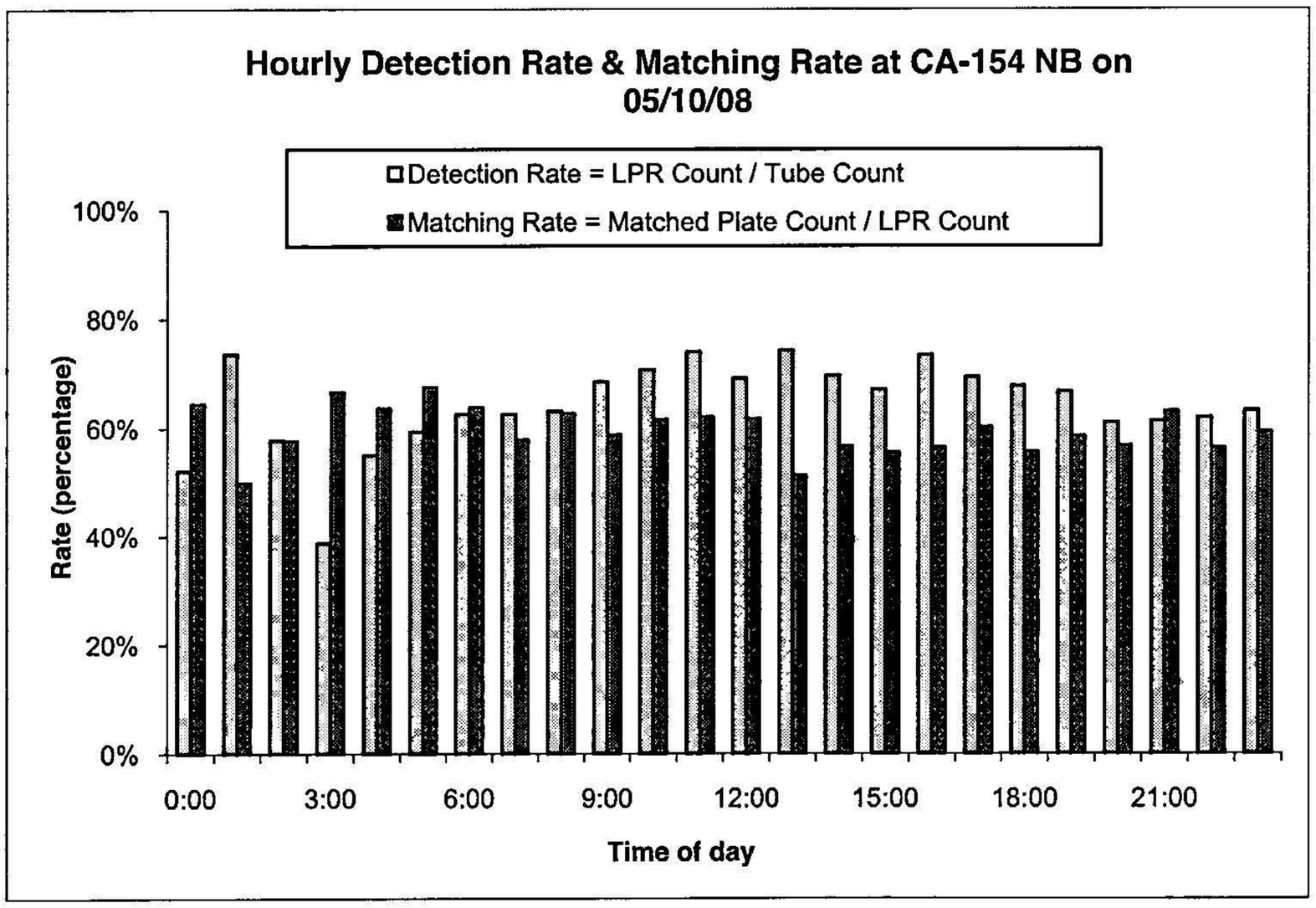


Figure 38: CA-154: Performance of LPR Camera on 05/10/08

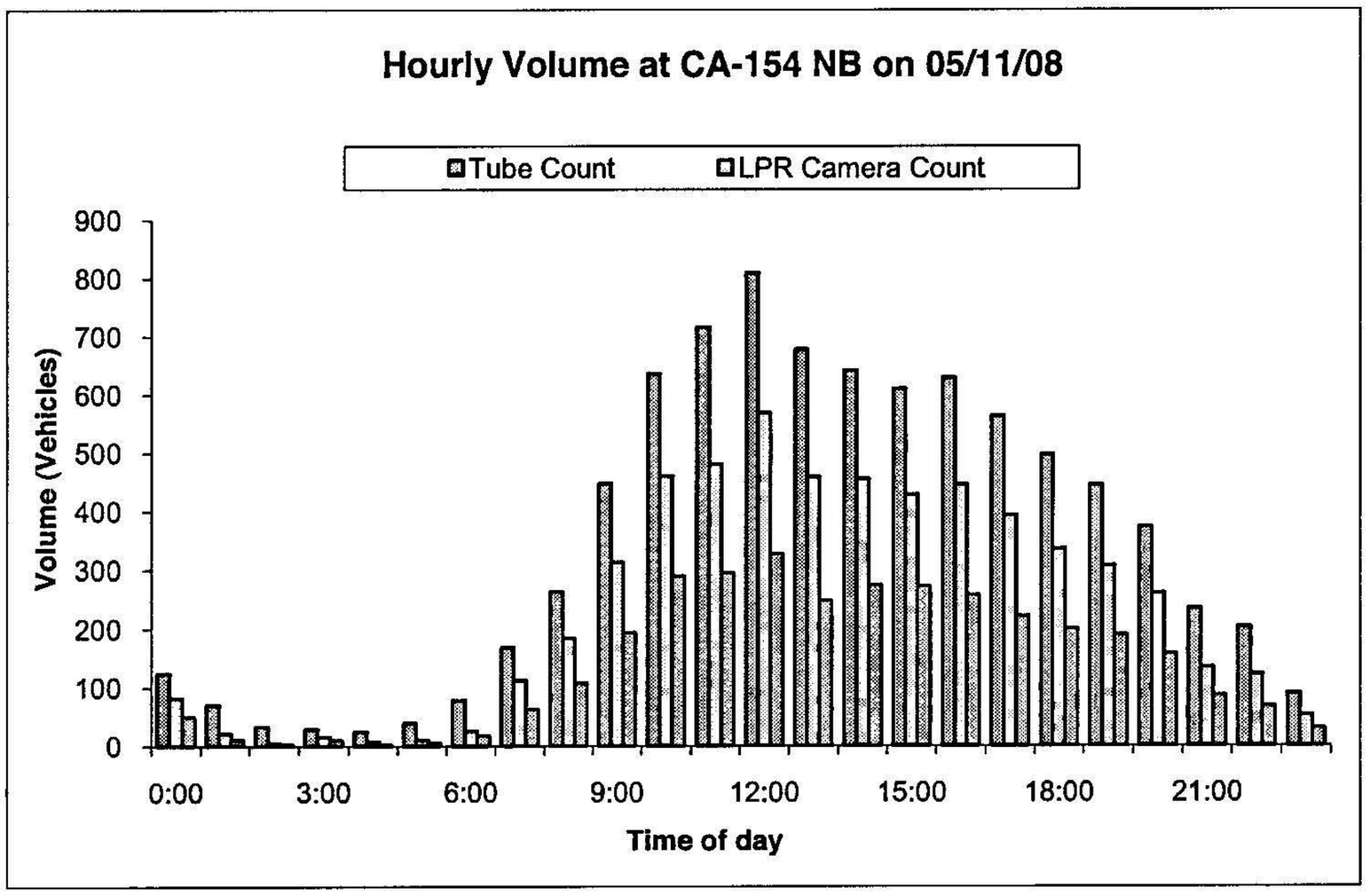


Figure 39: CA-154: Hourly Volume on 05/11/08

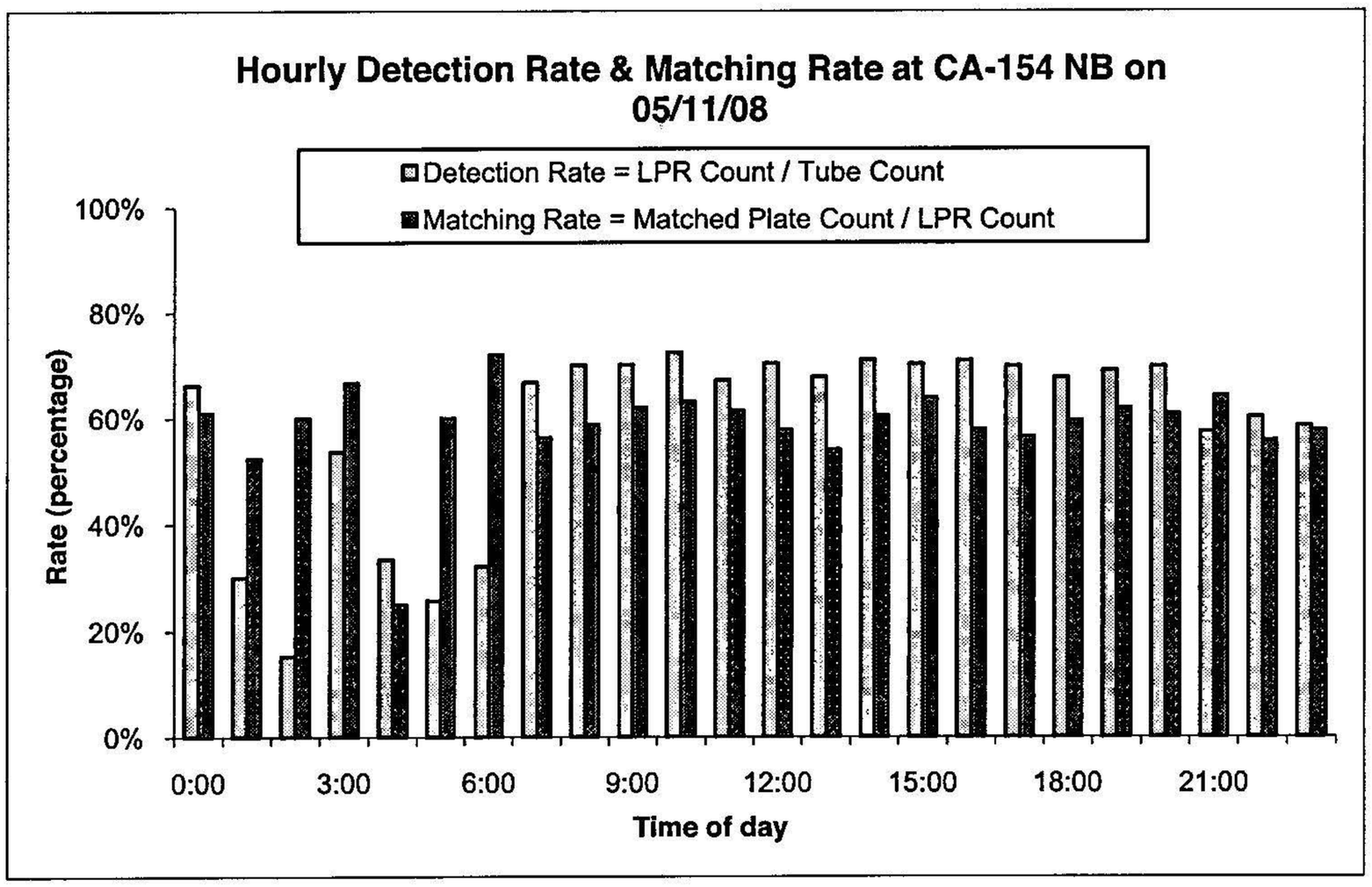


Figure 40: CA-154: Performance of LPR Camera on 05/11/08

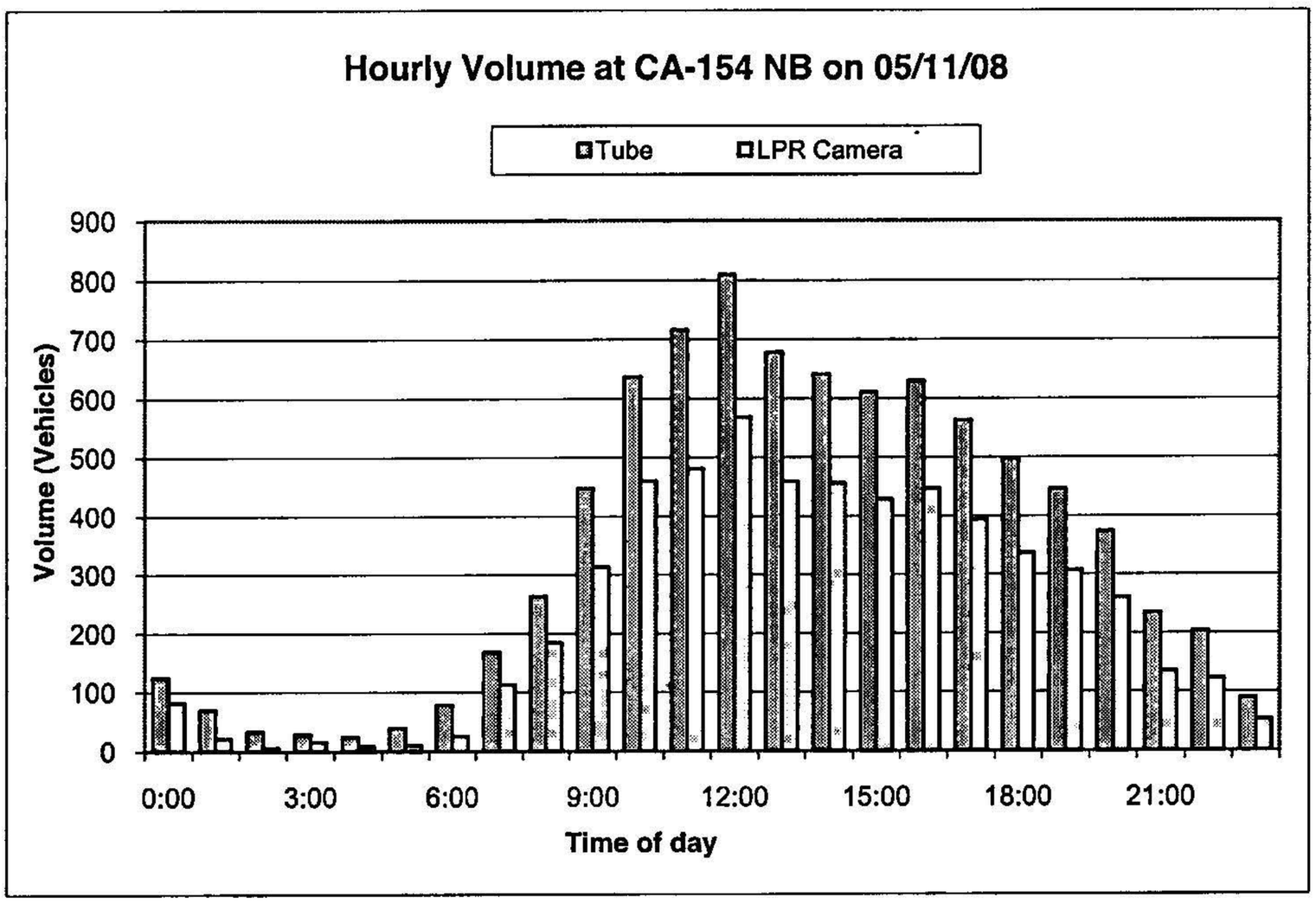


Figure 41: CA-154: Hourly Volume on 05/12/08

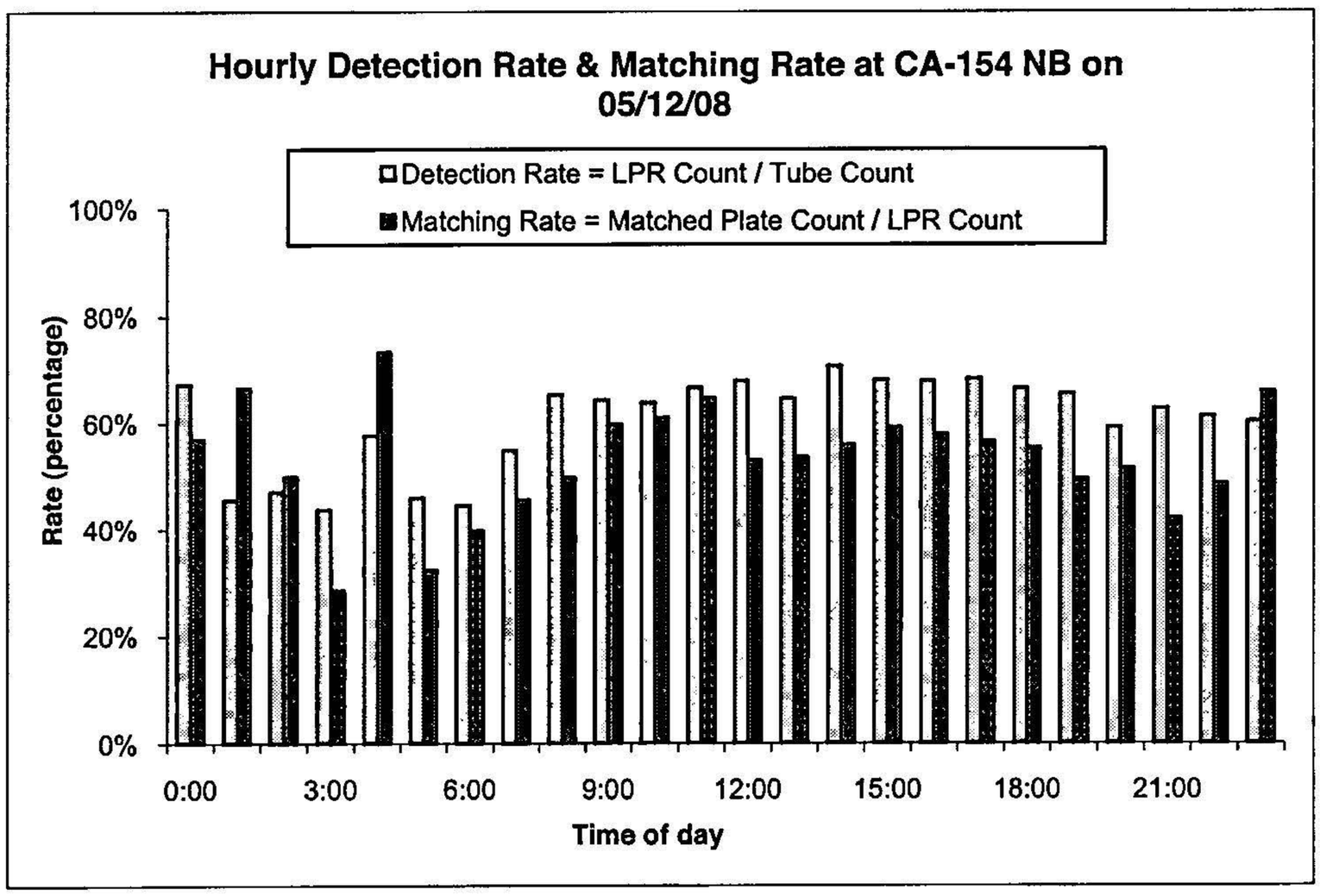
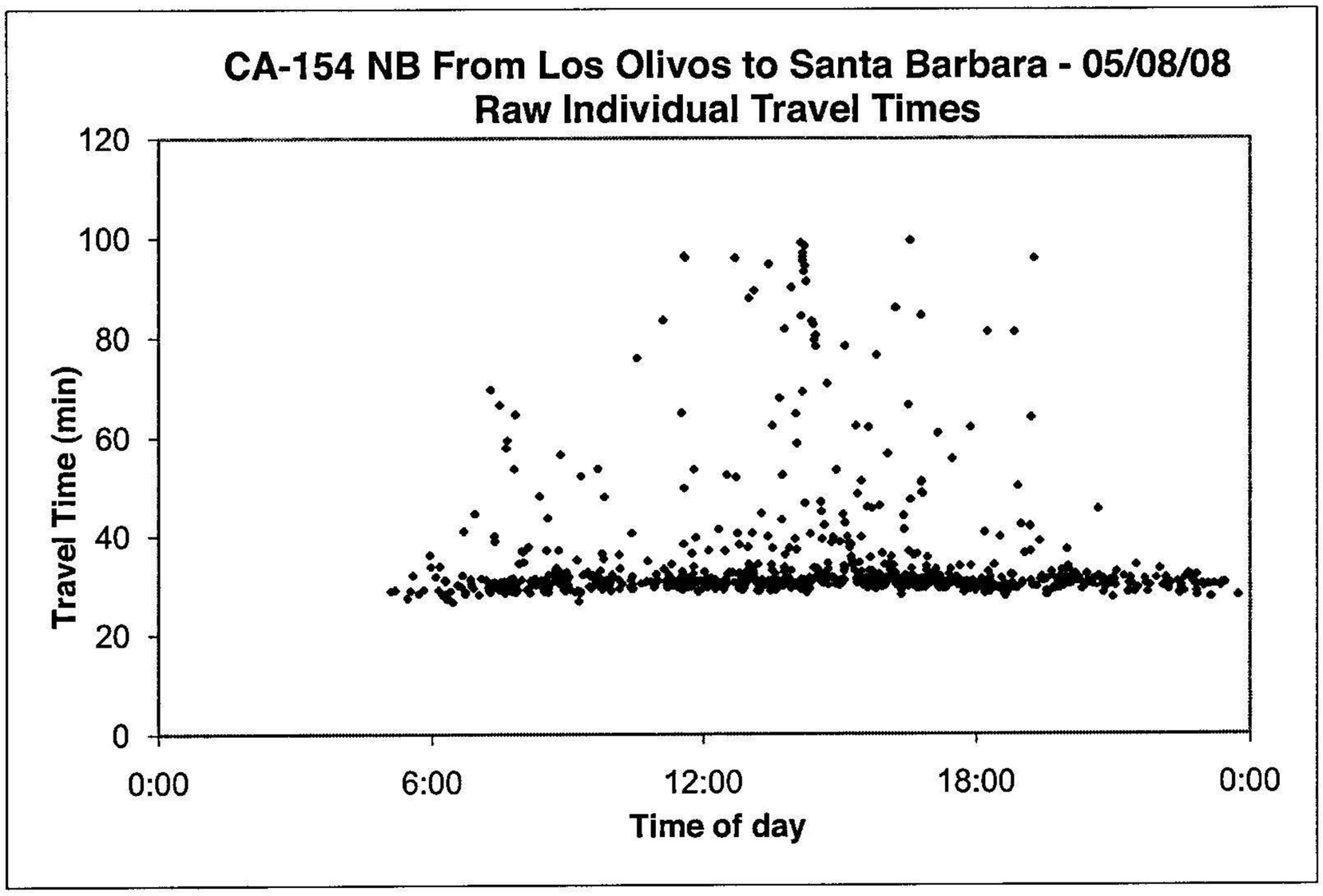
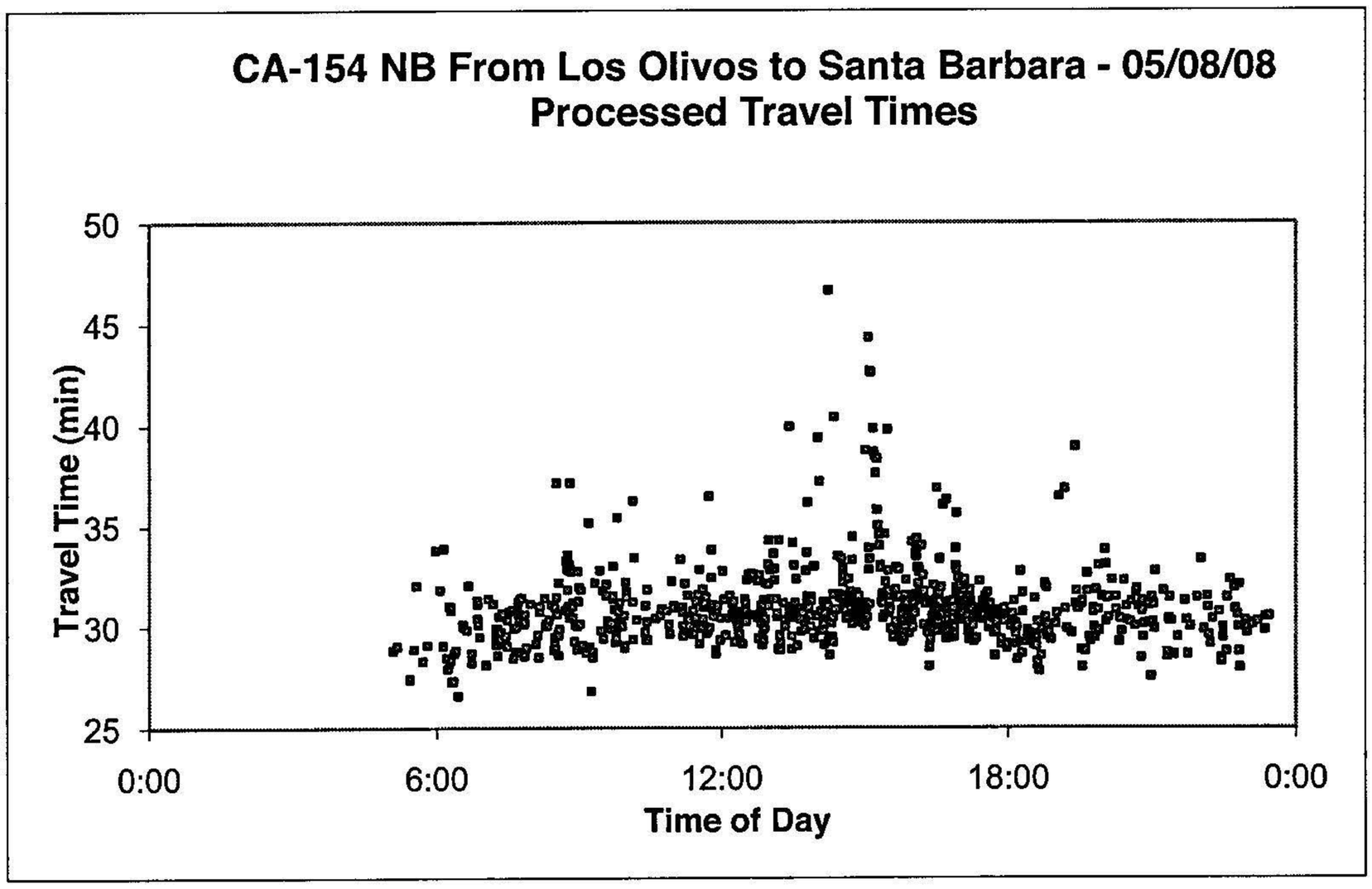


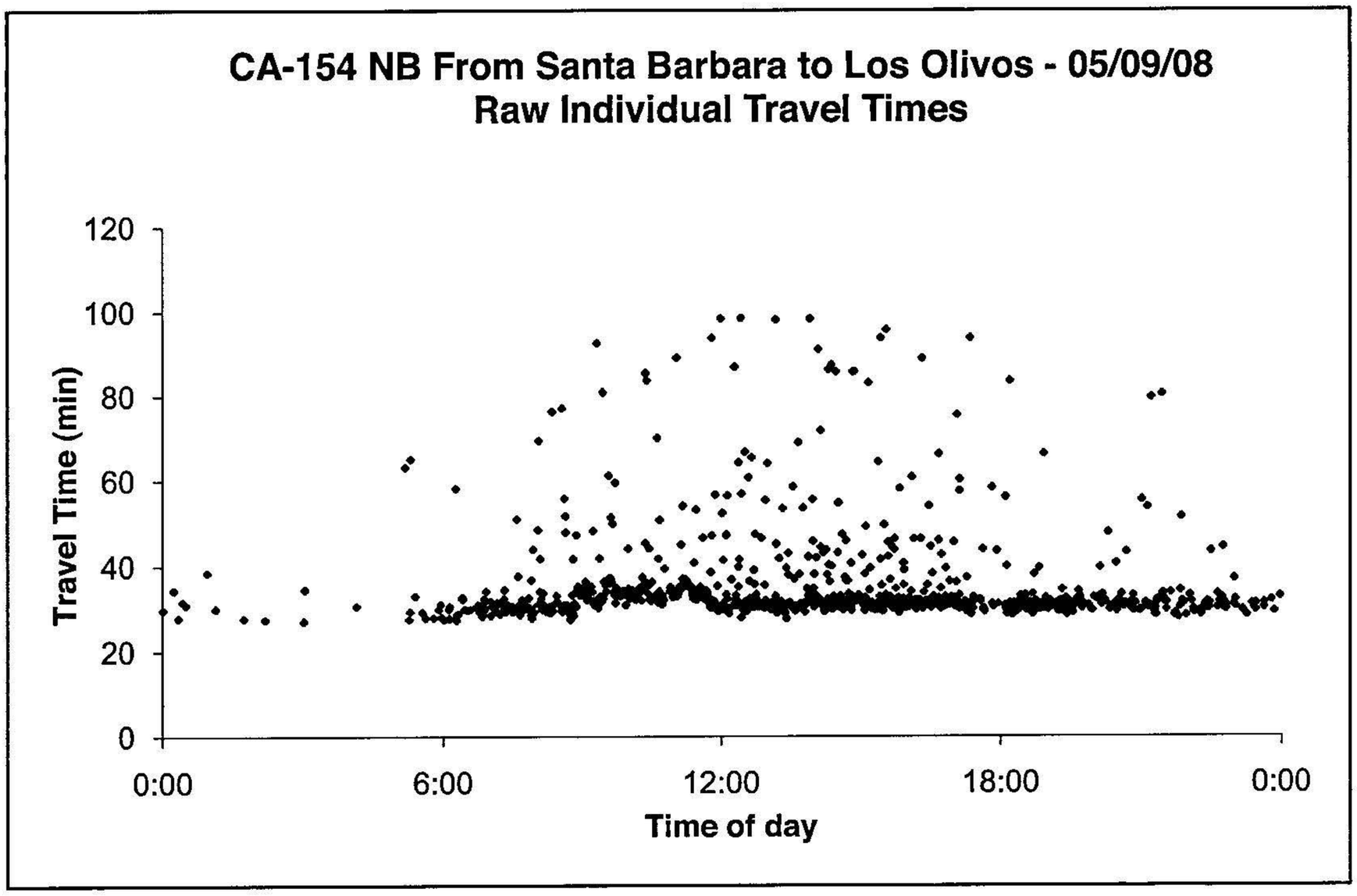
Figure 42: CA-154: Performance of LPR Camera on 05/12/08

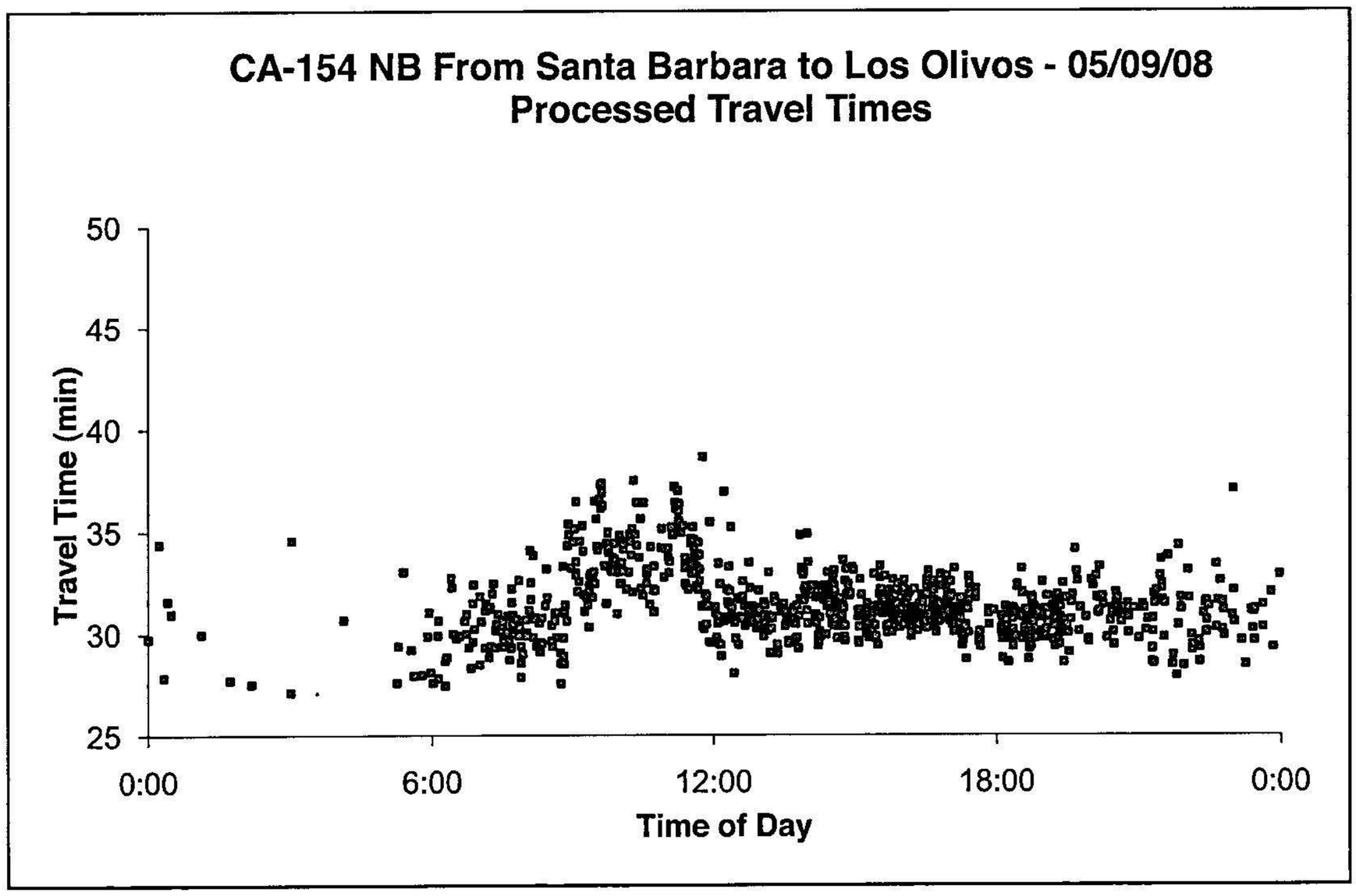
C. Travel Time Distribution (Figures are not indexed)

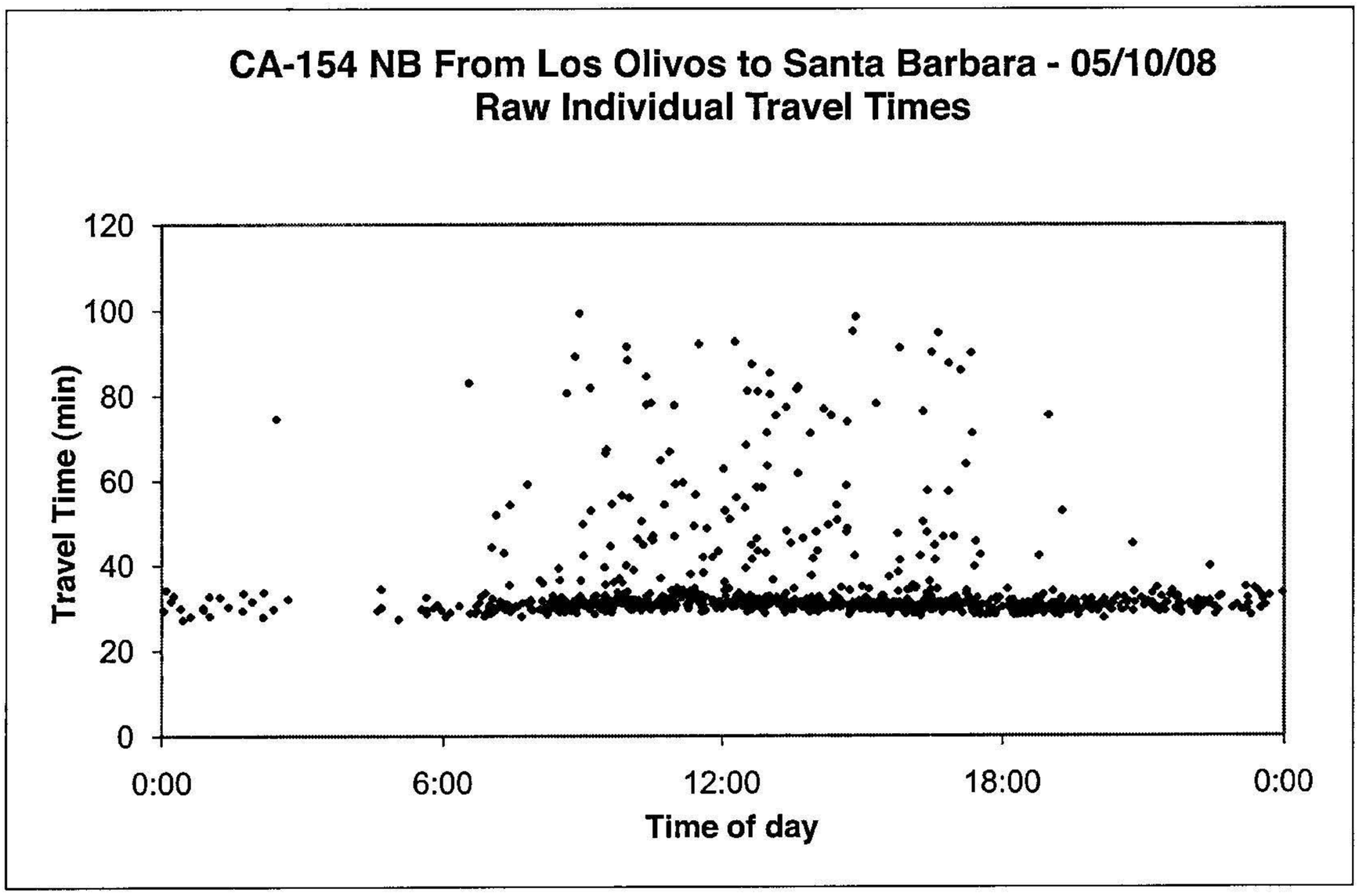
C.1 CA-154 From Los Olivos to Santa Barbara Travel Time Distribution

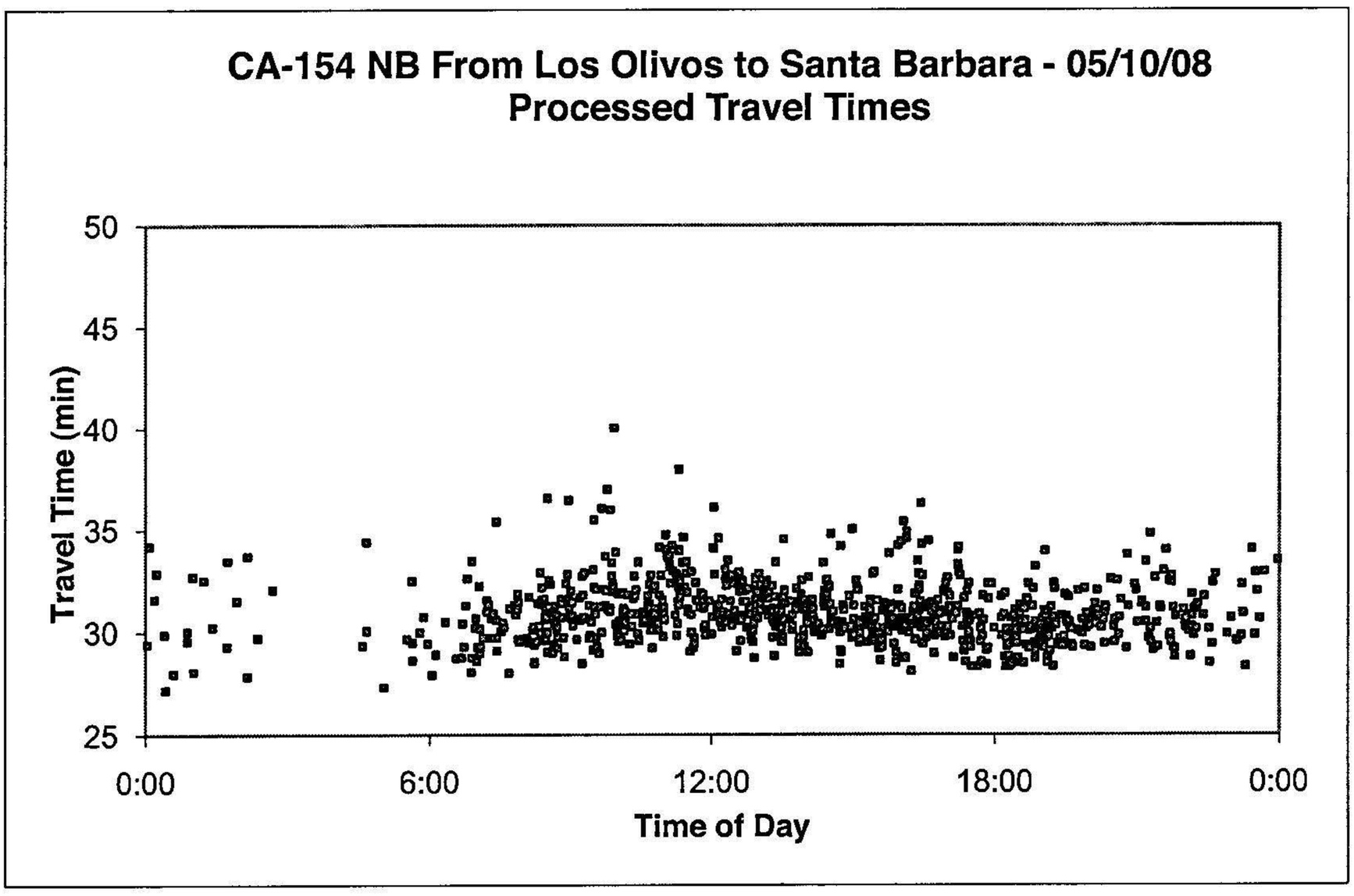


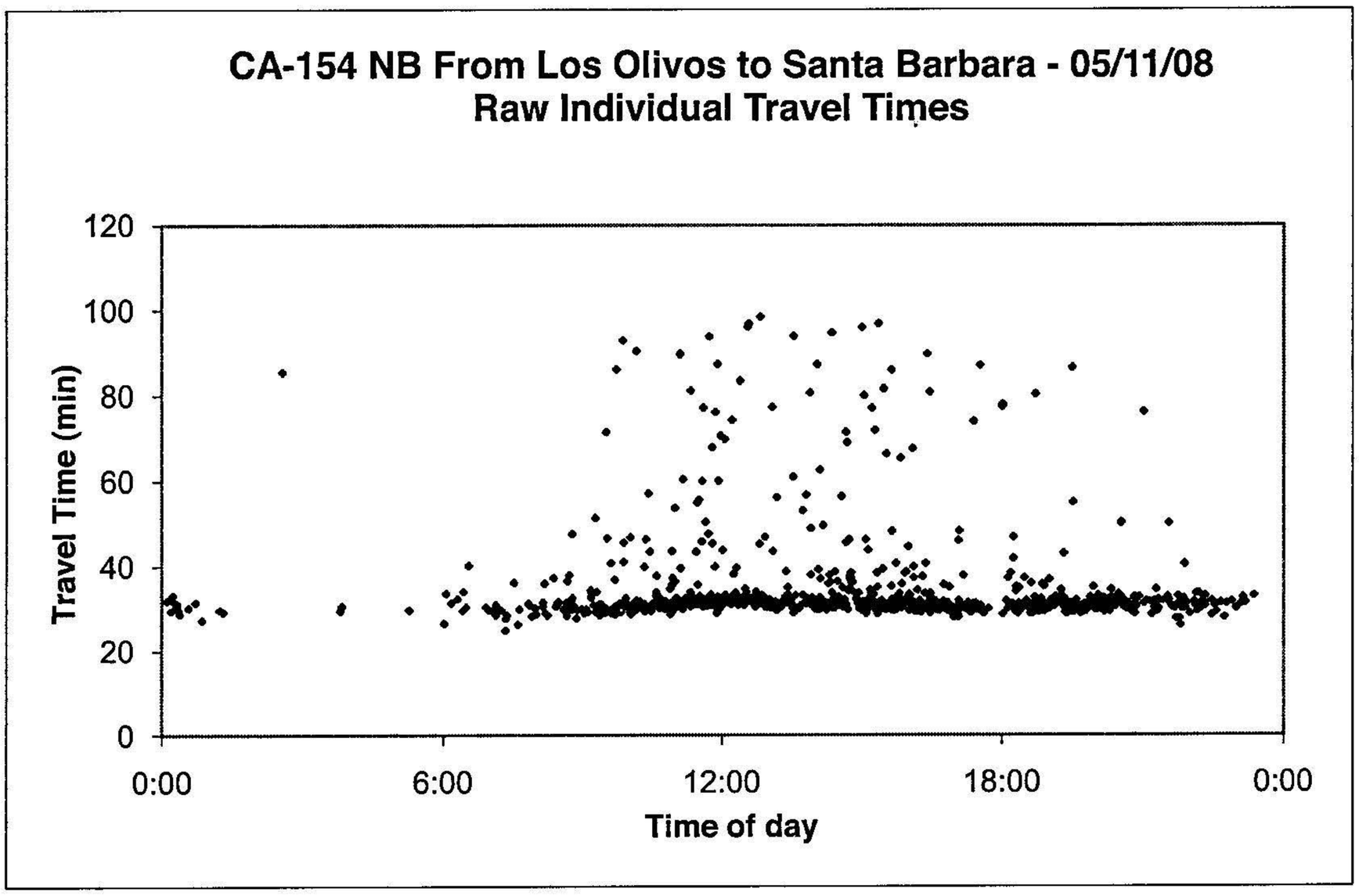


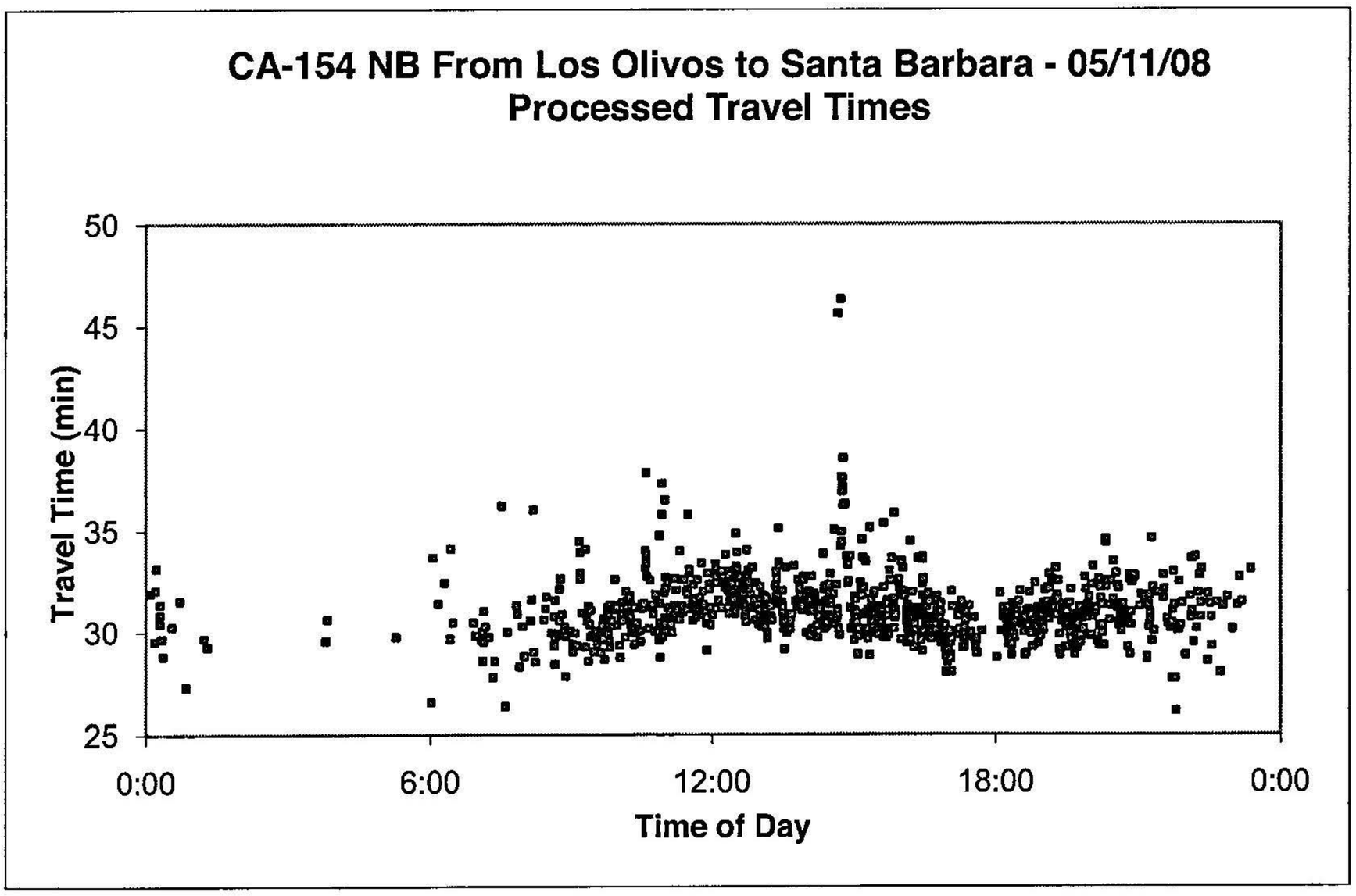

CA-154 NB From Santa Barbara to Los Olivos - 05/09/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

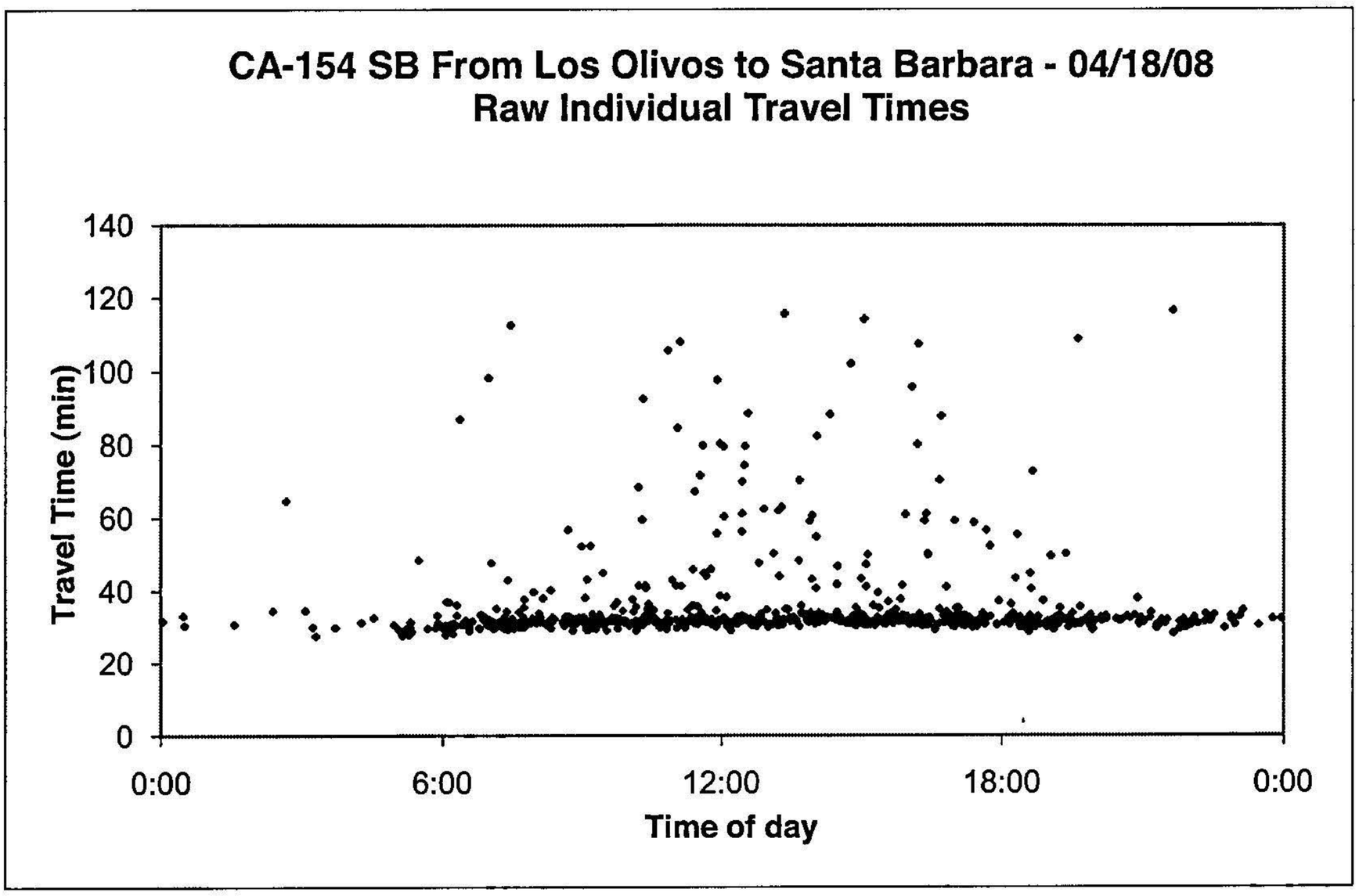

CA-154 NB From Santa Barbara to Los Olivos - 05/09/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

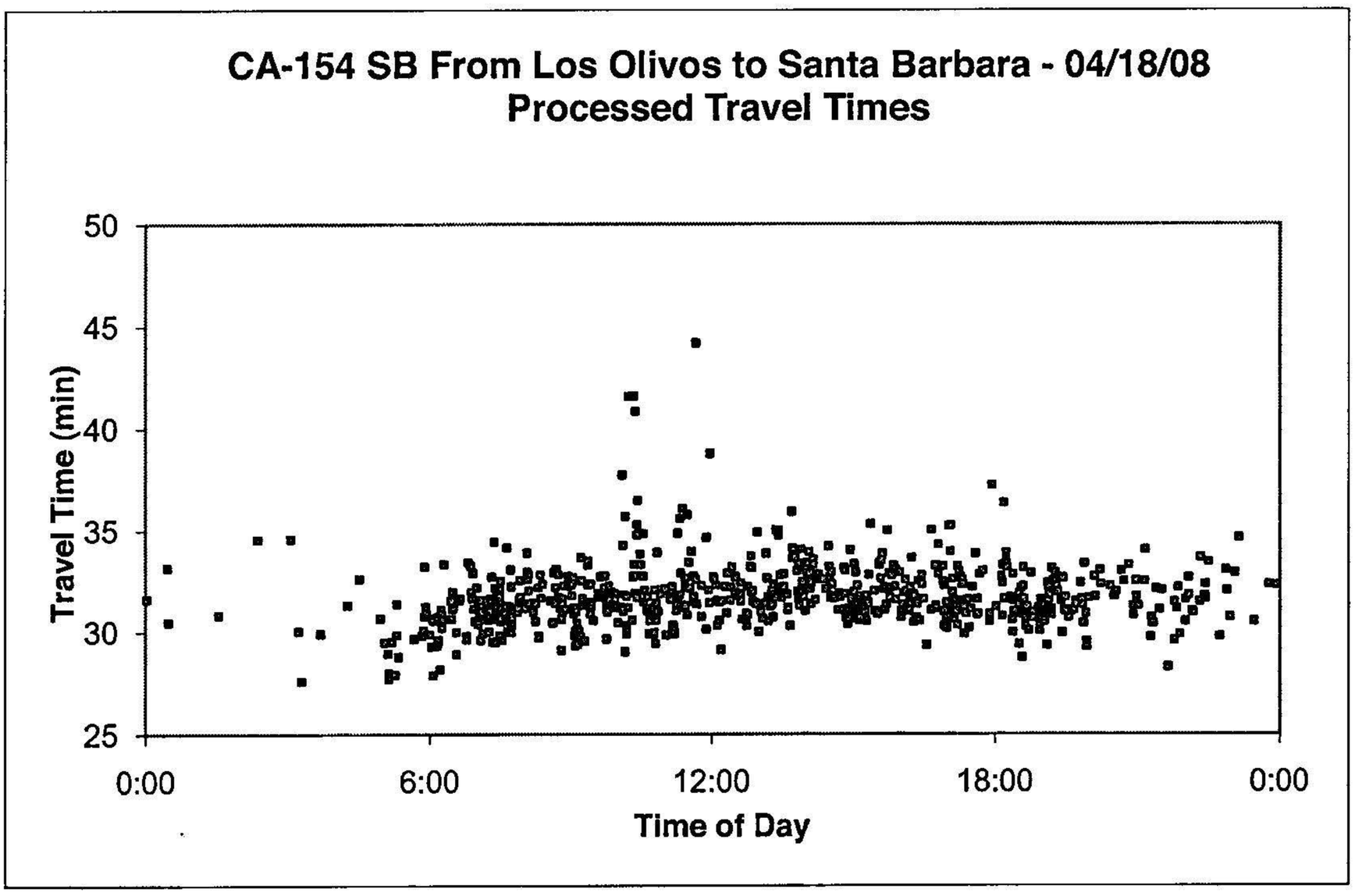

CA-154 NB From Los Olivos to Santa Barbara - 05/10/08
Raw Individual Travel Times
Travel Time (min)
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100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

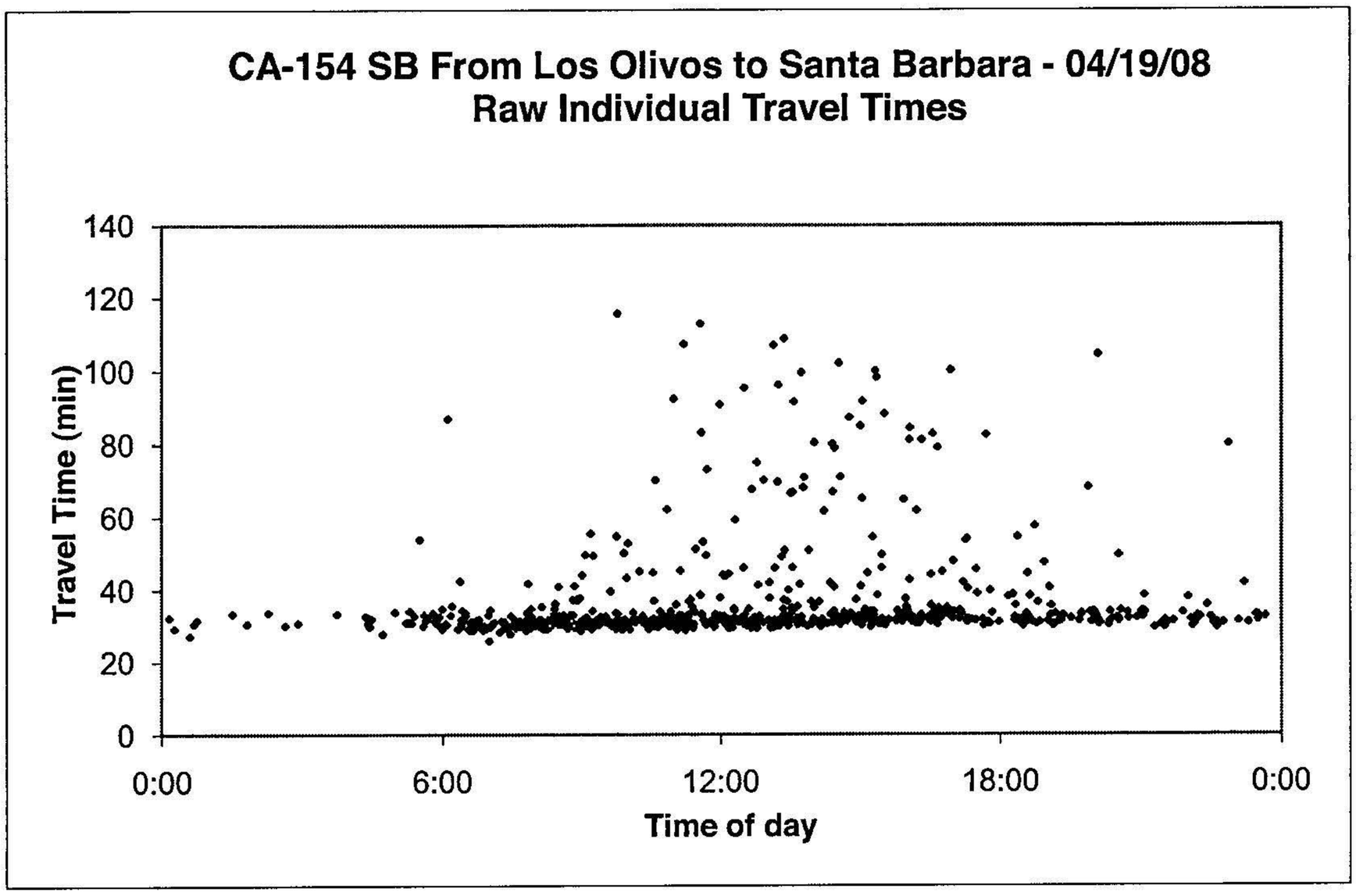

CA-154 NB From Los Olivos to Santa Barbara - 05/10/08
Processed Travel Times
Travel Time (min)
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35
30
25
0:00
6:00
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0:00
Time of Day

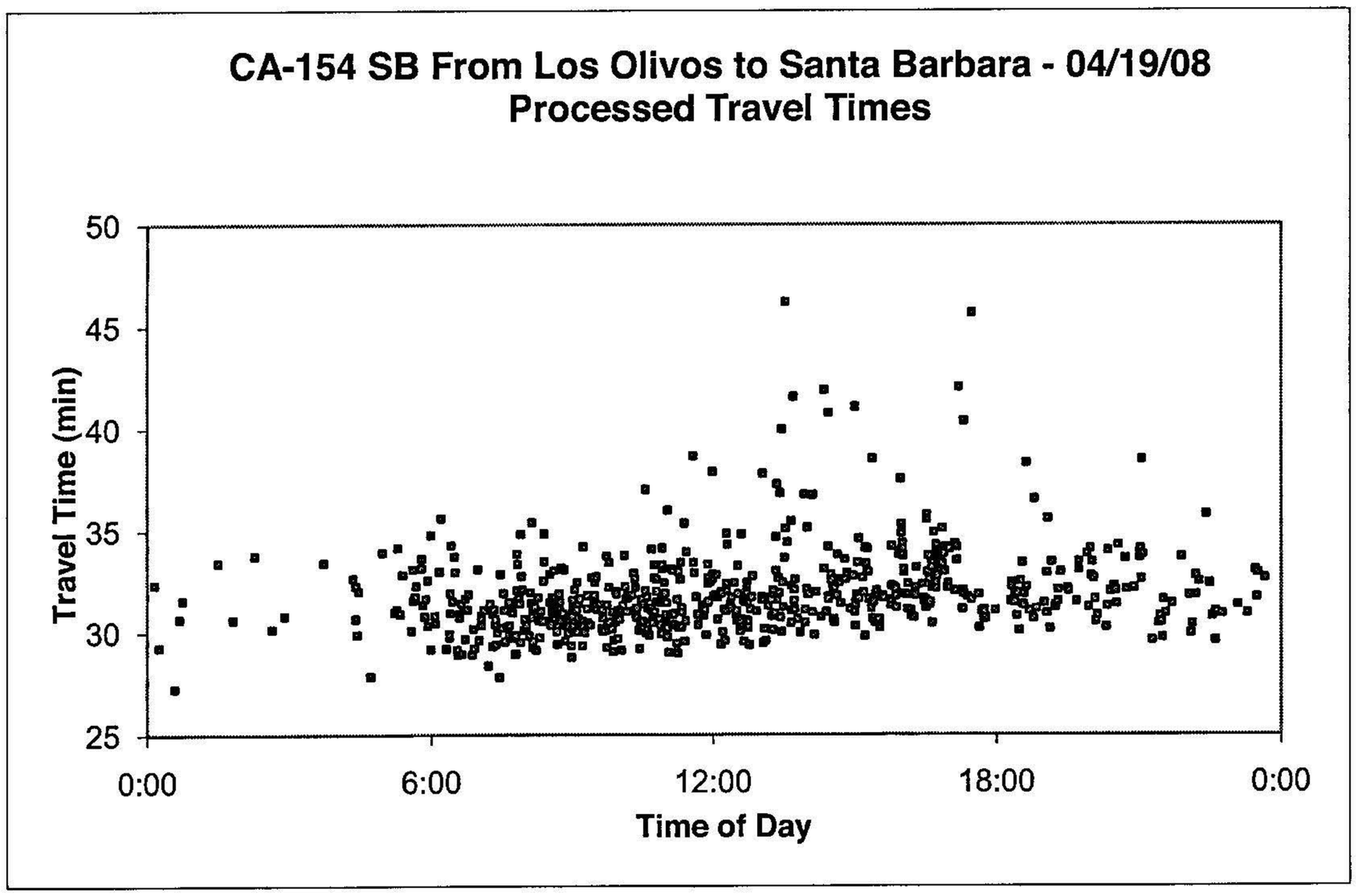

CA-154 NB From Los Olivos to Santa Barbara - 05/11/08
Raw Individual Travel Times
Travel Time (min)
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100
80
60
40
20
0
0:00
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12:00
18:00
0:00
Time of day

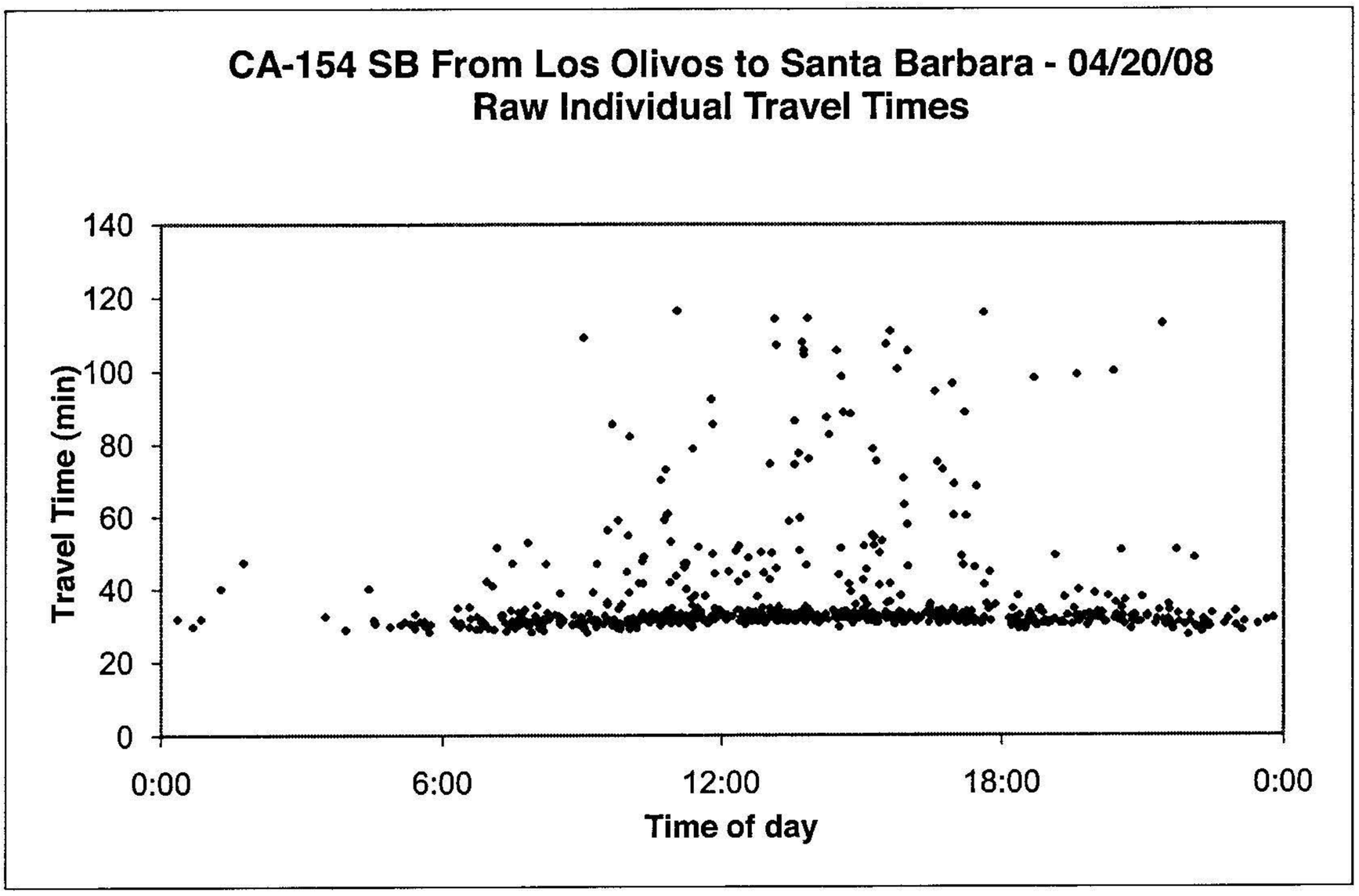

CA-154 NB From Los Olivos to Santa Barbara - 05/11/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

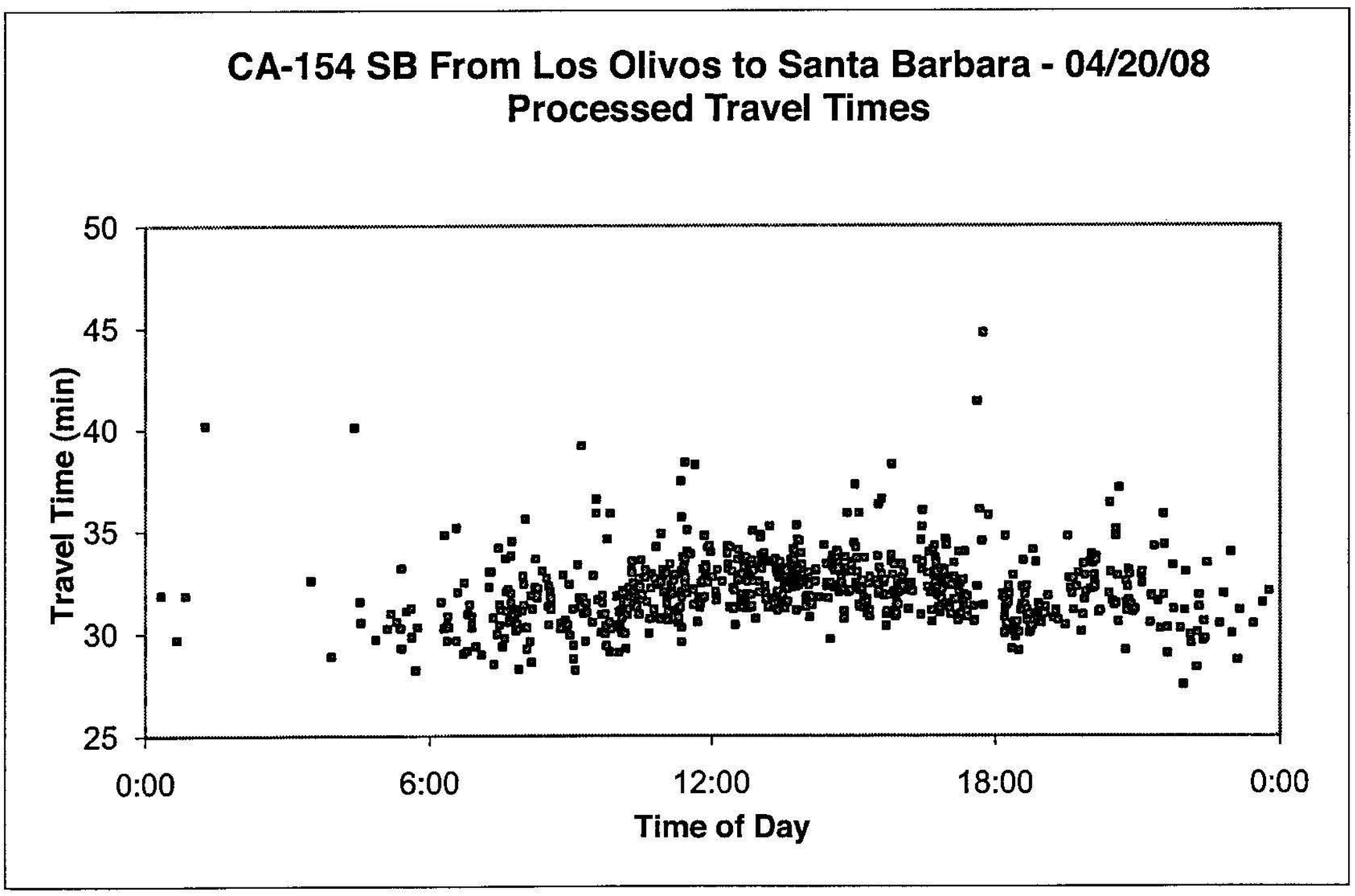

CA-154 SB From Los Olivos to Santa Barbara - 04/18/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

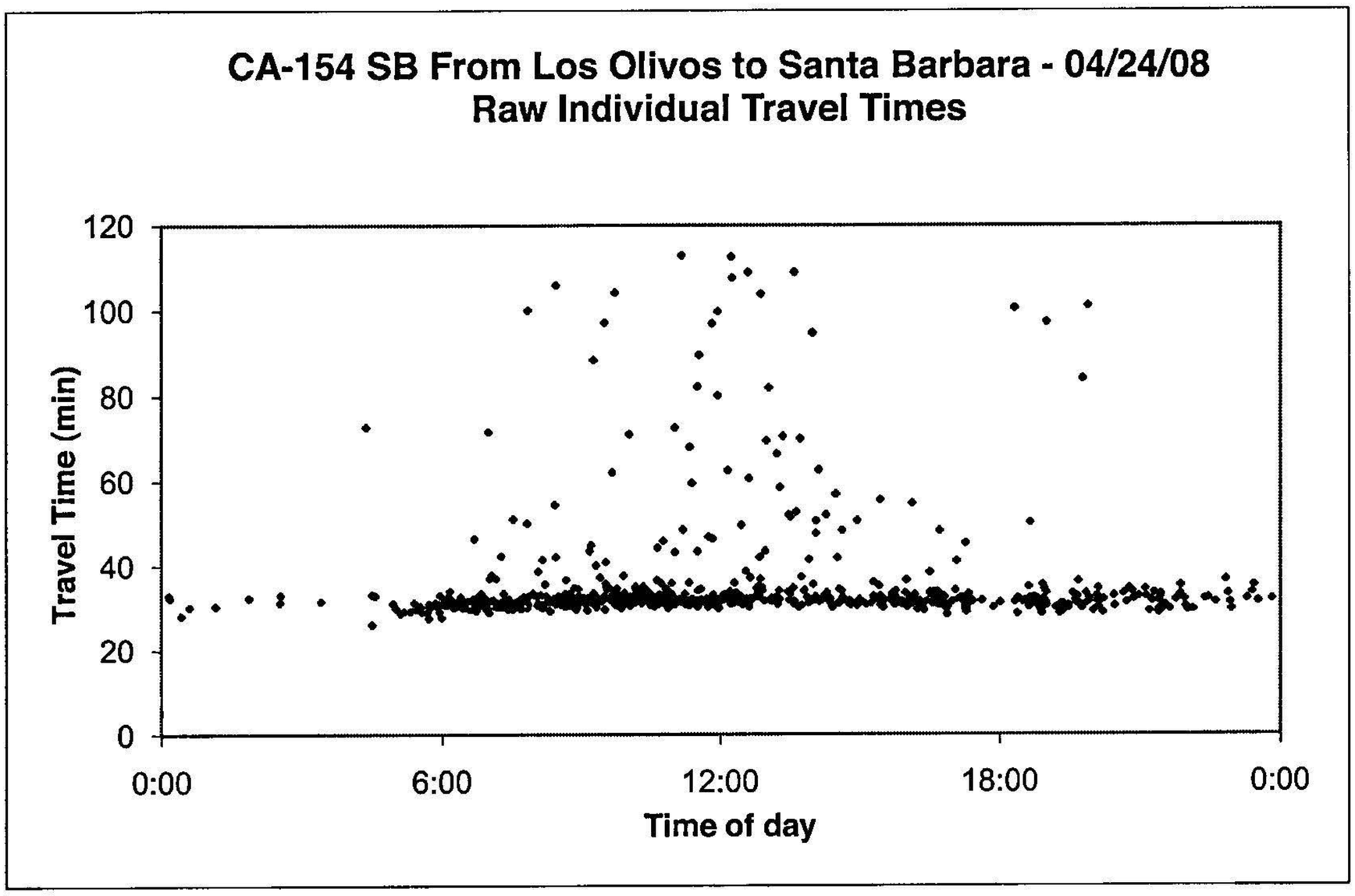

CA-154 SB From Los Olivos to Santa Barbara - 04/18/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

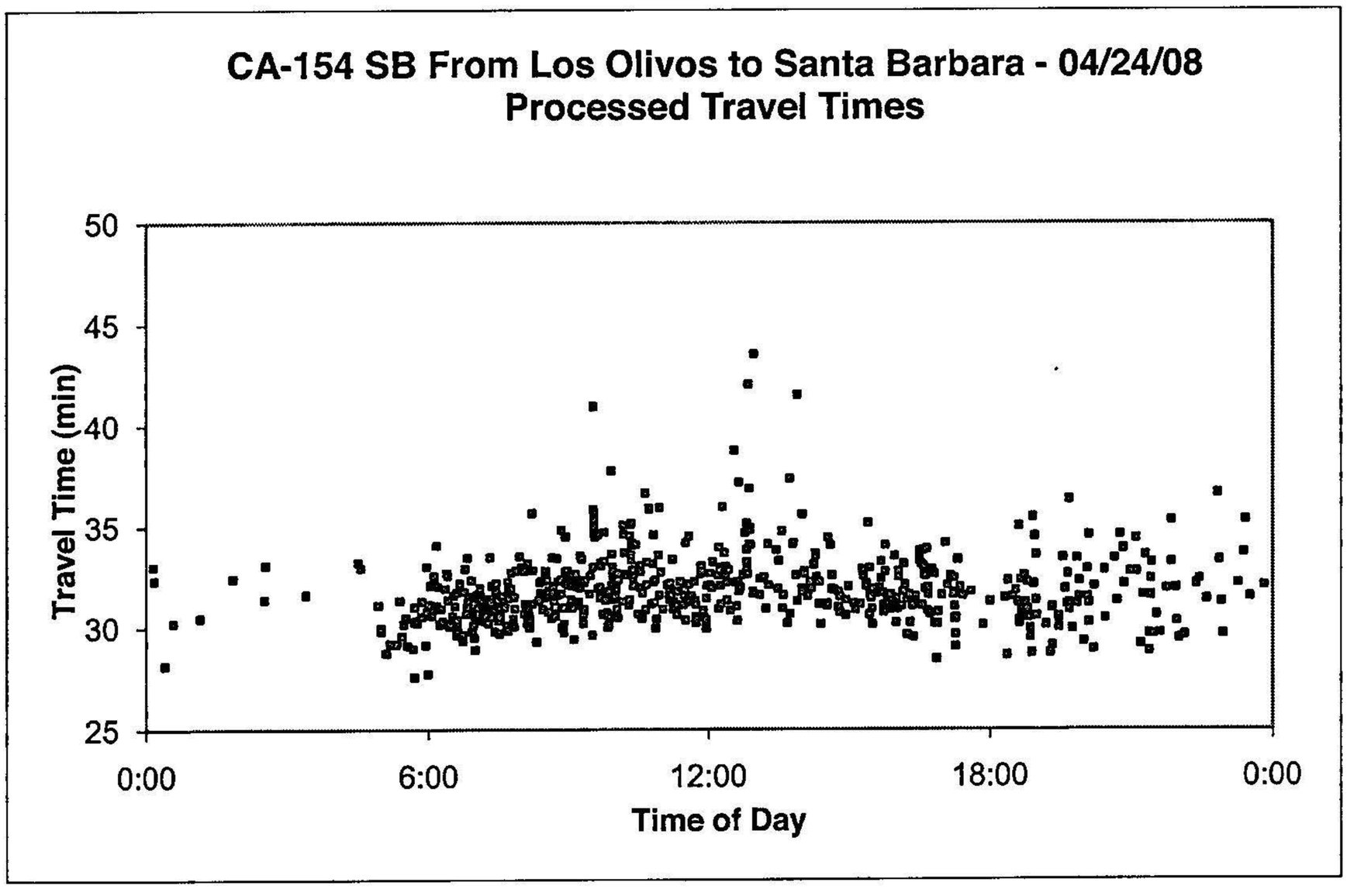

CA-154 SB From Los Olivos to Santa Barbara - 04/19/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

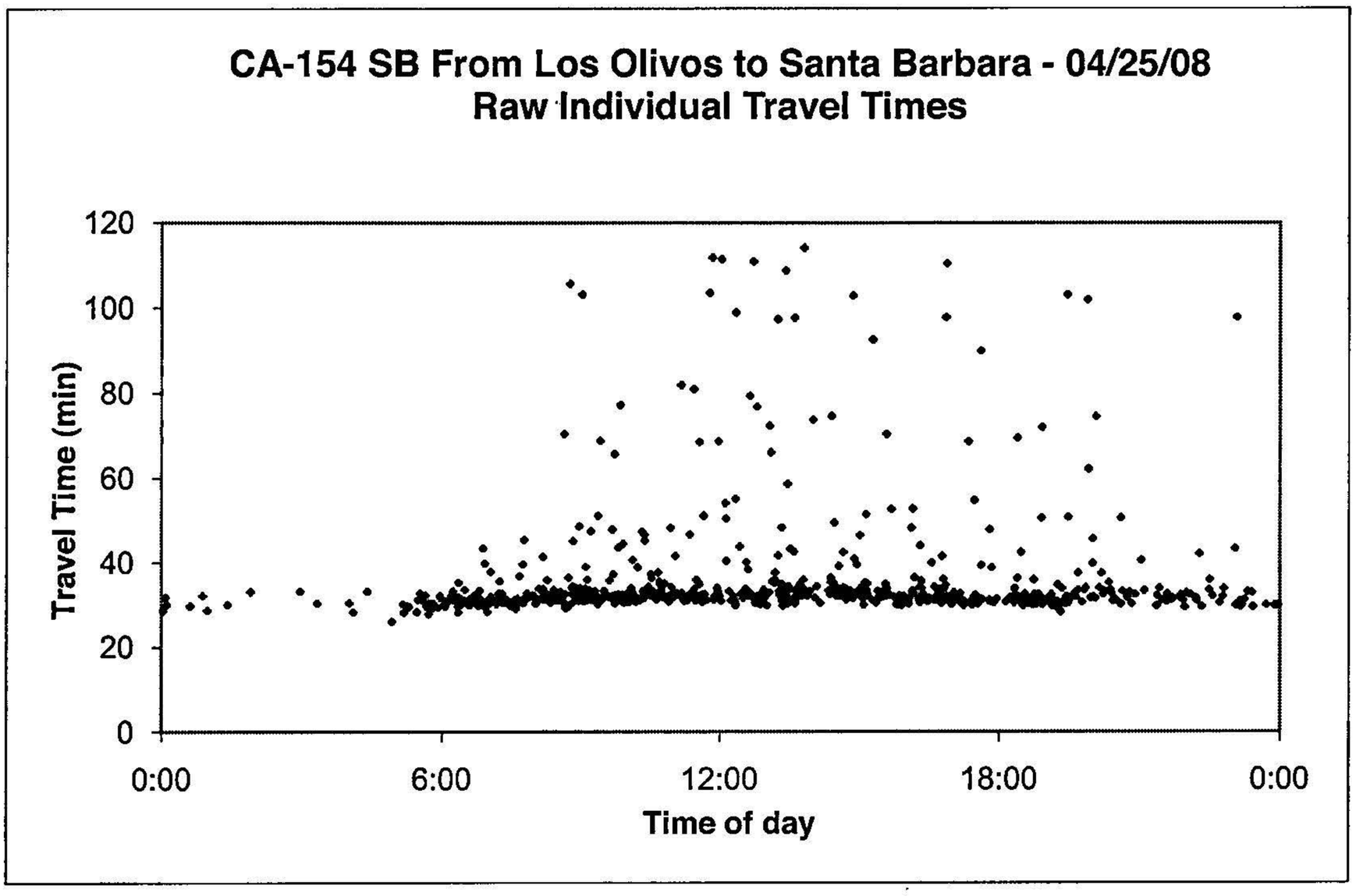

CA-154 SB From Los Olivos to Santa Barbara - 04/19/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

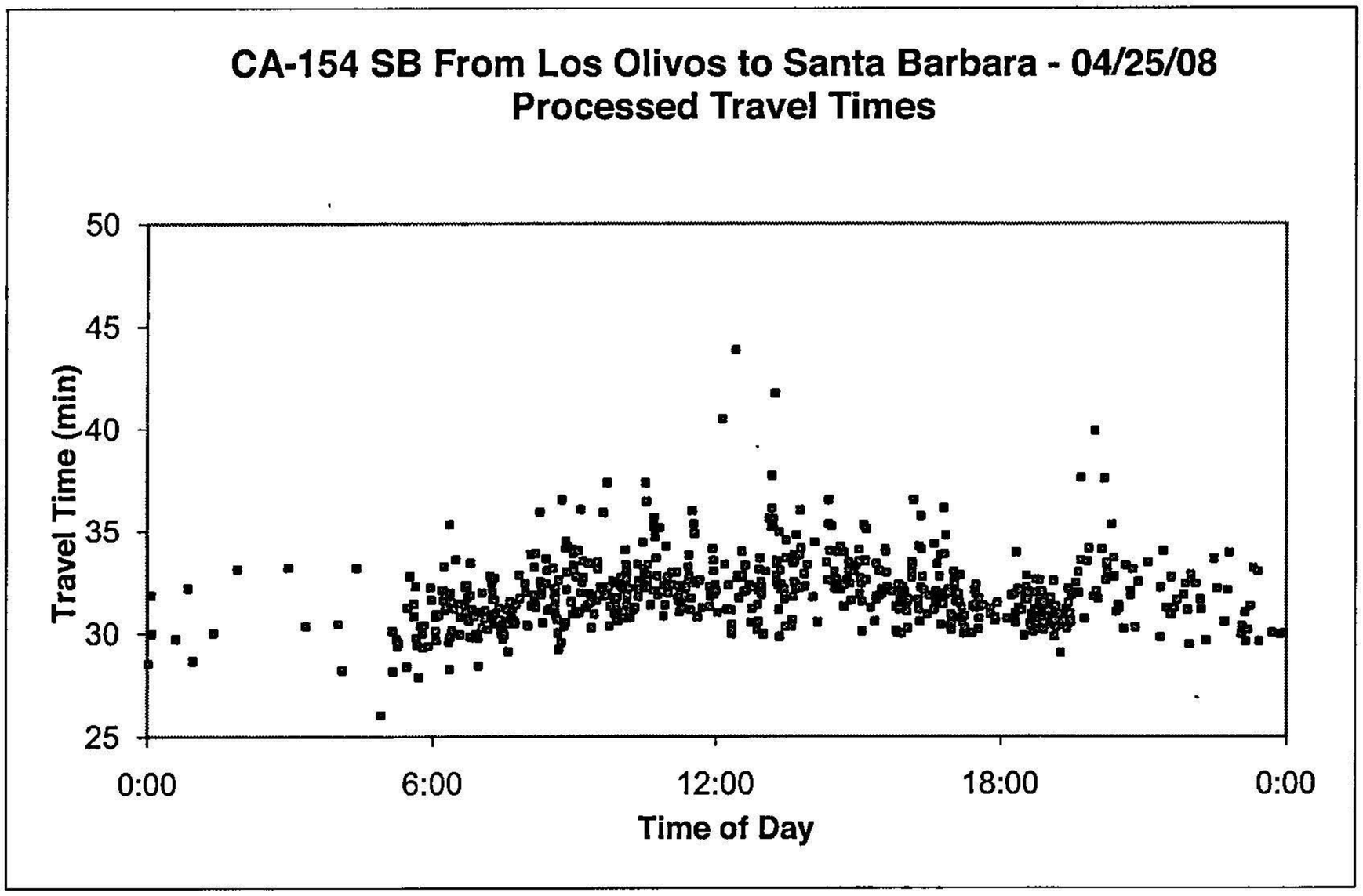

CA-154 SB From Los Olivos to Santa Barbara - 04/20/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

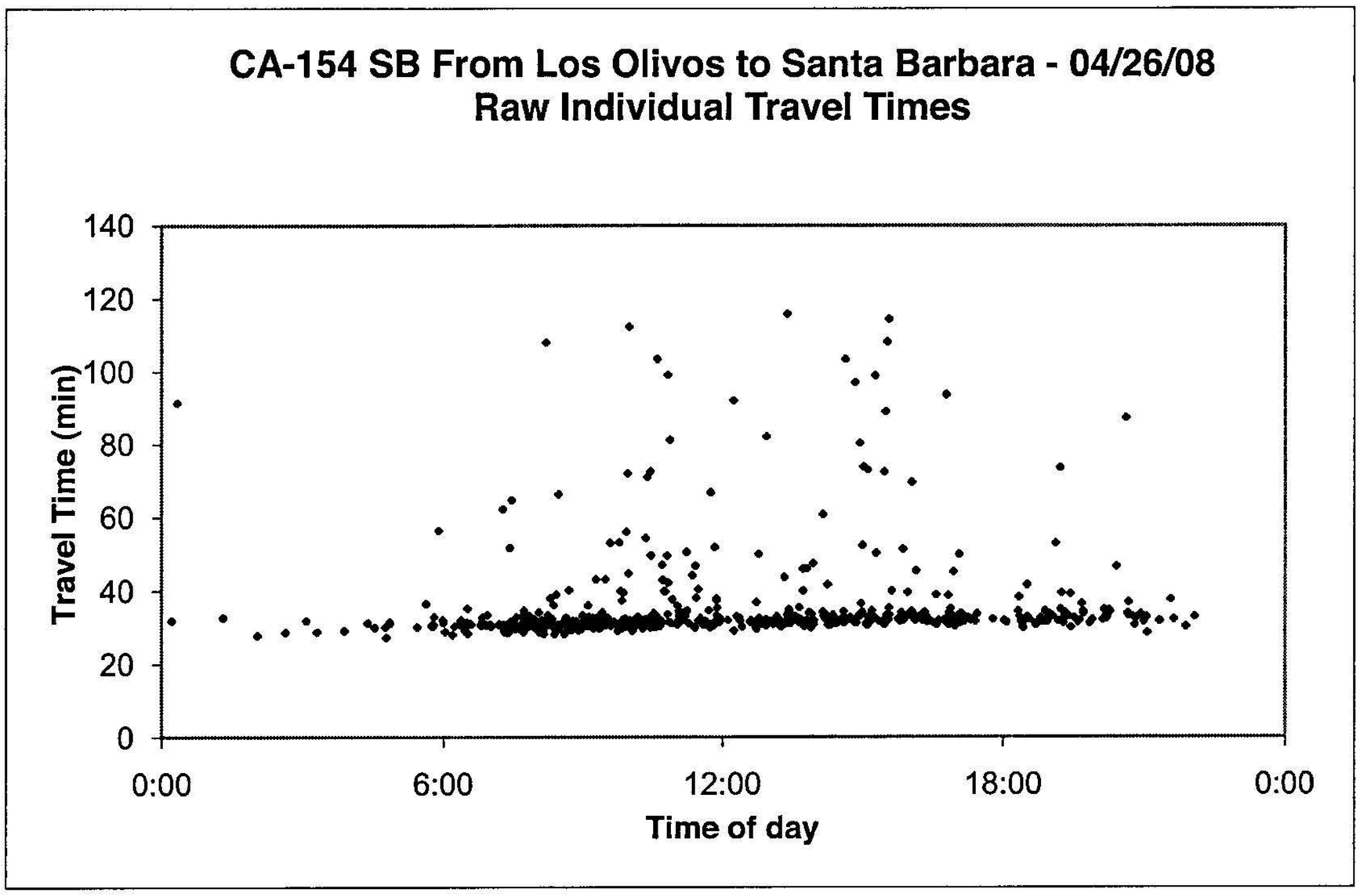

CA-154 SB From Los Olivos to Santa Barbara - 04/20/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

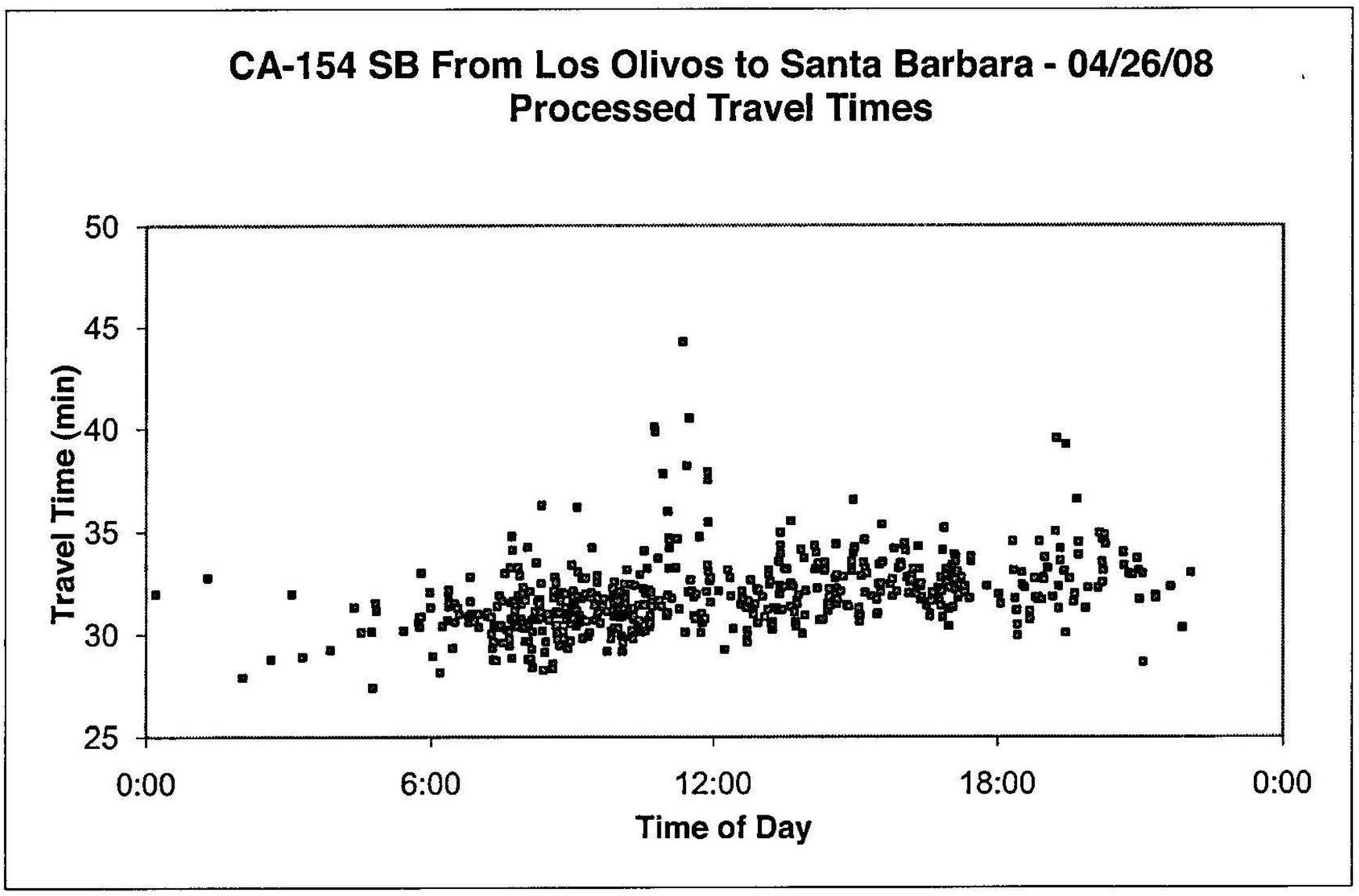

CA-154 SB From Los Olivos to Santa Barbara - 04/24/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

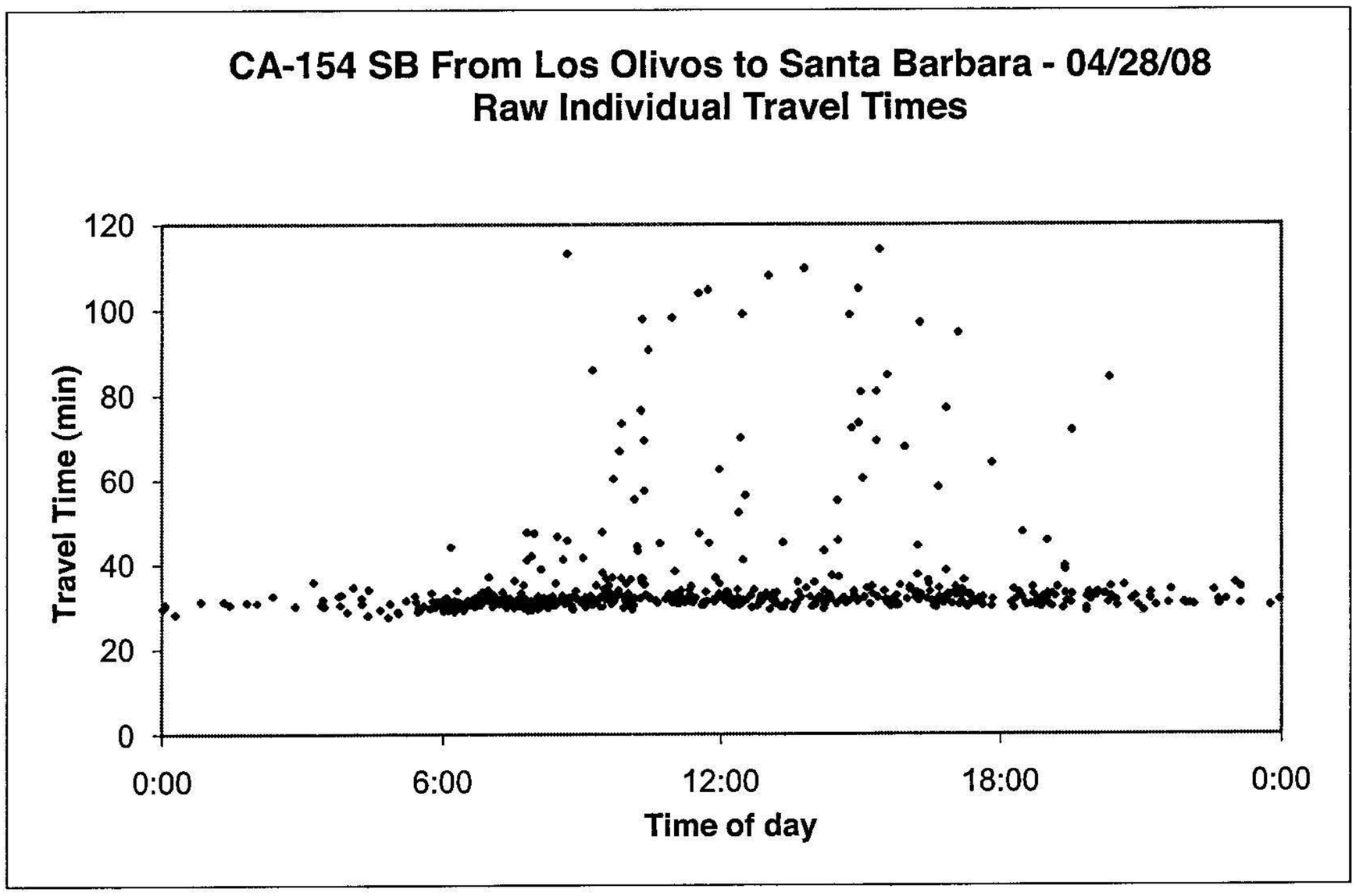

CA-154 SB From Los Olivos to Santa Barbara - 04/24/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

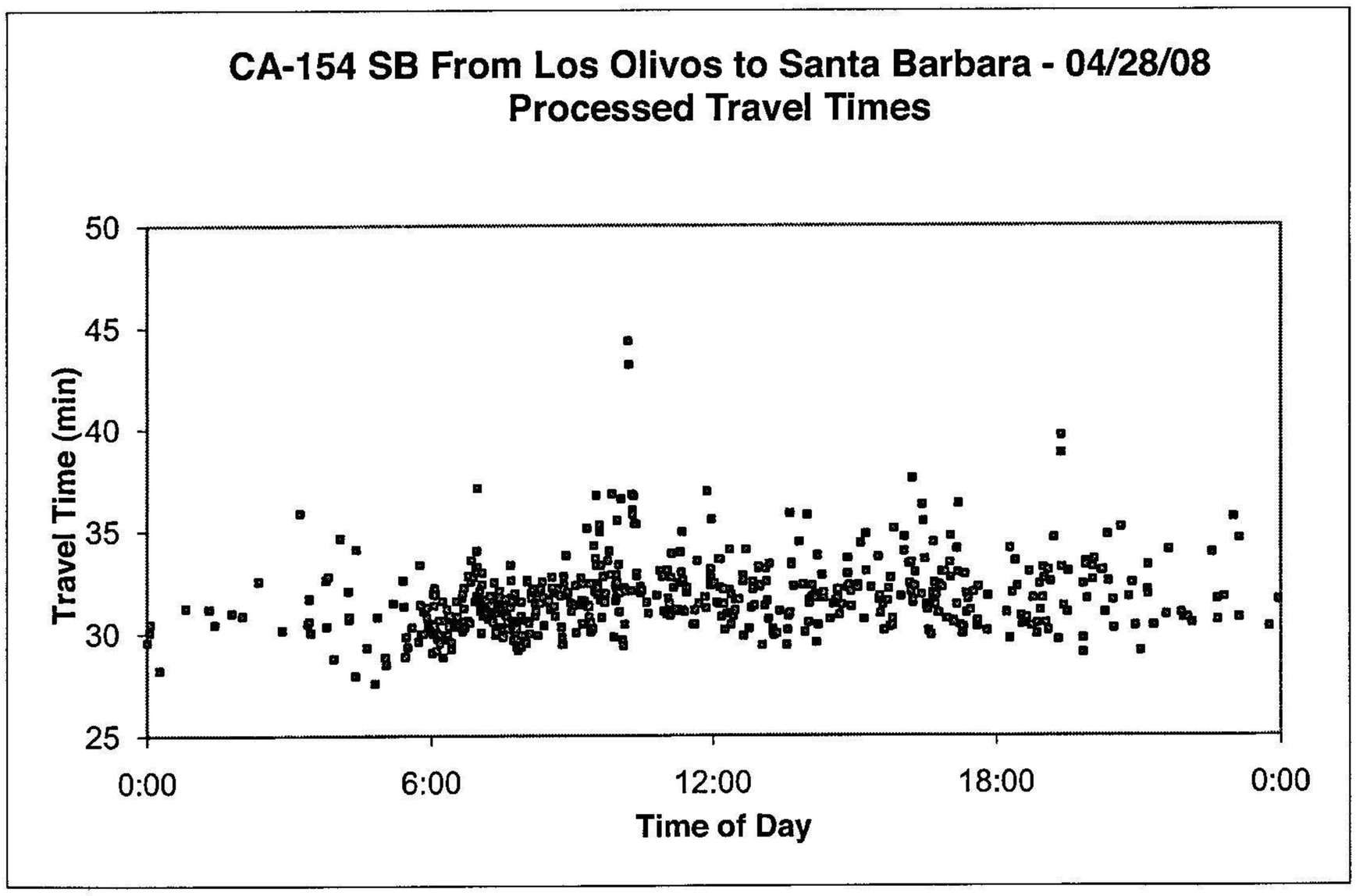

CA-154 SB From Los Olivos to Santa Barbara - 04/25/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


CA-154 SB From Los Olivos to Santa Barbara - 04/25/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

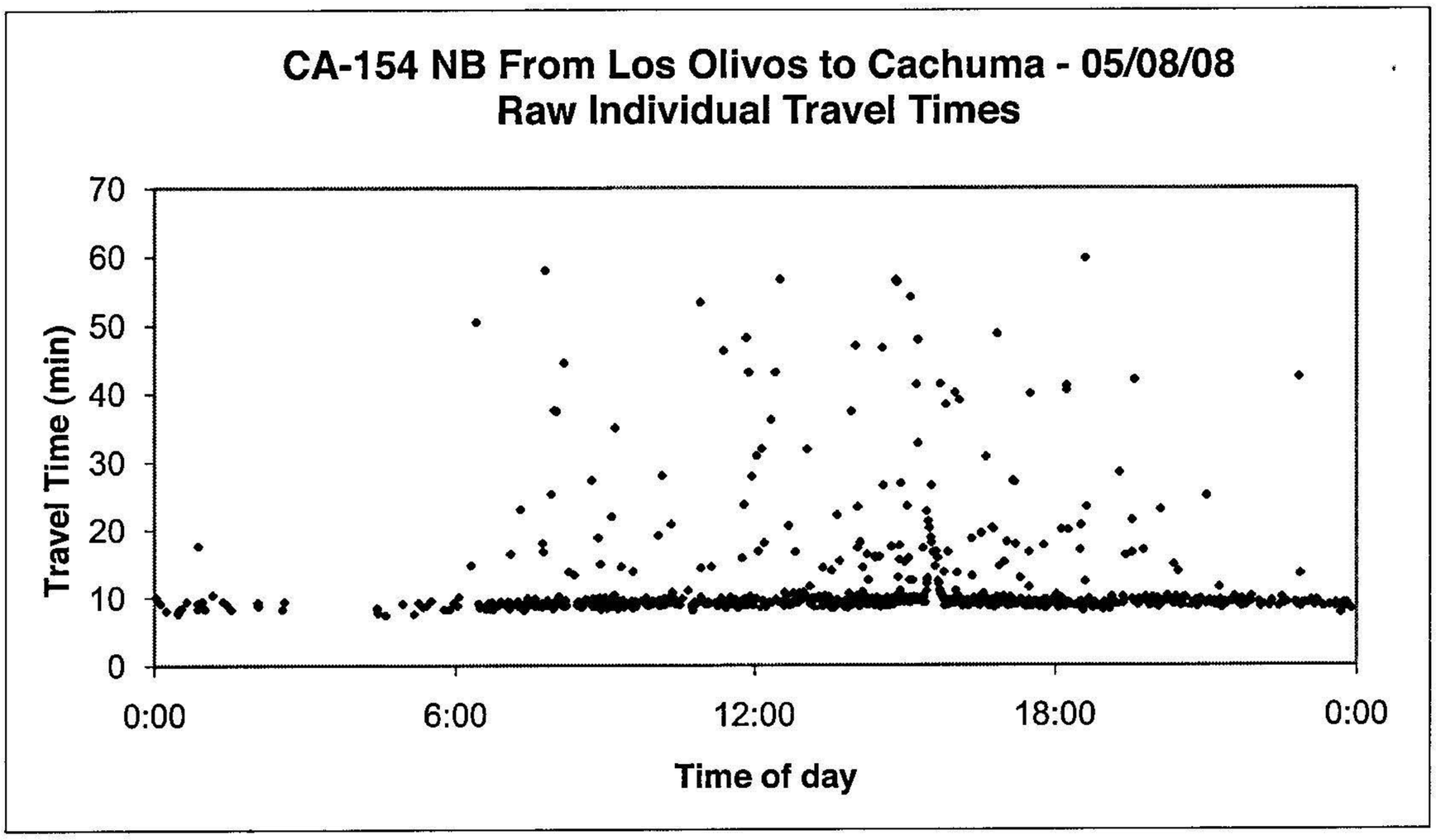

CA-154 SB From Los Olivos to Santa Barbara - 04/26/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

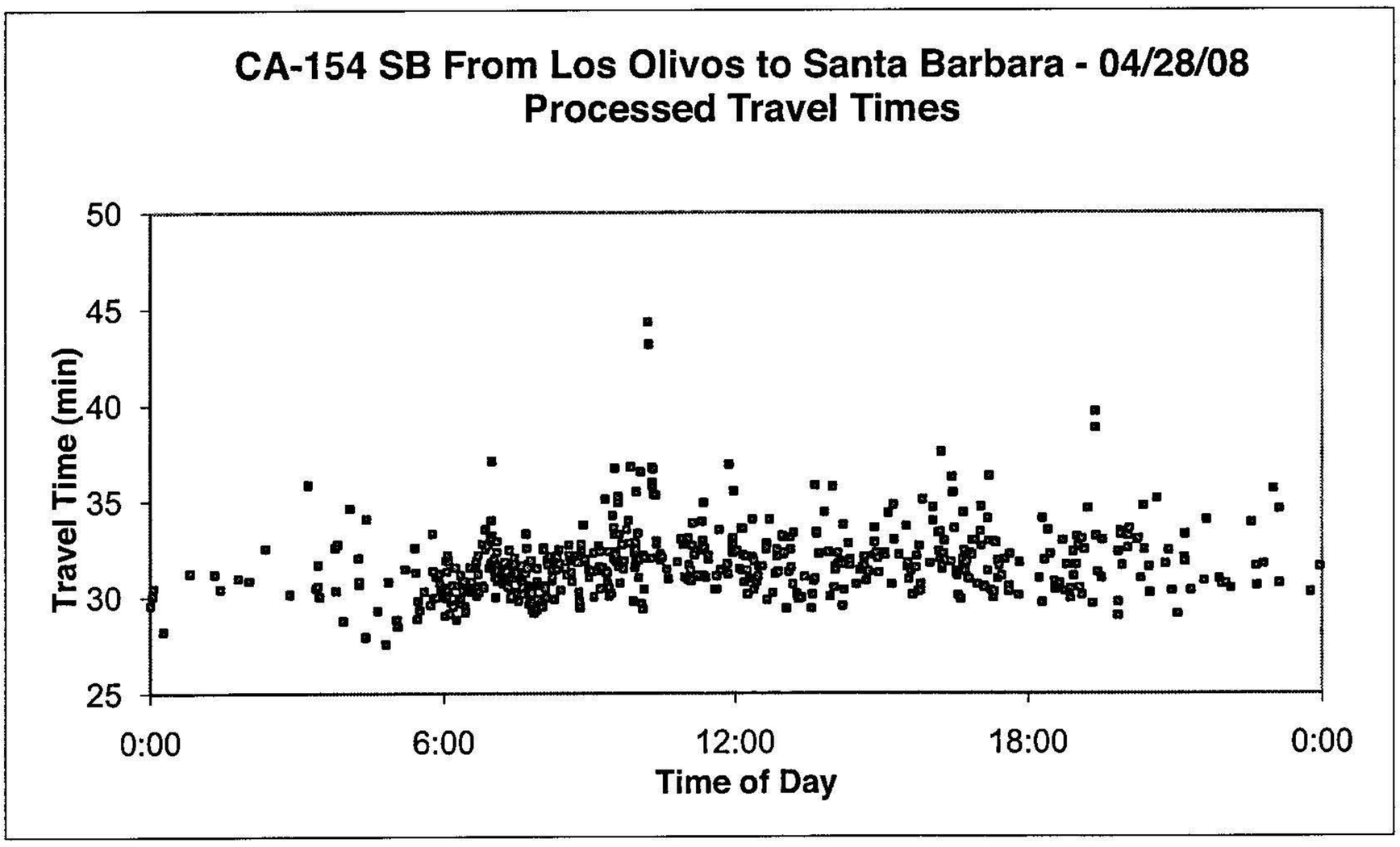

CA-154 SB From Los Olivos to Santa Barbara - 04/26/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

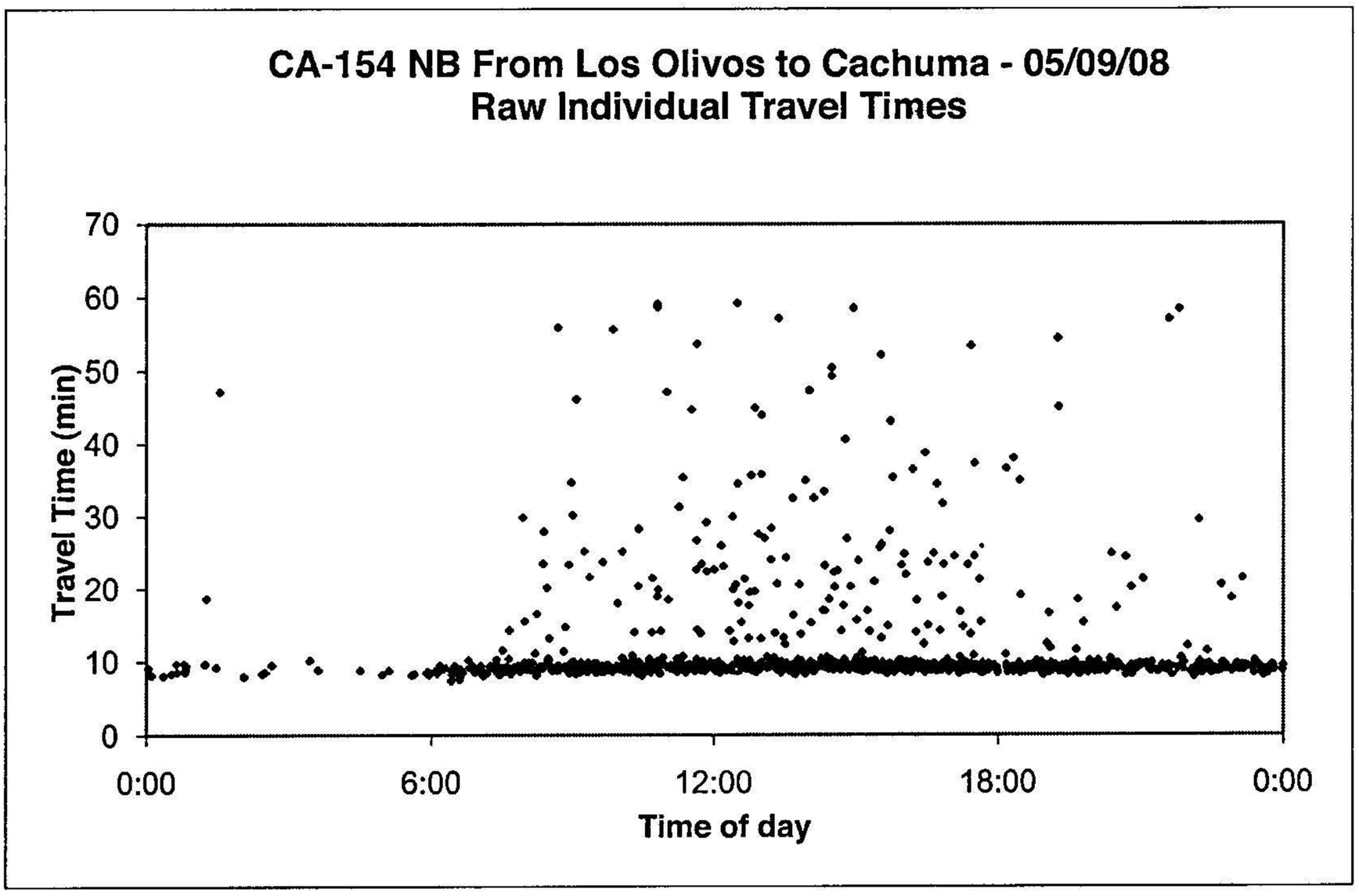

CA-154 SB From Los Olivos to Santa Barbara - 04/28/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

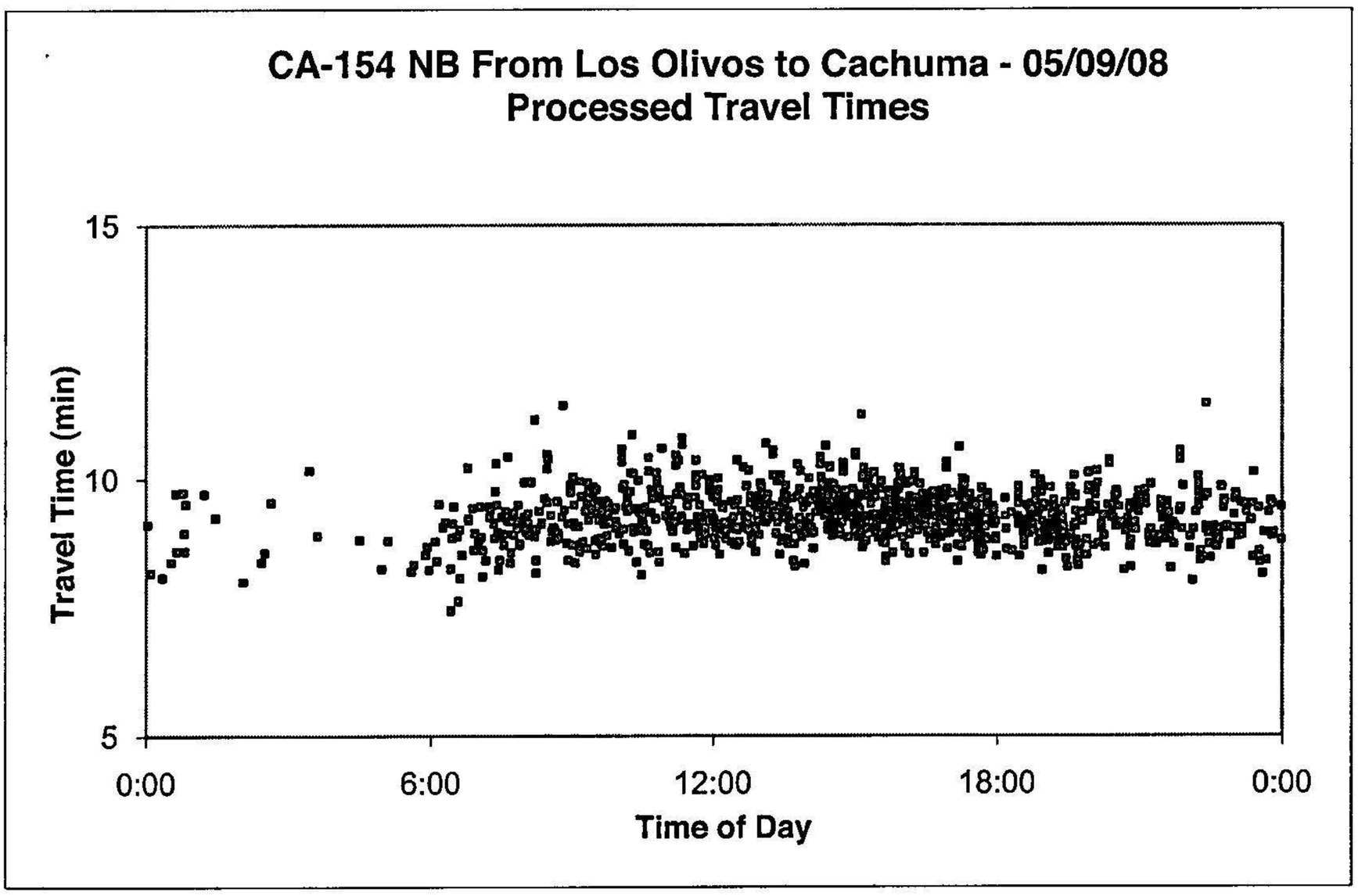

CA-154 SB From Los Olivos to Santa Barbara - 04/28/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
0:00
6:00
12:00
18:00
0:00
Time of Day

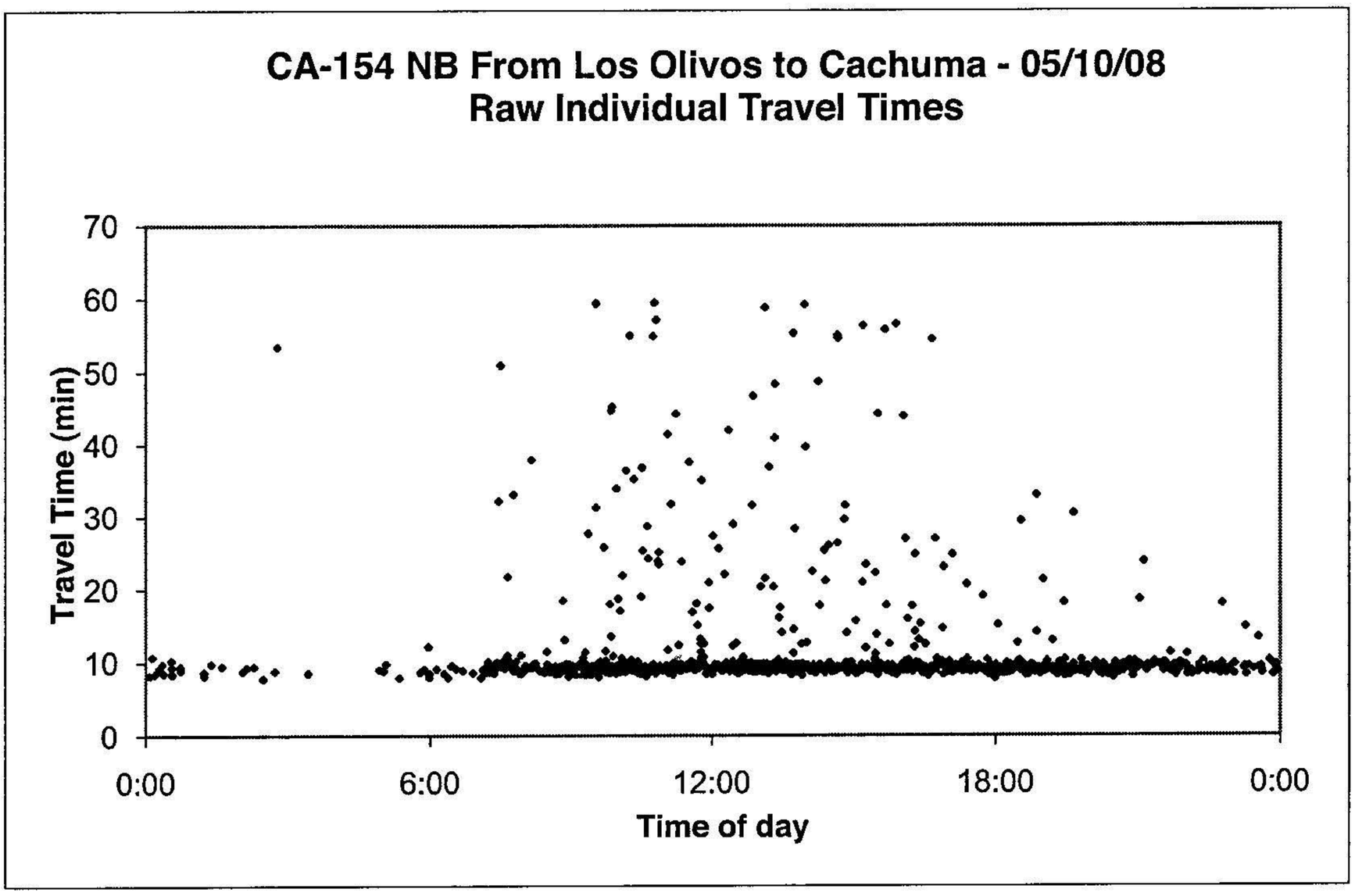
C.2 CA-154 From Los Olivos to Cachuma Travel Time Distribution

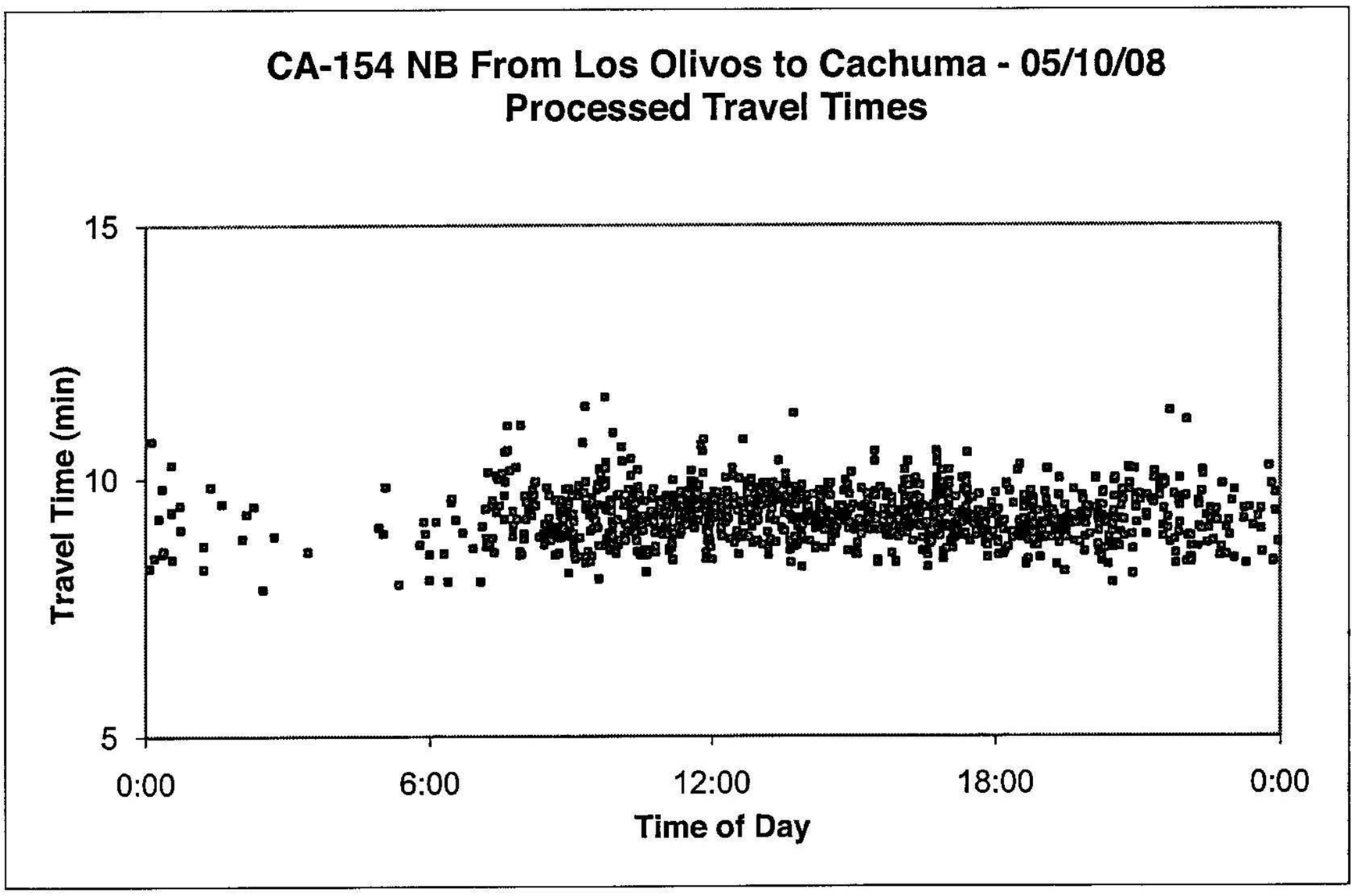


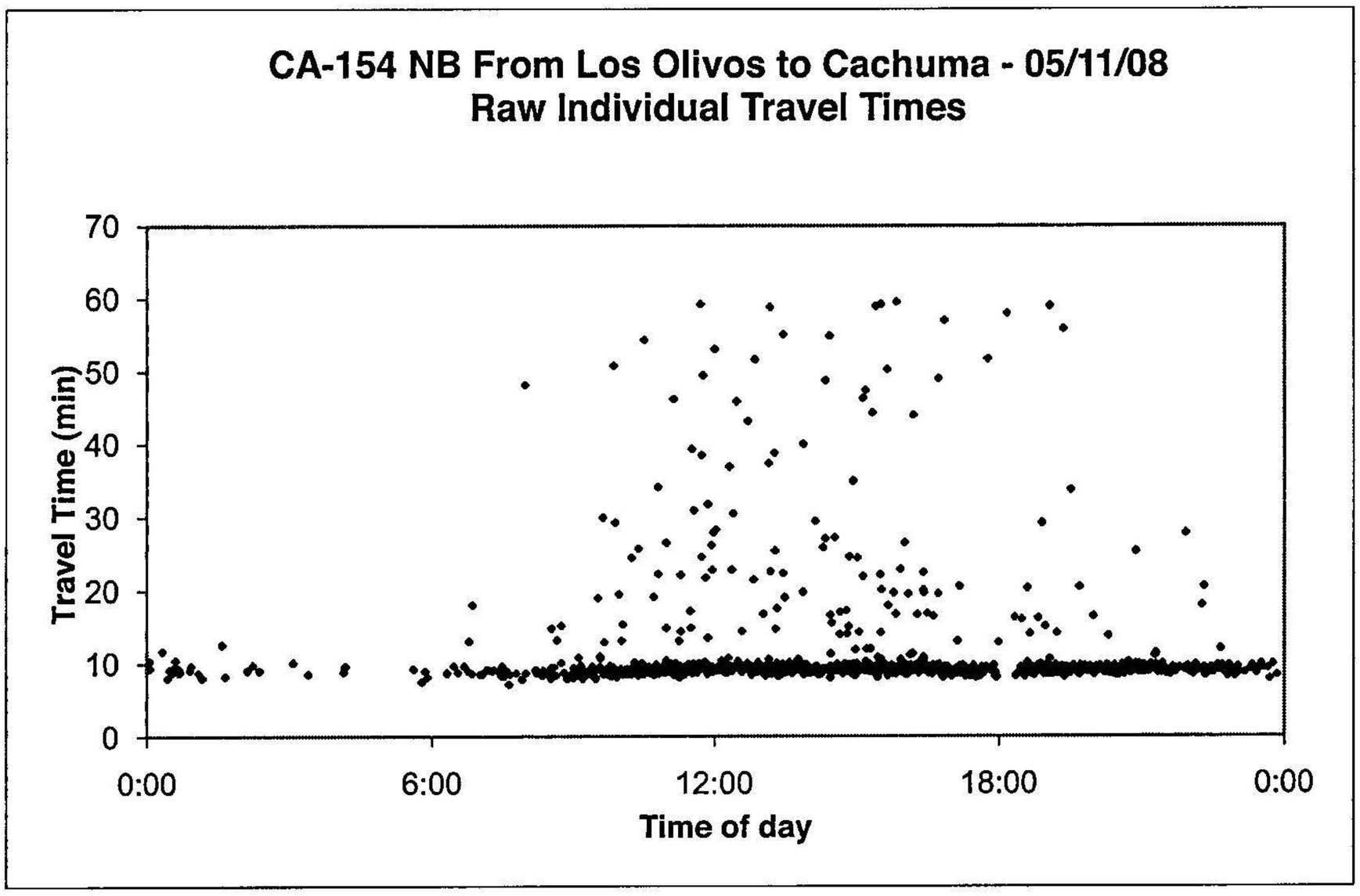


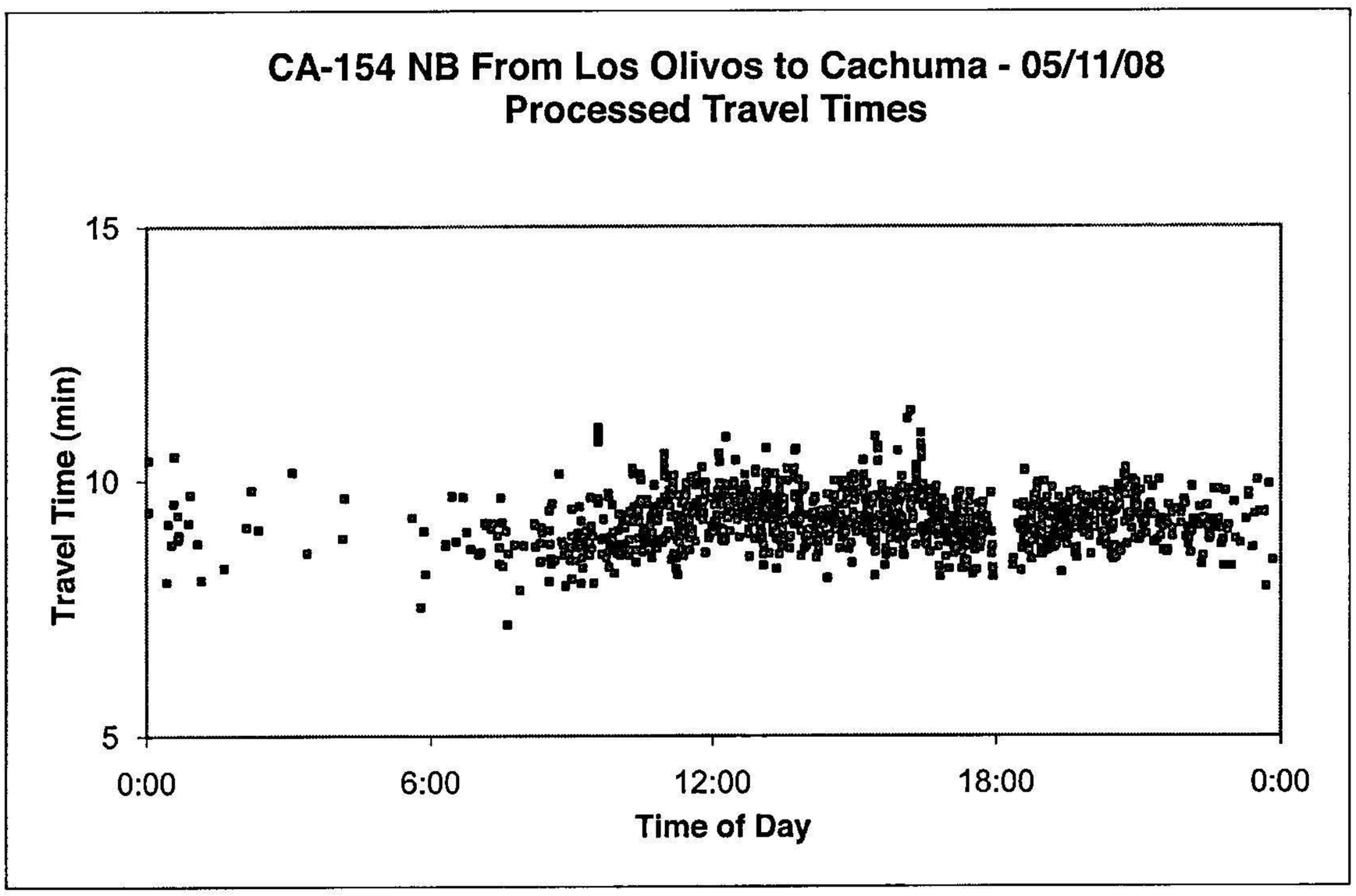

CA-154 NB From Los Olivos to Cachuma - 05/09/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

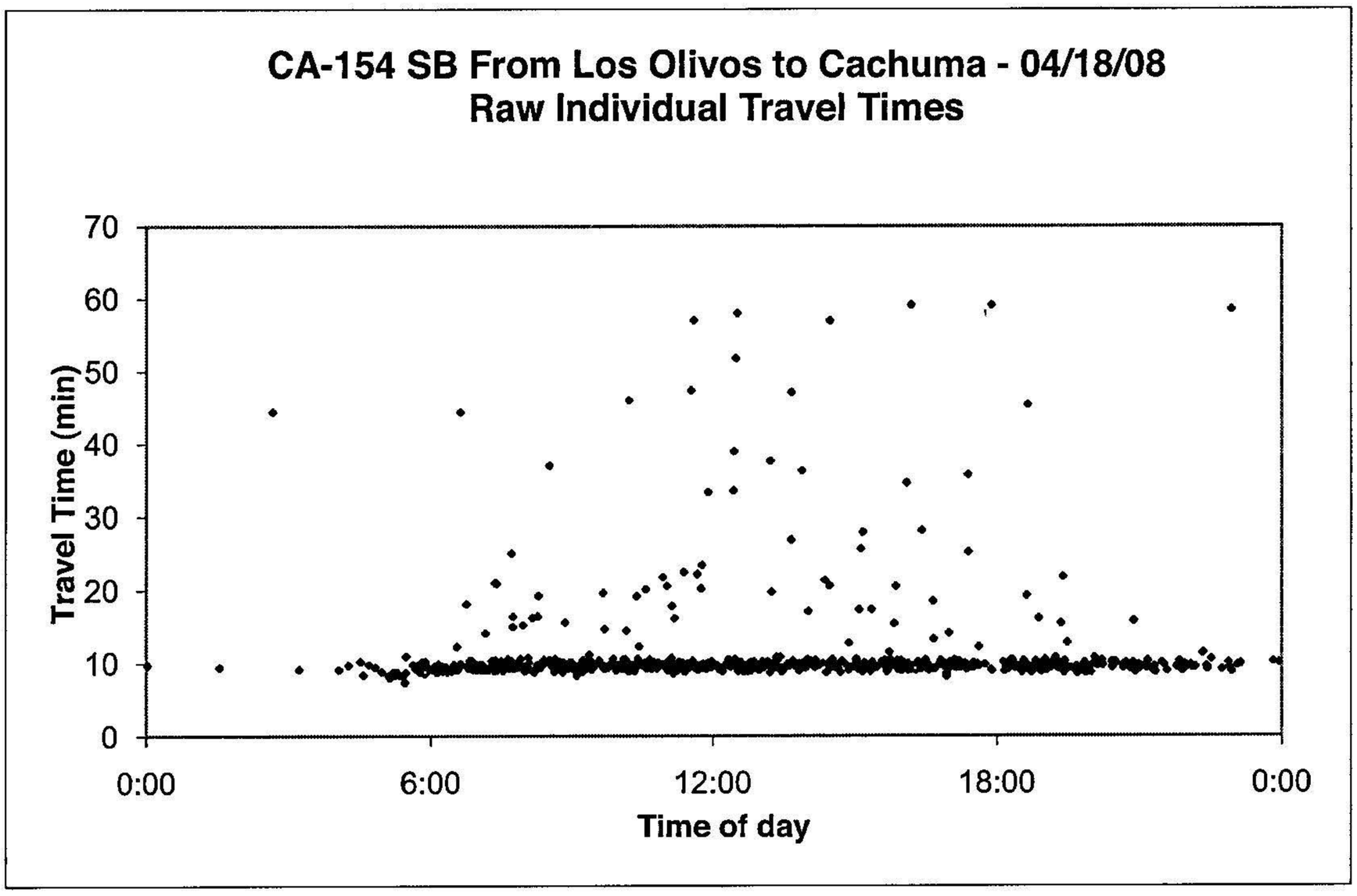

CA-154 NB From Los Olivos to Cachuma - 05/09/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

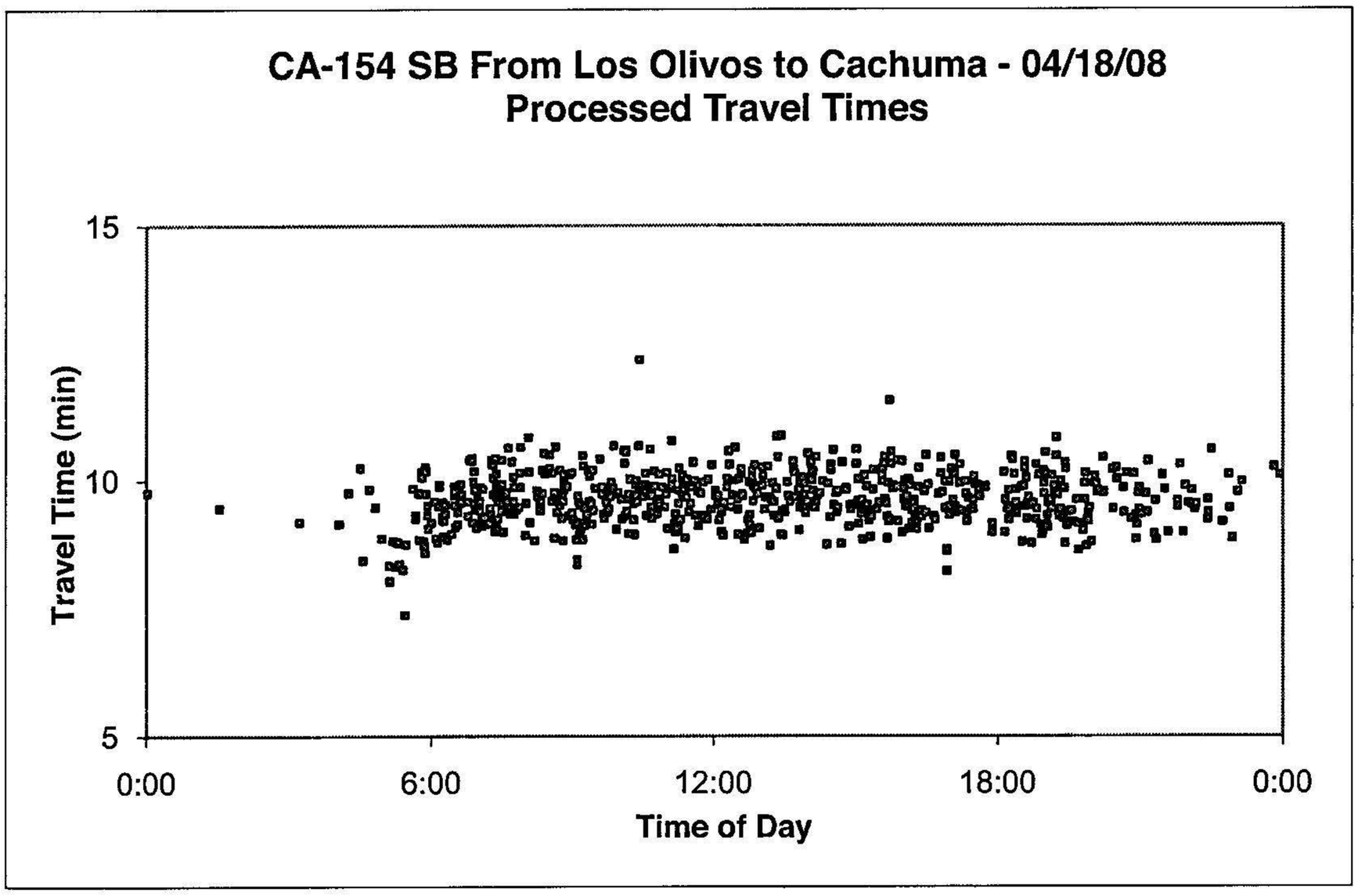

CA-154 NB From Los Olivos to Cachuma - 05/10/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

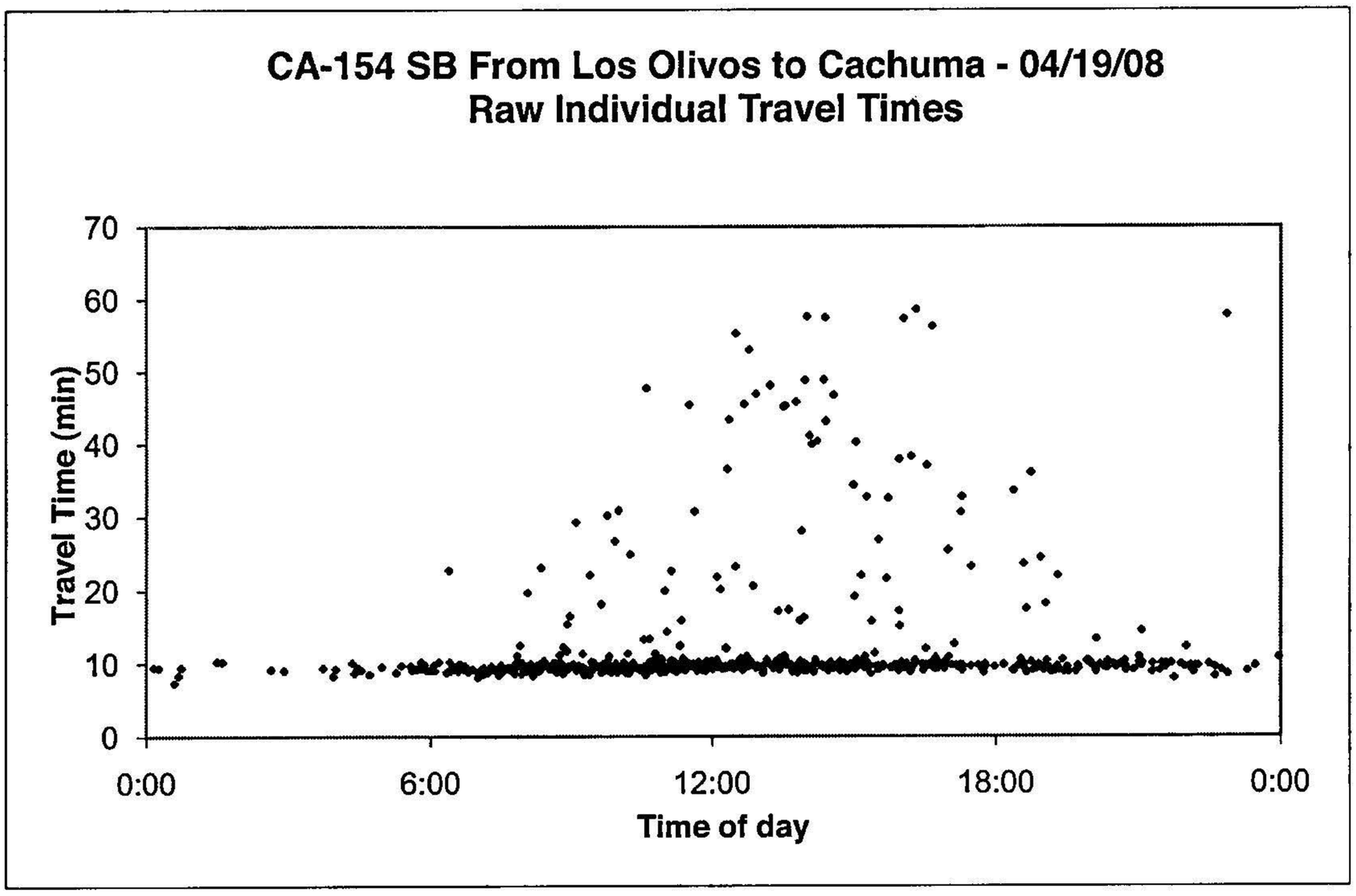

CA-154 NB From Los Olivos to Cachuma - 05/10/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

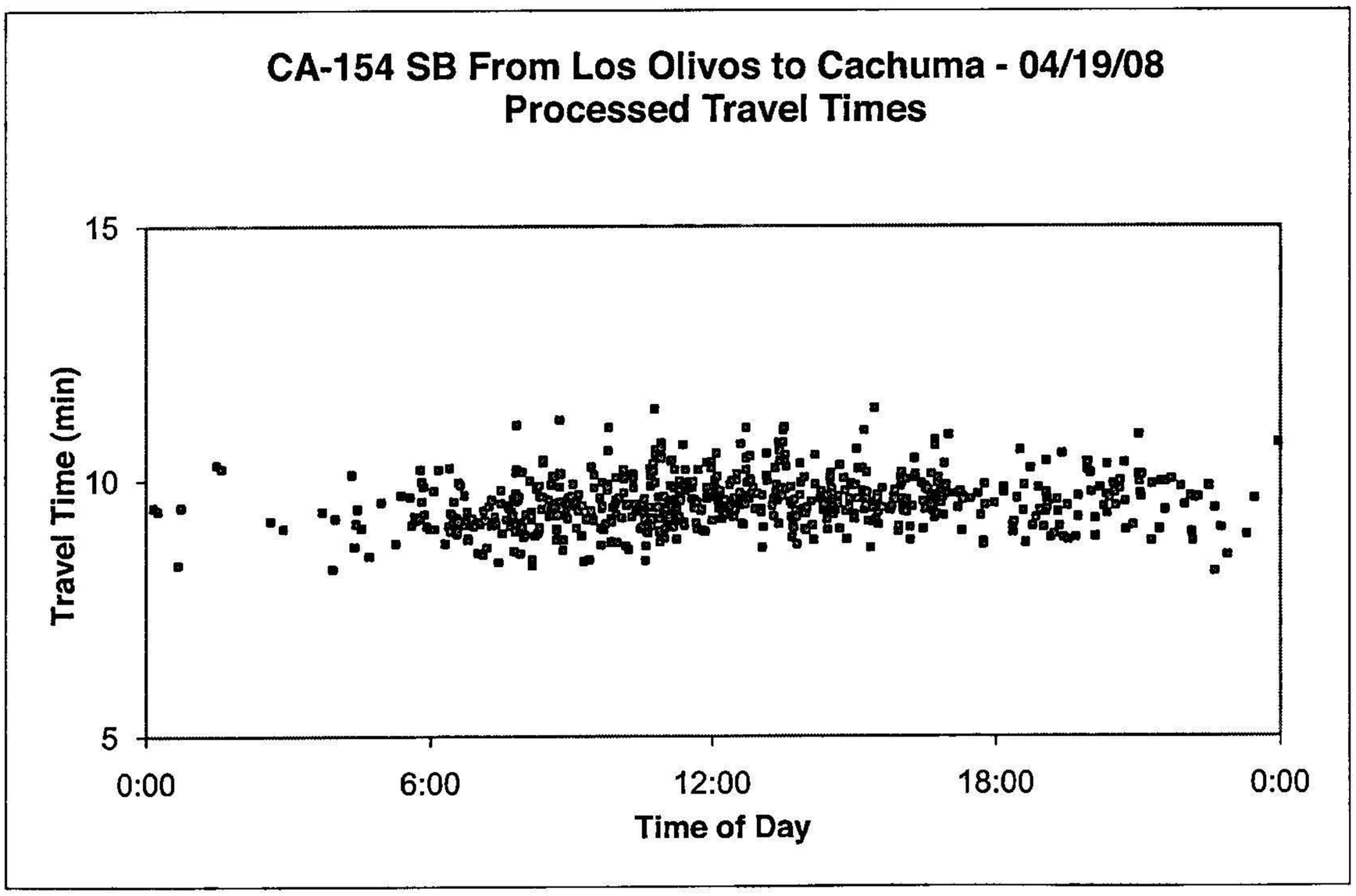

CA-154 NB From Los Olivos to Cachuma - 05/11/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

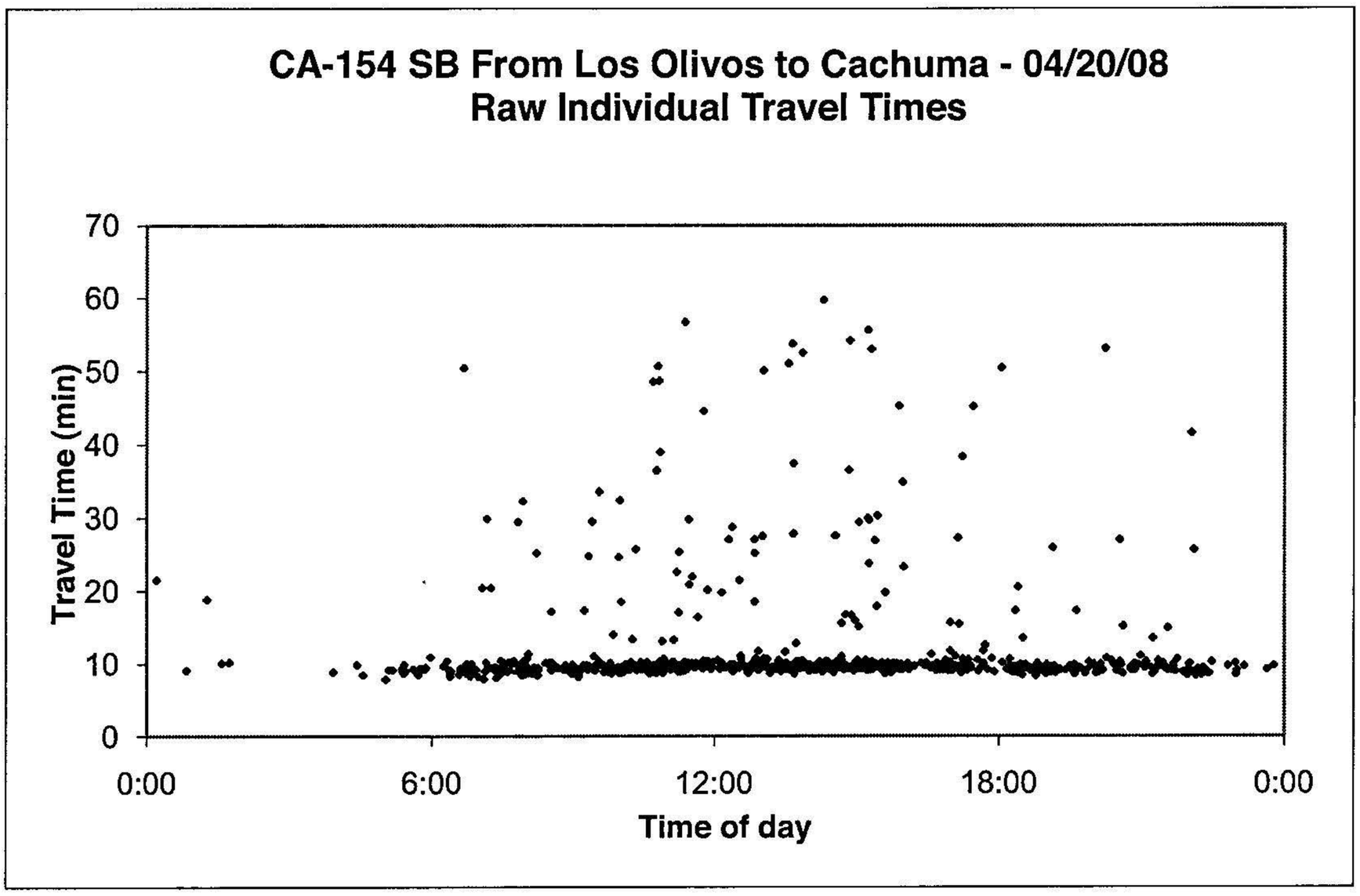

CA-154 NB From Los Olivos to Cachuma - 05/11/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

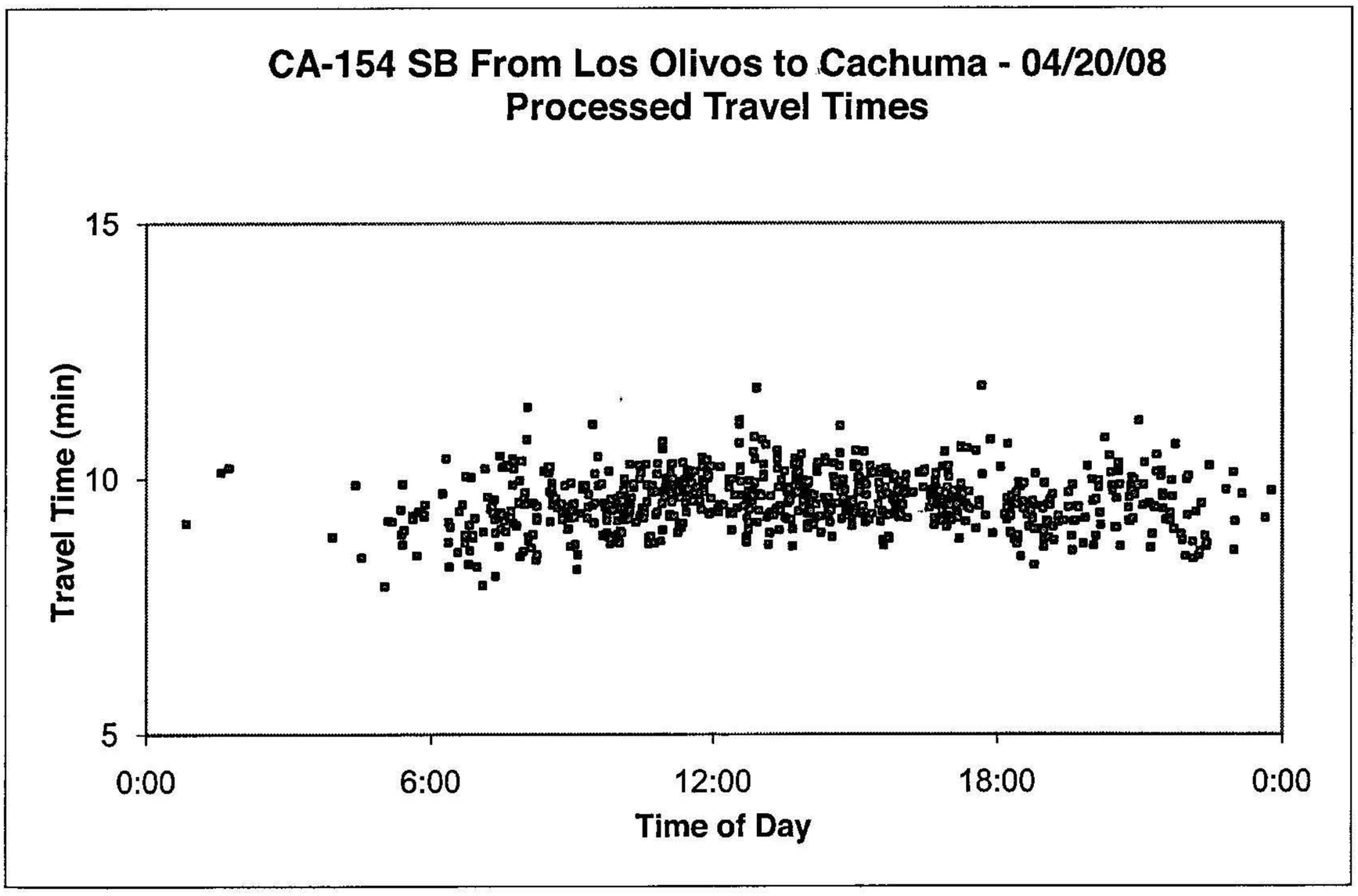

CA-154 SB From Los Olivos to Cachuma - 04/18/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

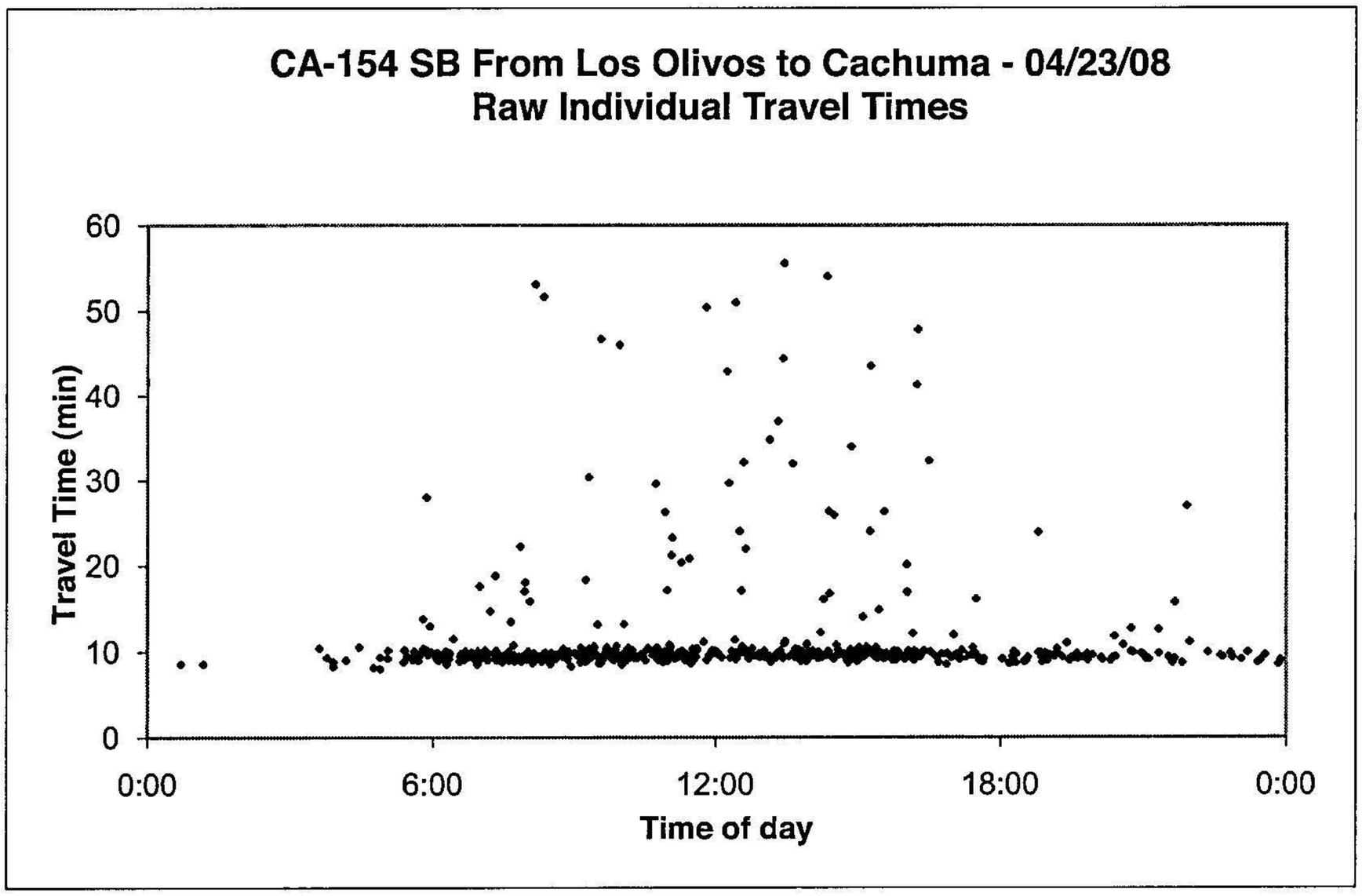

CA-154 SB From Los Olivos to Cachuma - 04/18/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

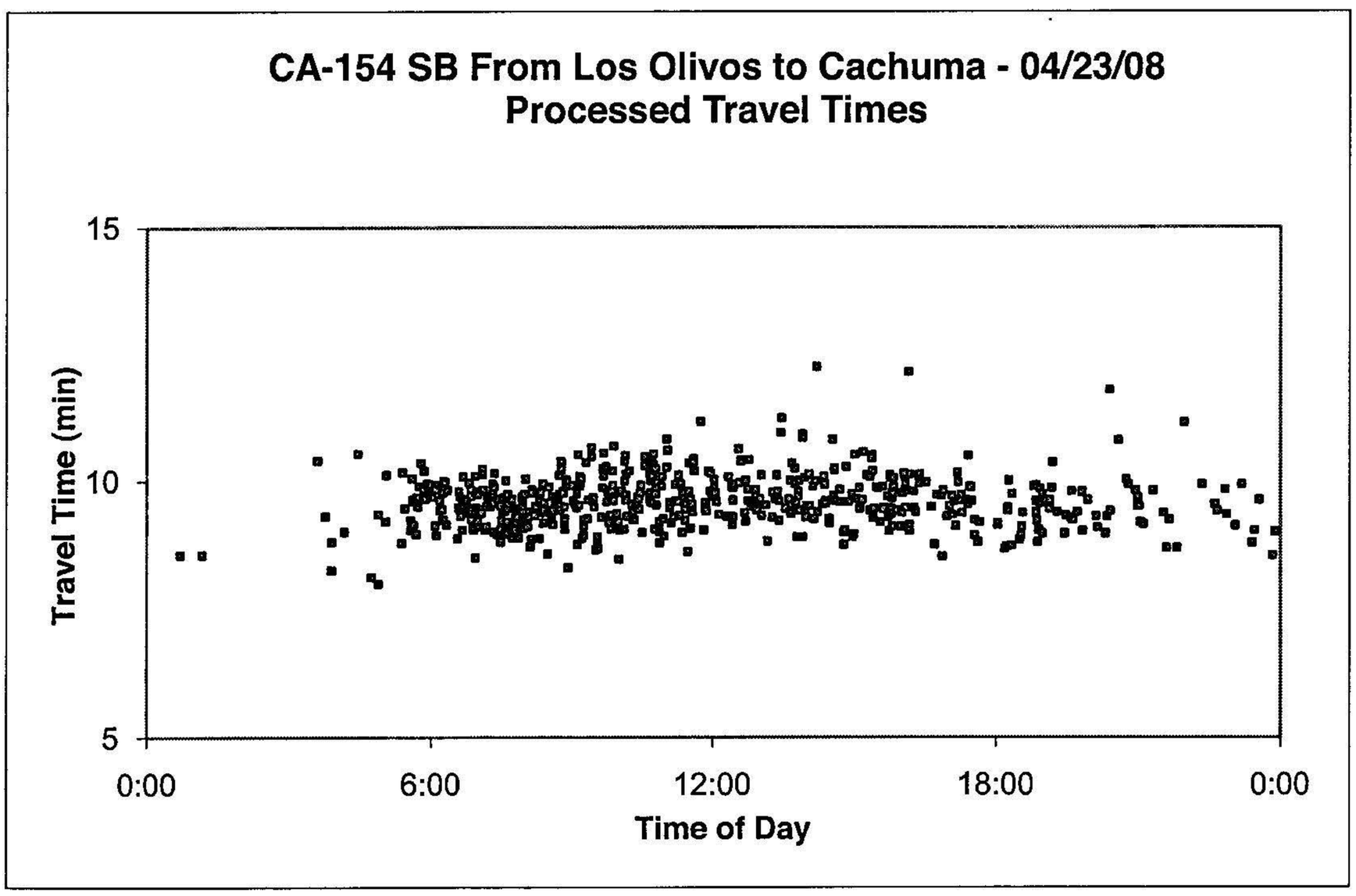

CA-154 SB From Los Olivos to Cachuma - 04/19/08
Raw Individual Travel Times
Travel Time (min)
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60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

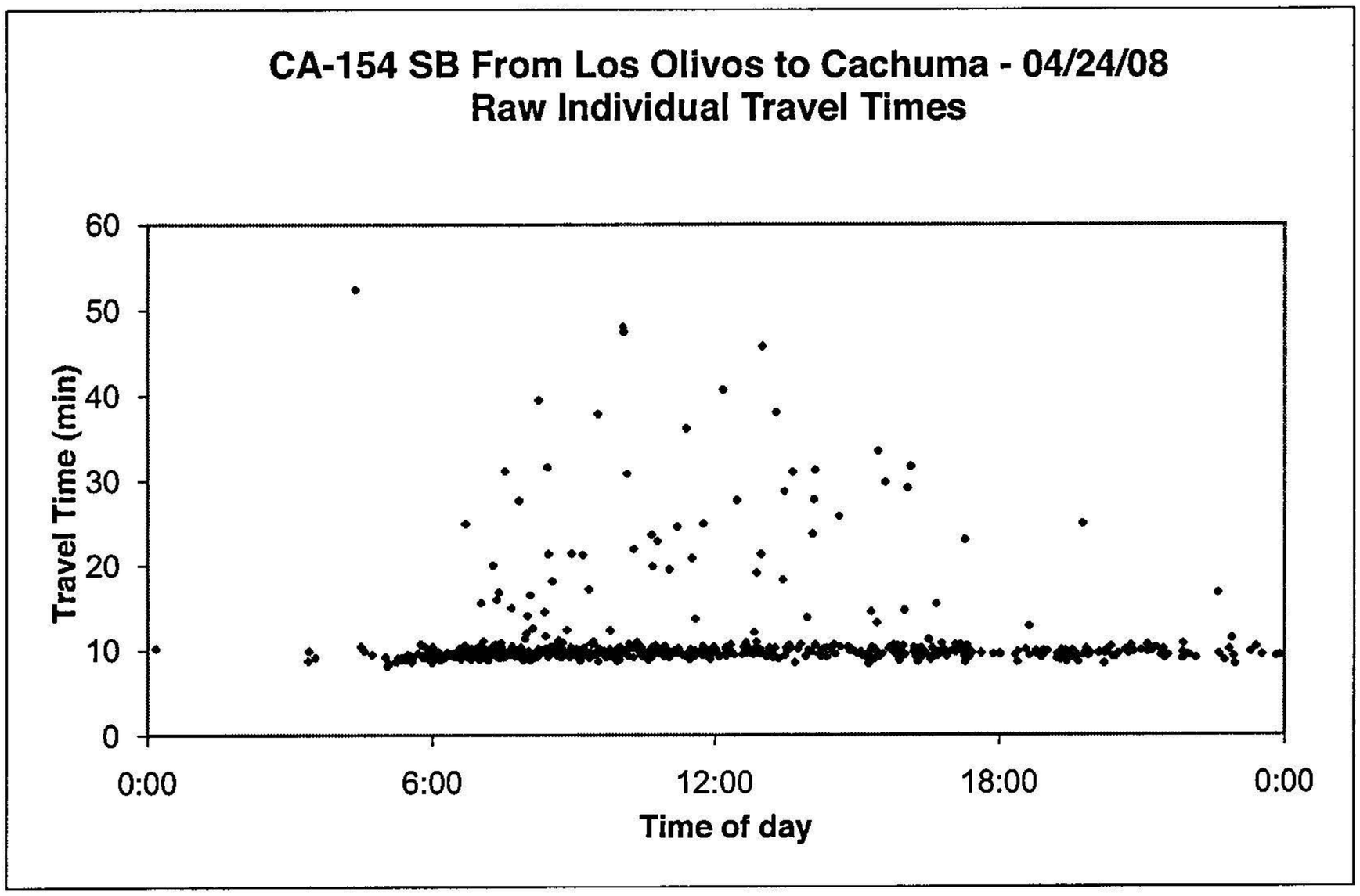

CA-154 SB From Los Olivos to Cachuma - 04/19/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

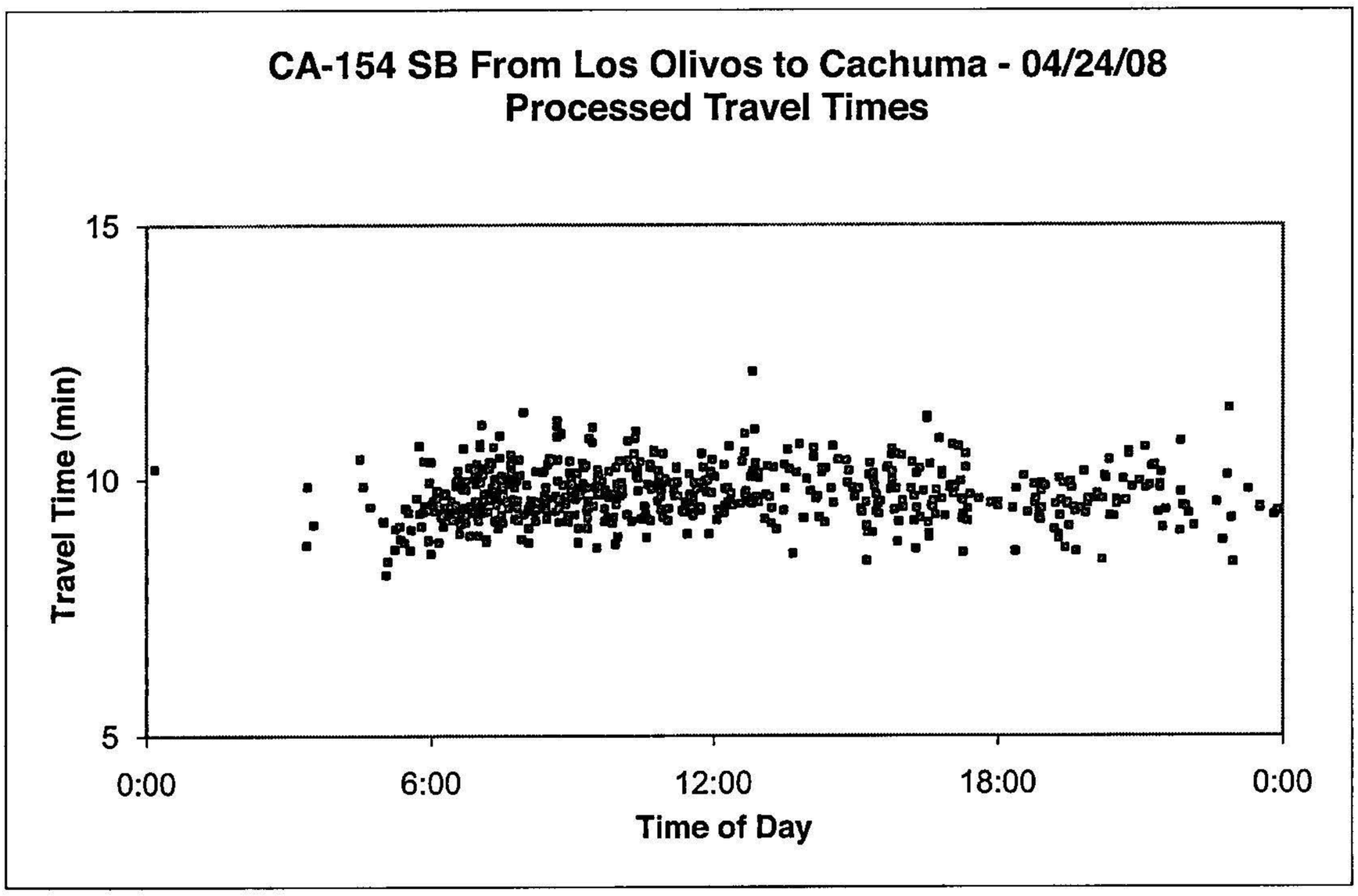

CA-154 SB From Los Olivos to Cachuma - 04/20/08
Raw Individual Travel Times
Travel Time (min)
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60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

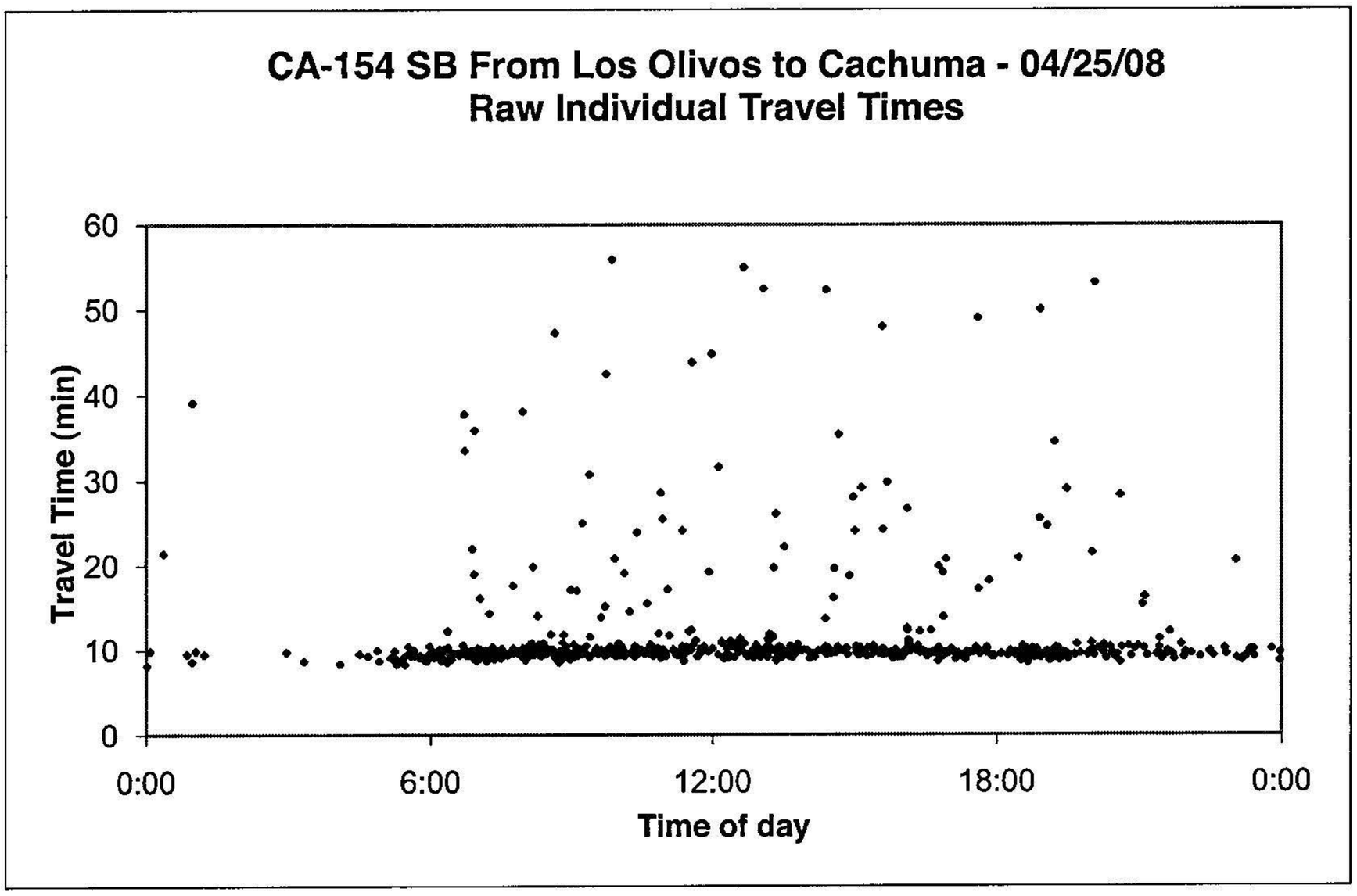

CA-154 SB From Los Olivos to Cachuma - 04/20/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

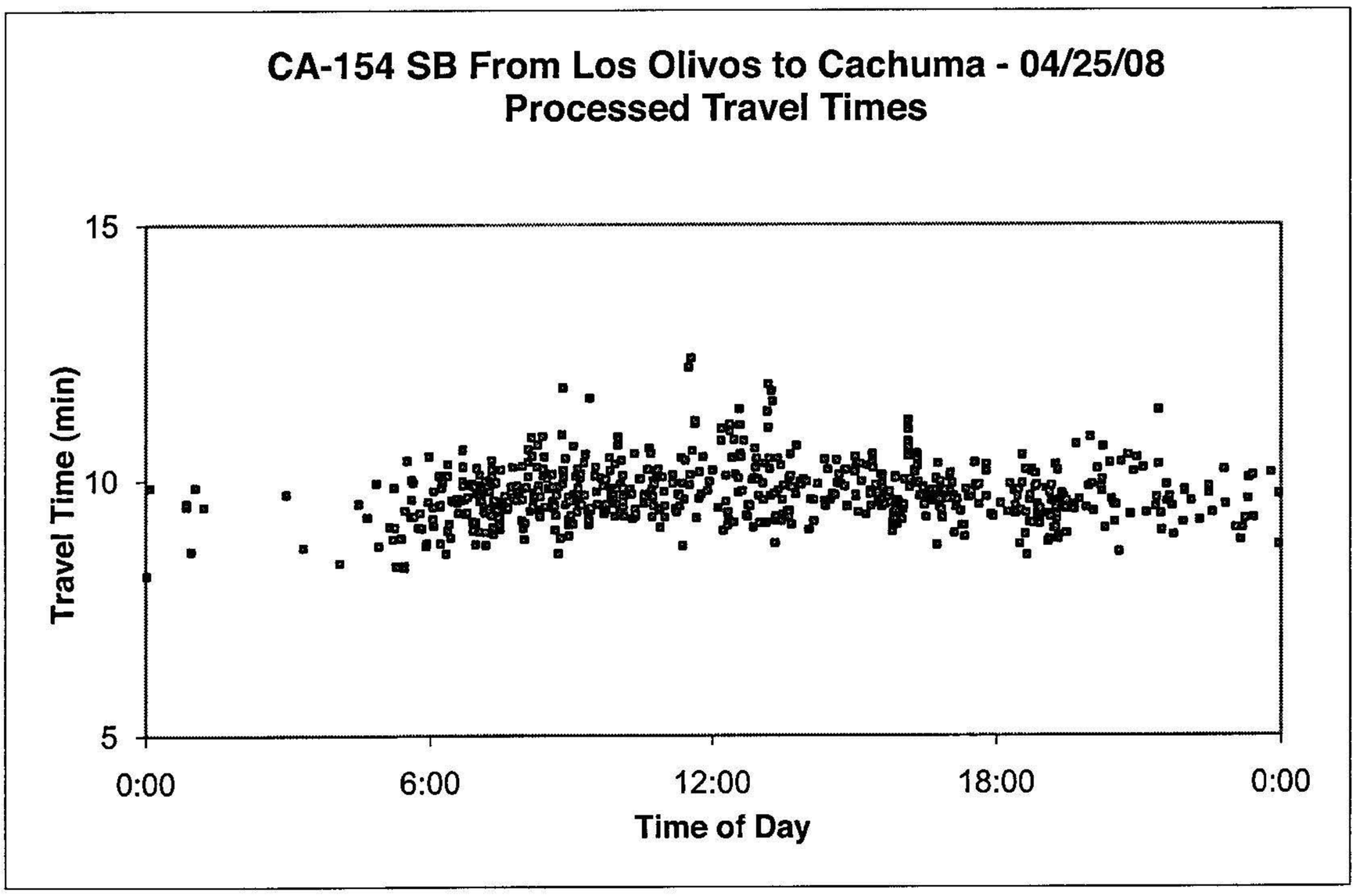

CA-154 SB From Los Olivos to Cachuma - 04/23/08
Raw Individual Travel Times
Travel Time (min)
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50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

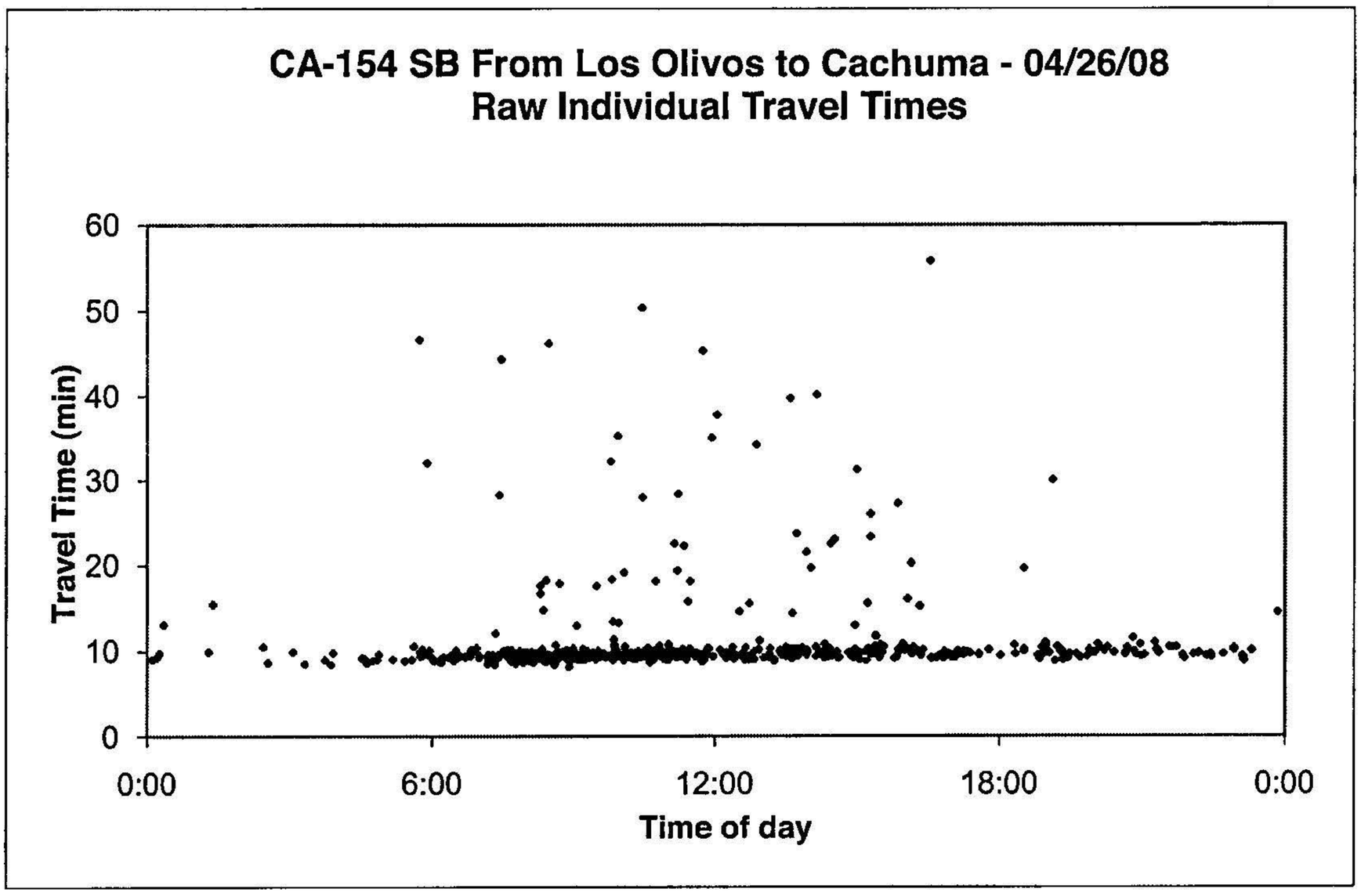

CA-154 SB From Los Olivos to Cachuma - 04/23/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

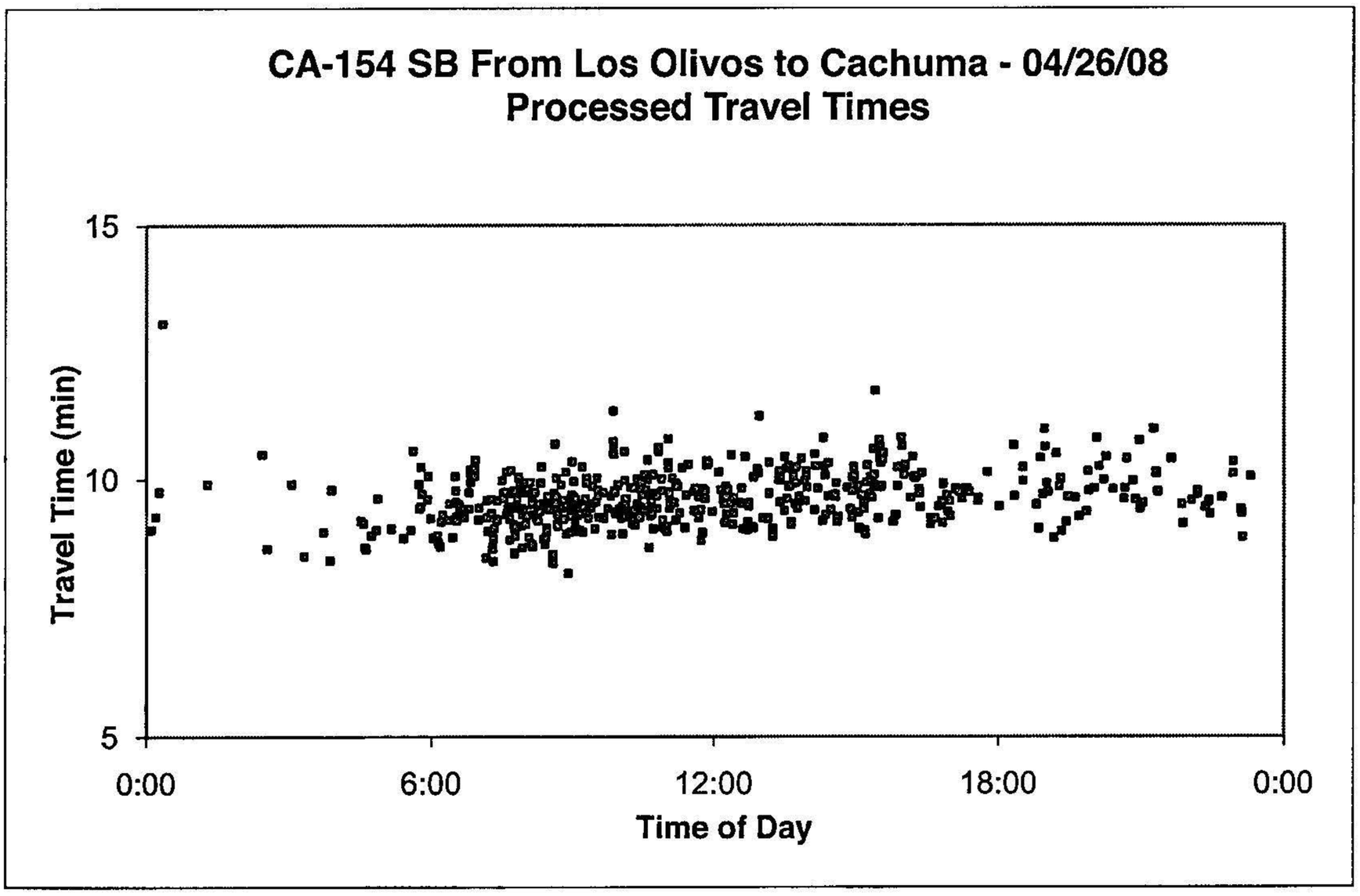

CA-154 SB From Los Olivos to Cachuma - 04/24/08
Raw Individual Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

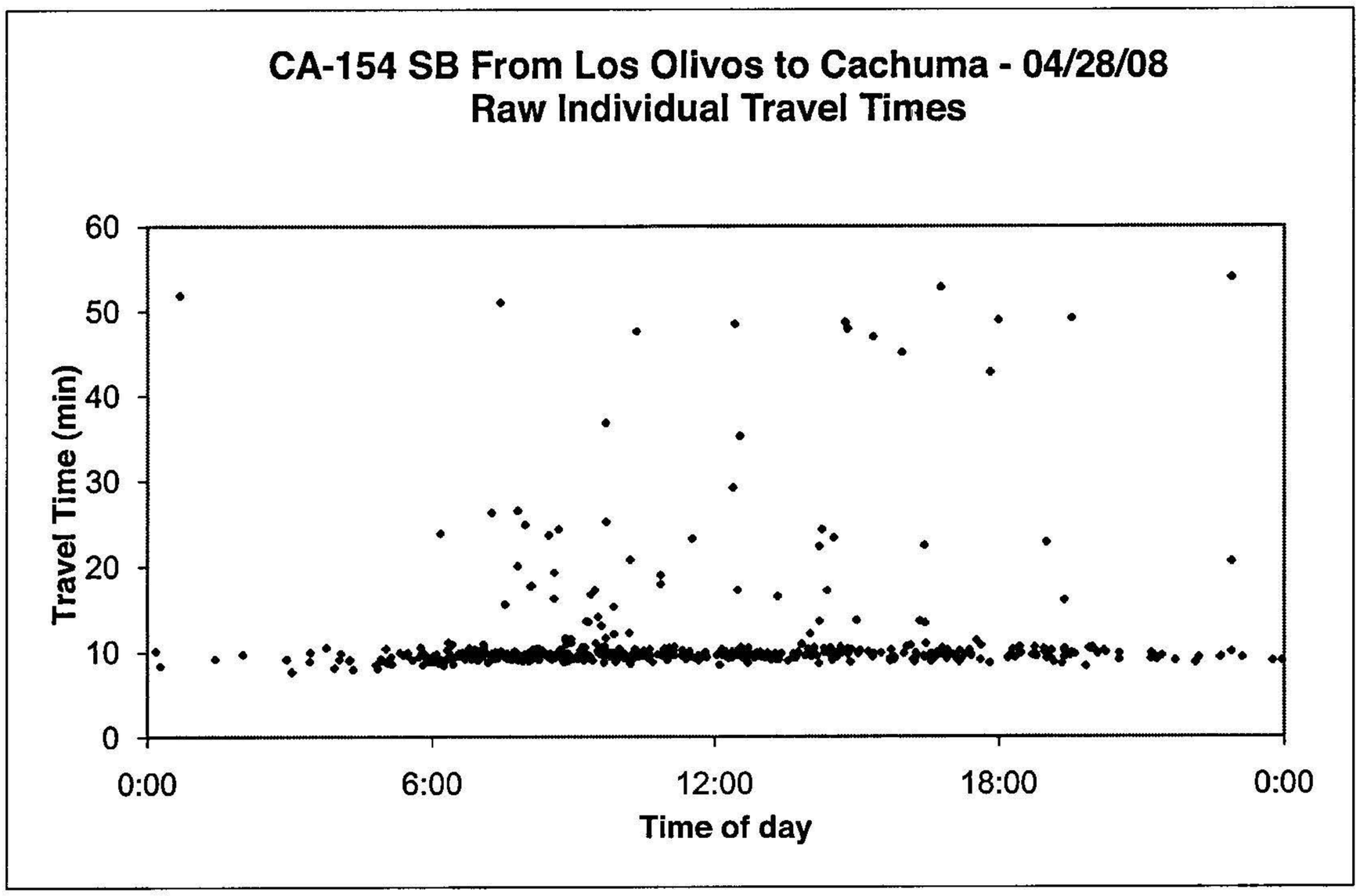

CA-154 SB From Los Olivos to Cachuma - 04/24/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

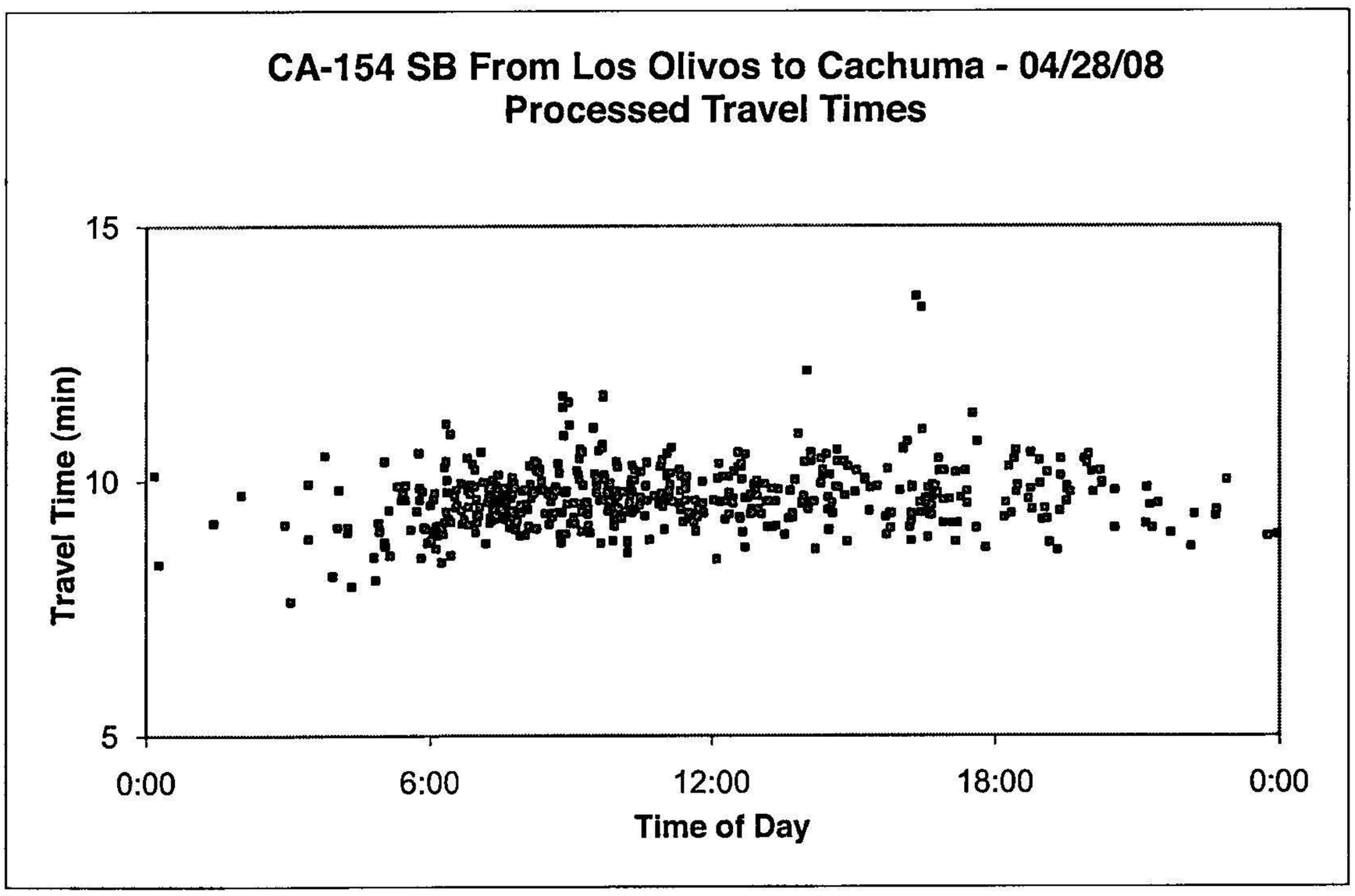

CA-154 SB From Los Olivos to Cachuma - 04/25/08
Raw Individual Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day


CA-154 SB From Los Olivos to Cachuma - 04/25/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

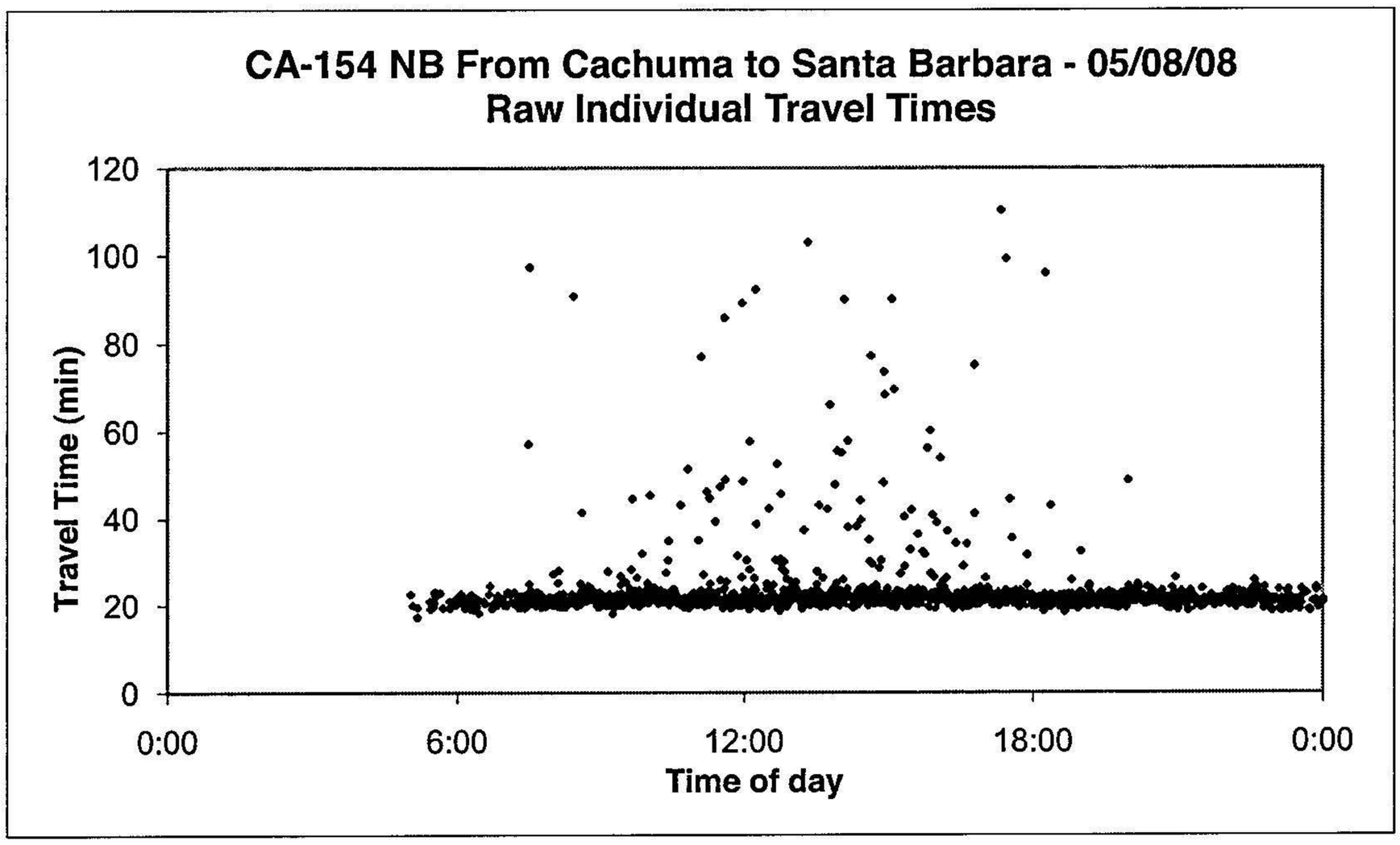

CA-154 SB From Los Olivos to Cachuma - 04/26/08
Raw Individual Travel Times
Travel Time (min)
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50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

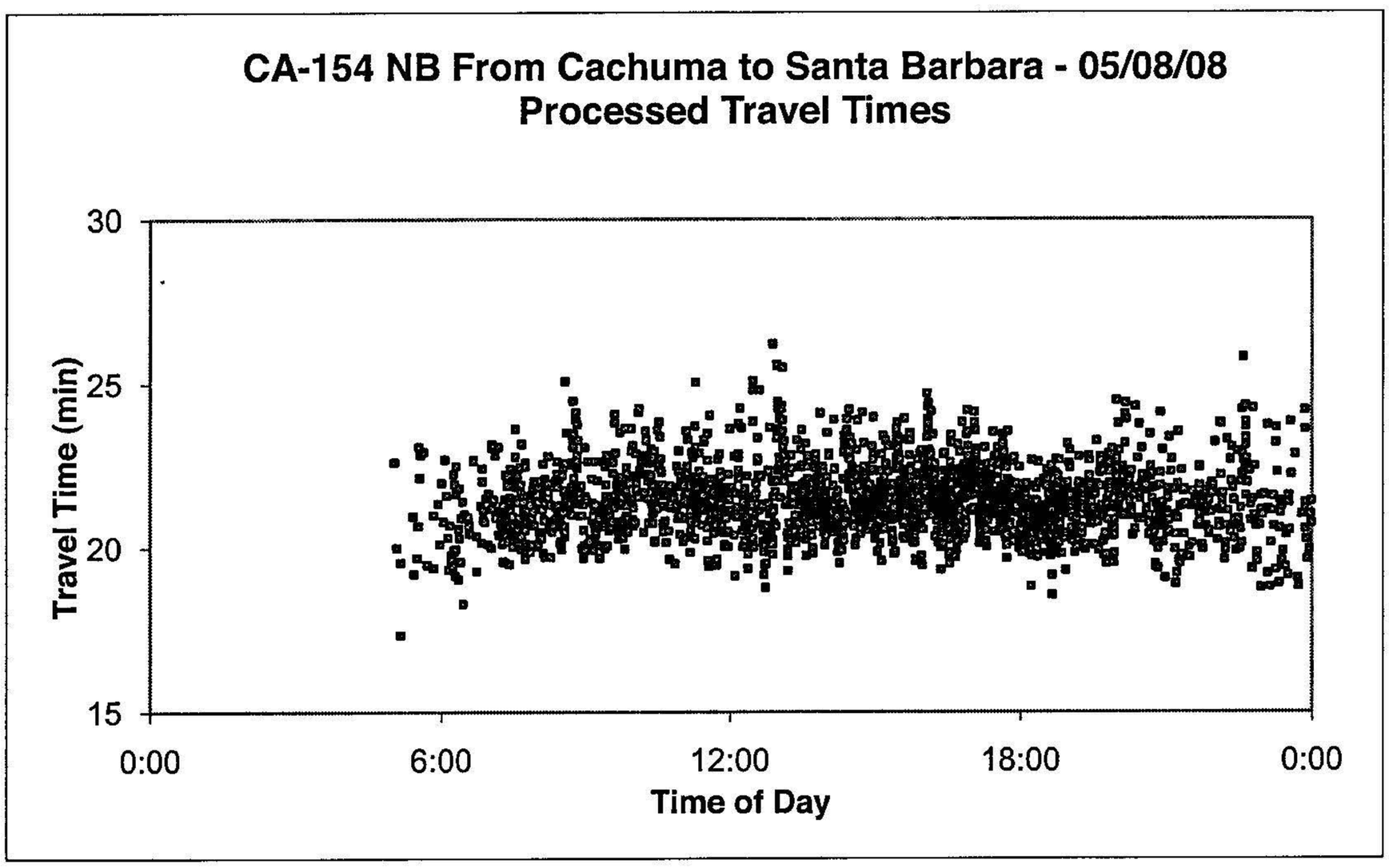

CA-154 SB From Los Olivos to Cachuma - 04/26/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

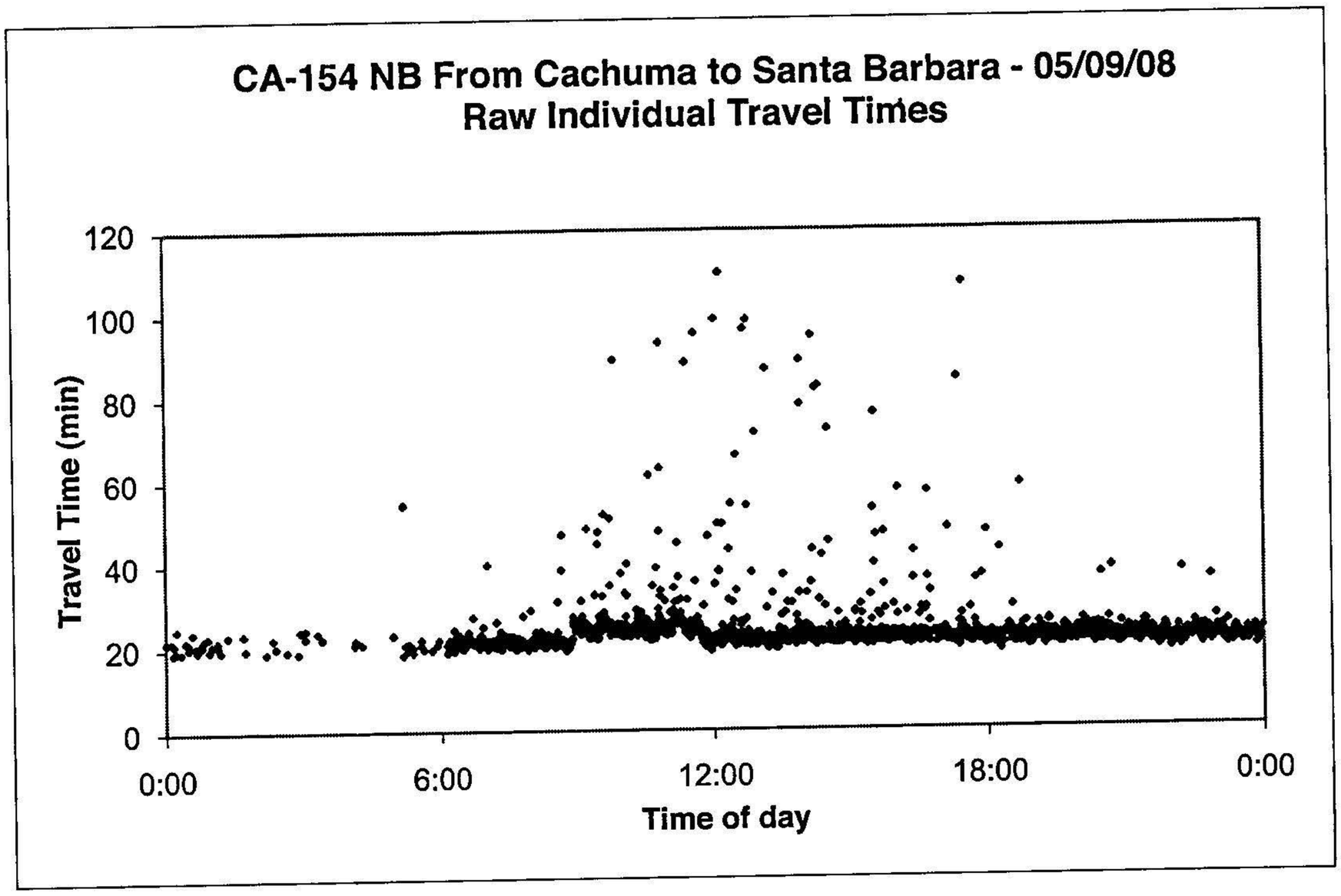

CA-154 SB From Los Olivos to Cachuma - 04/28/08
Raw Individual Travel Times
Travel Time (min)
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50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

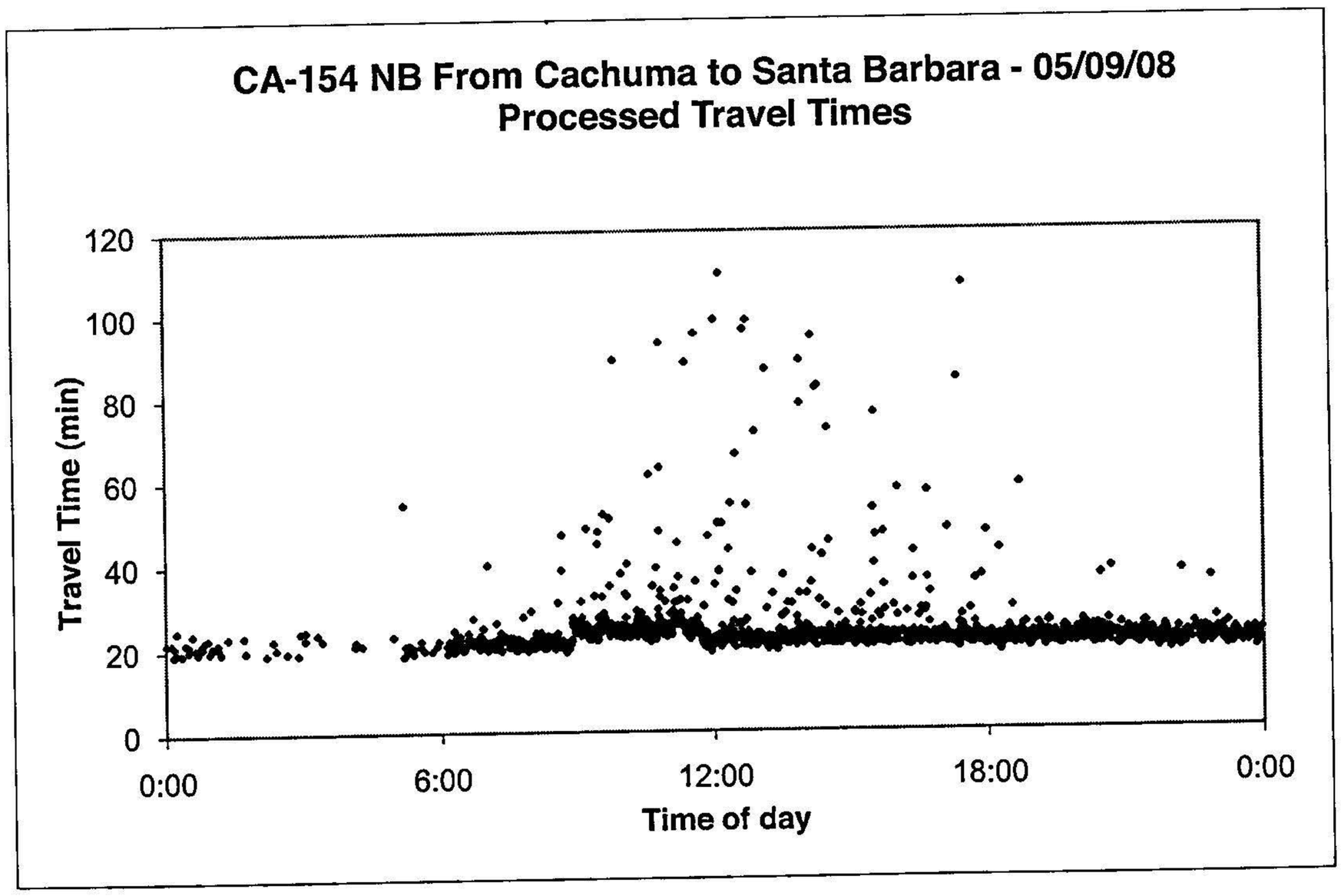

CA-154 SB From Los Olivos to Cachuma - 04/28/08
Processed Travel Times
Travel Time (min)
15
10
5
0:00
6:00
12:00
18:00
0:00
Time of Day

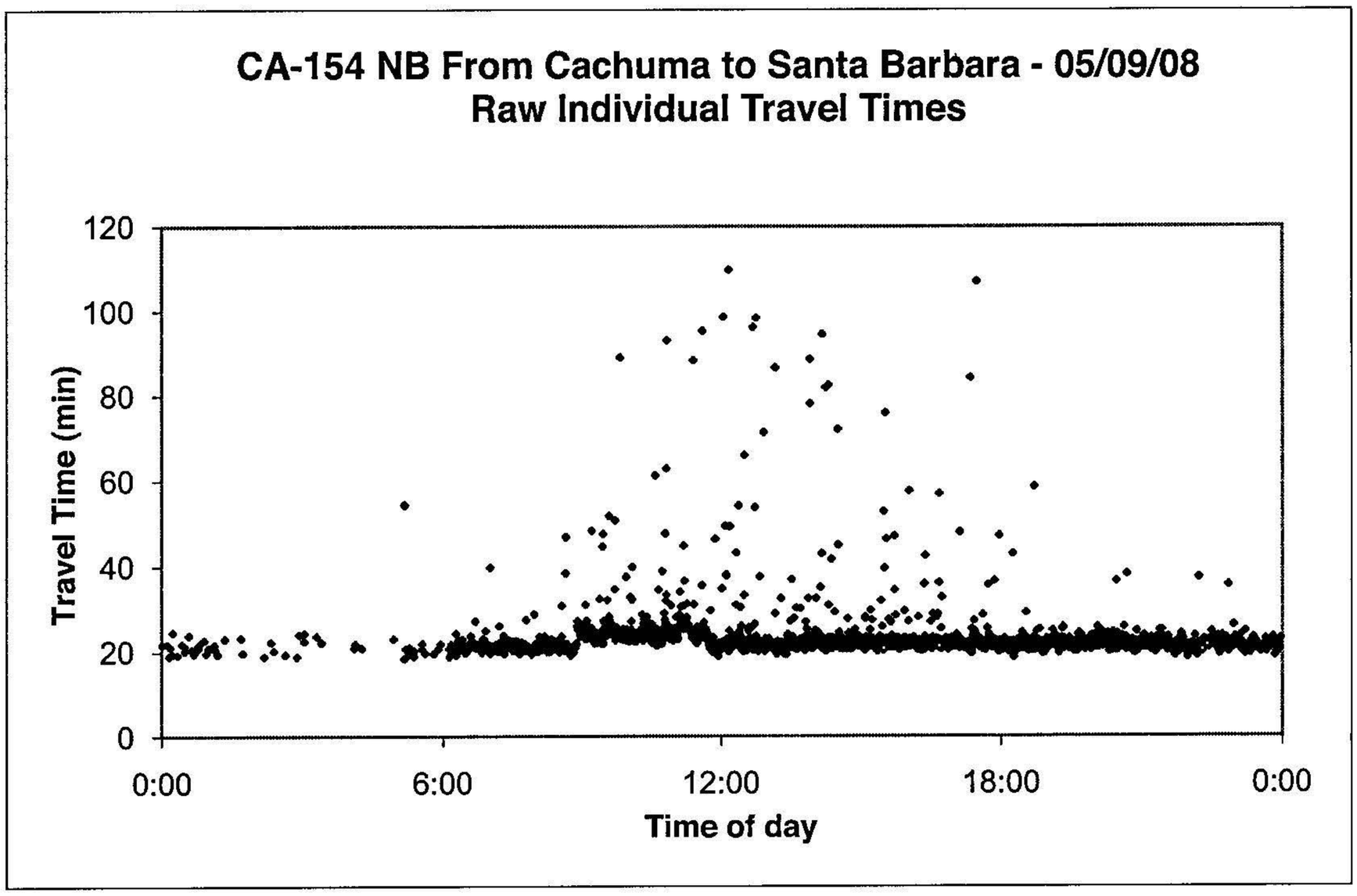
C.3 CA-154 From Cachuma to Santa Barbara Travel Time Distribution

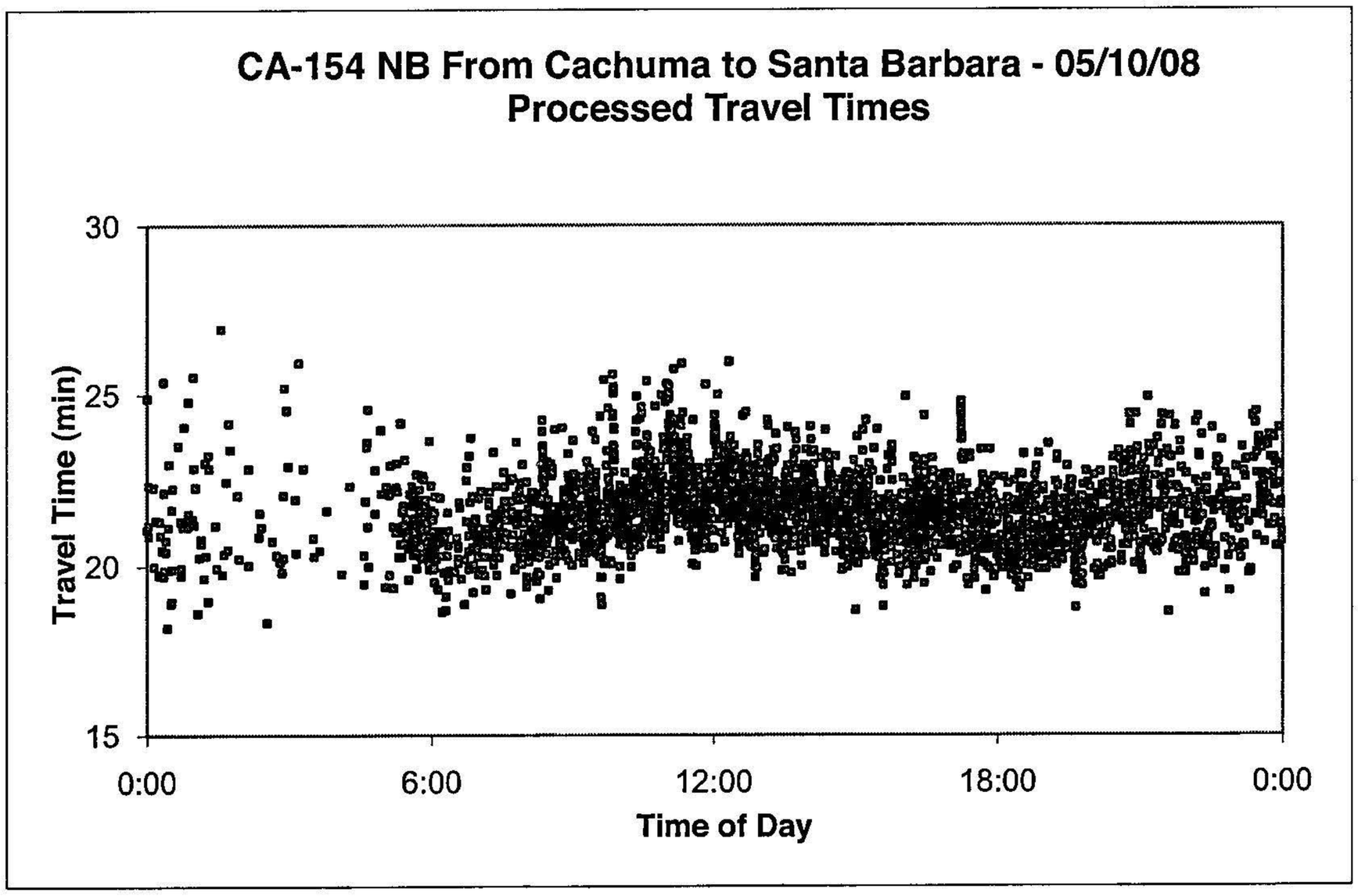


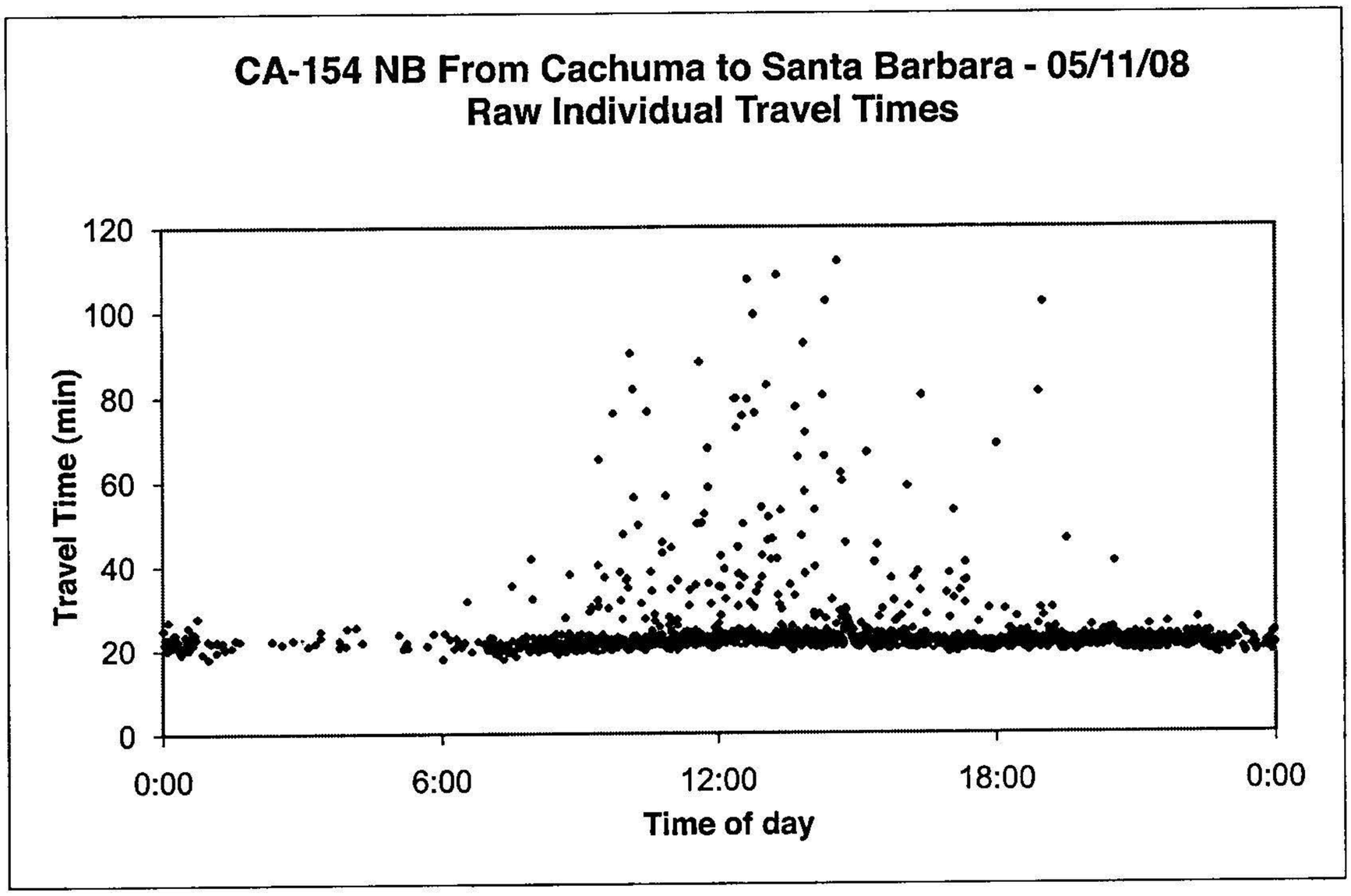


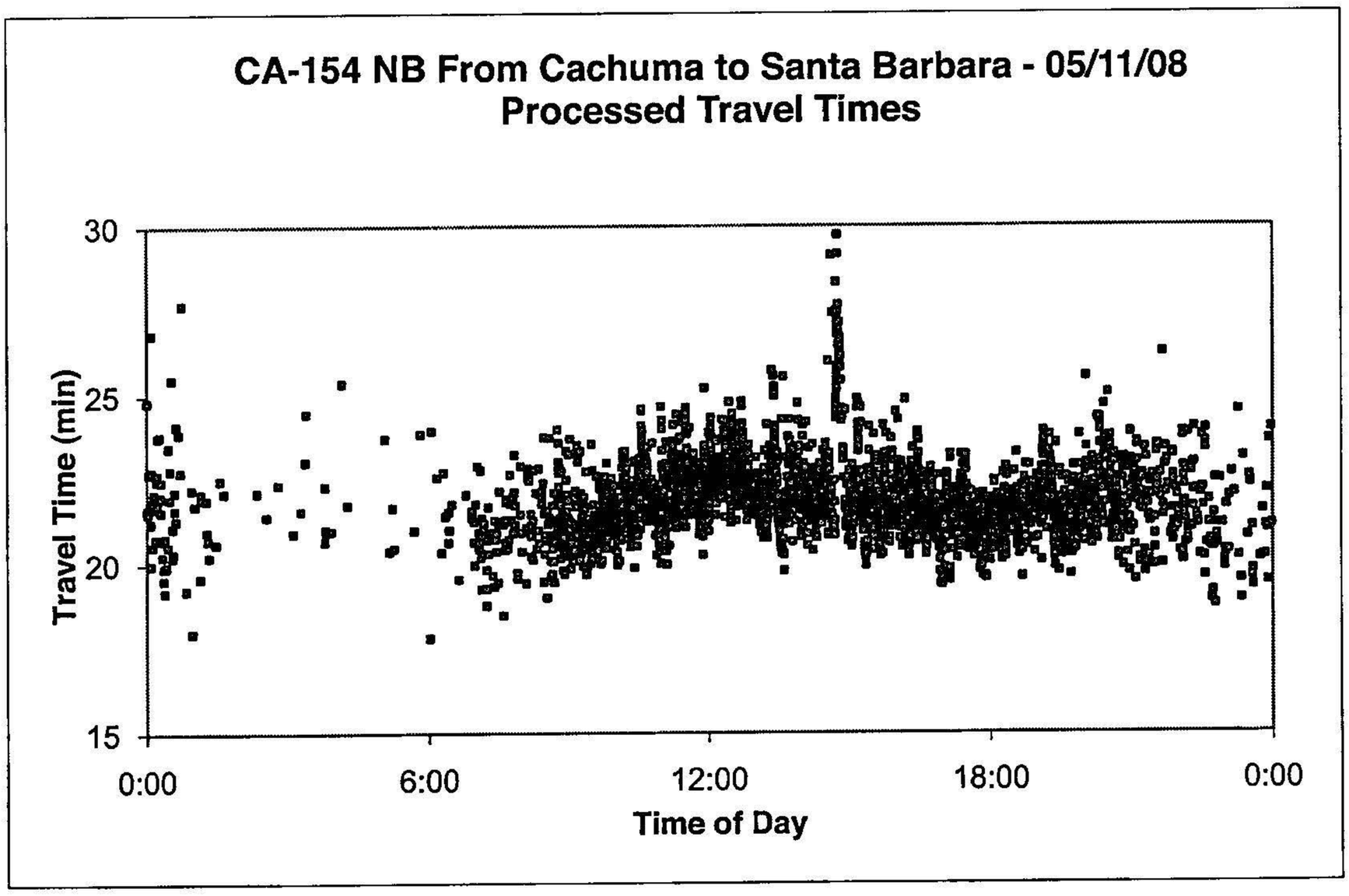

CA-154 NB From Cachuma to Santa Barbara - 05/09/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

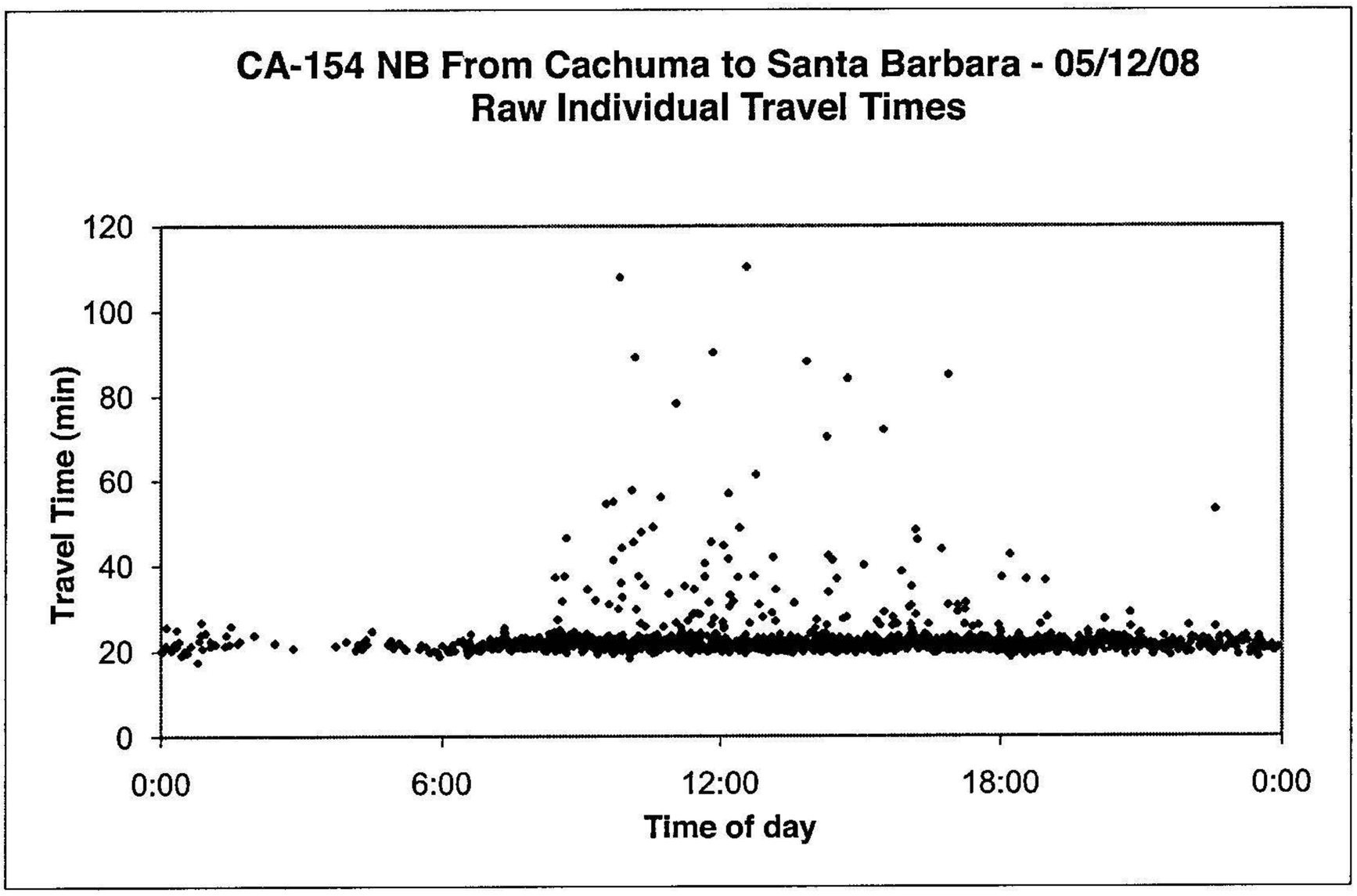

CA-154 NB From Cachuma to Santa Barbara - 05/09/08
Processed Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

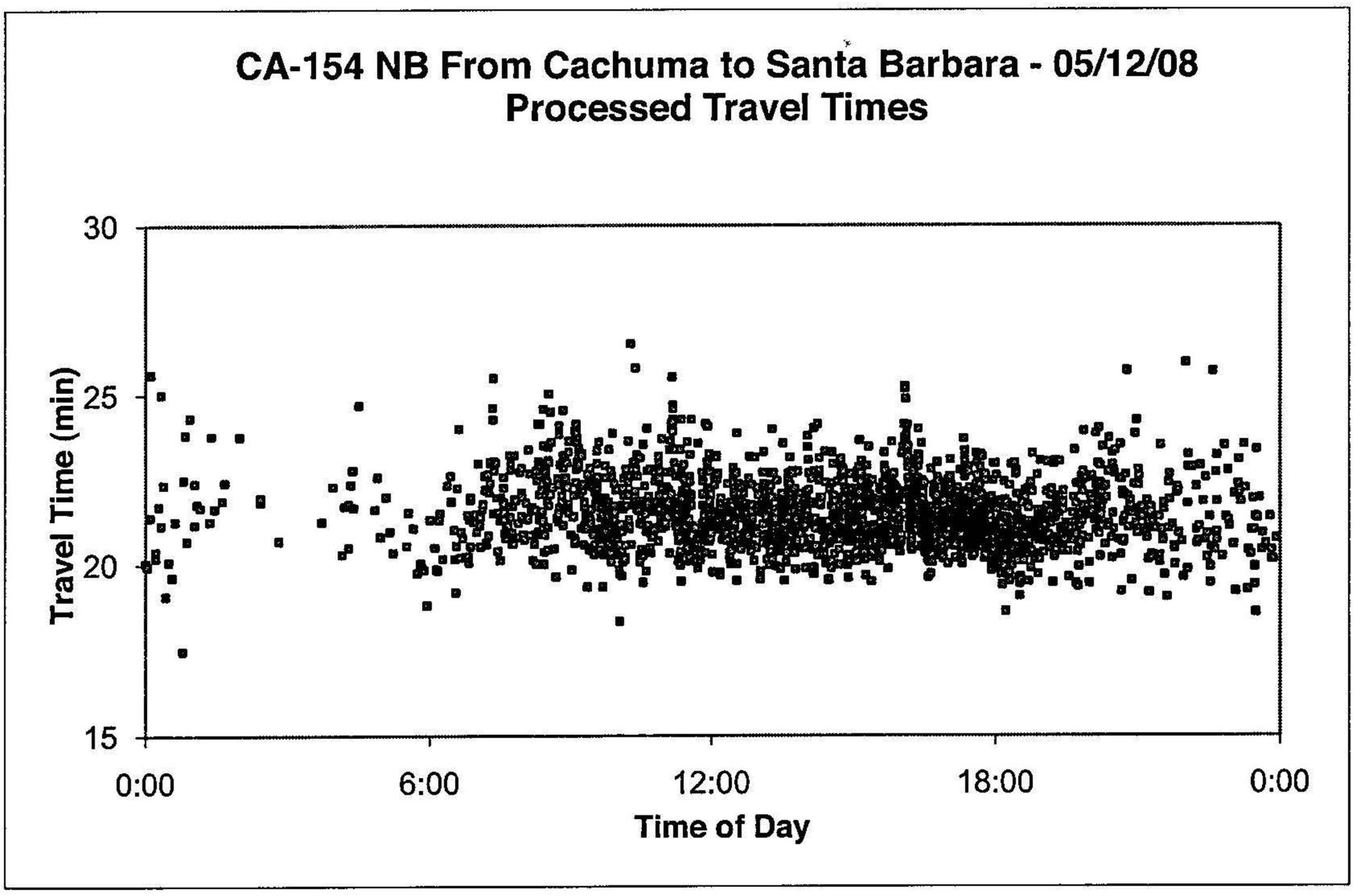

CA-154 NB From Cachuma to Santa Barbara - 05/09/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

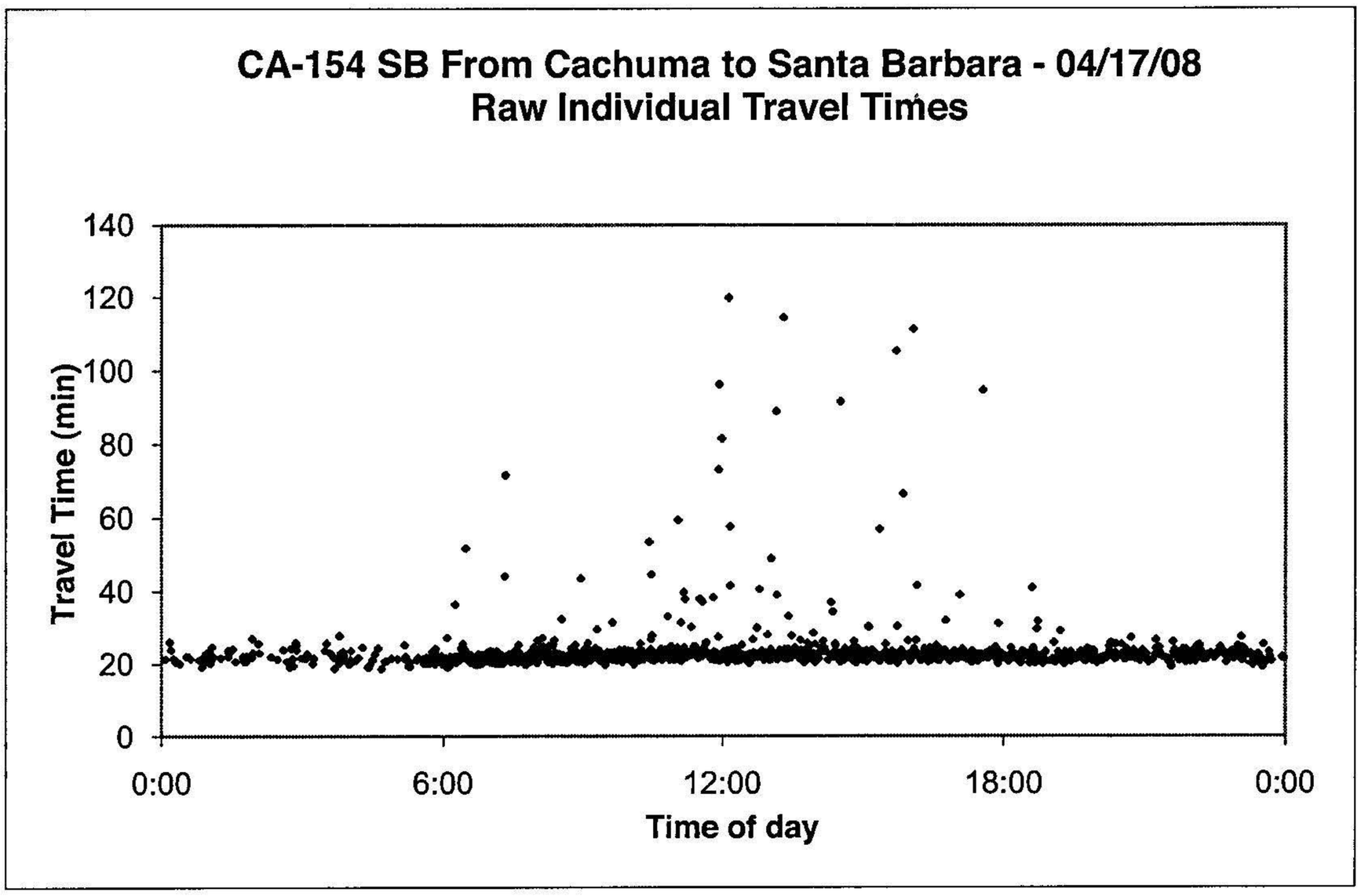

CA-154 NB From Cachuma to Santa Barbara - 05/10/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

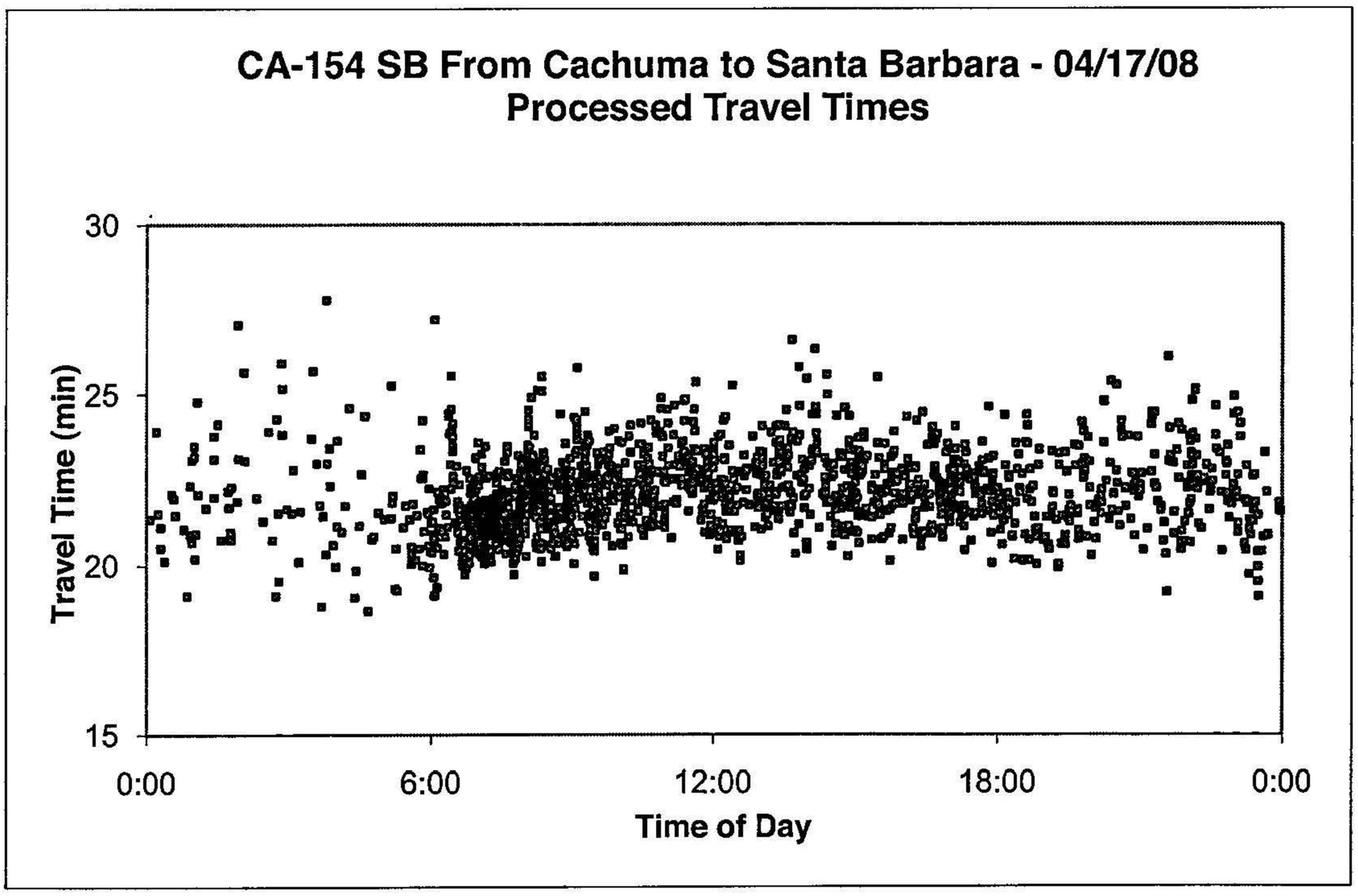

CA-154 NB From Cachuma to Santa Barbara - 05/11/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

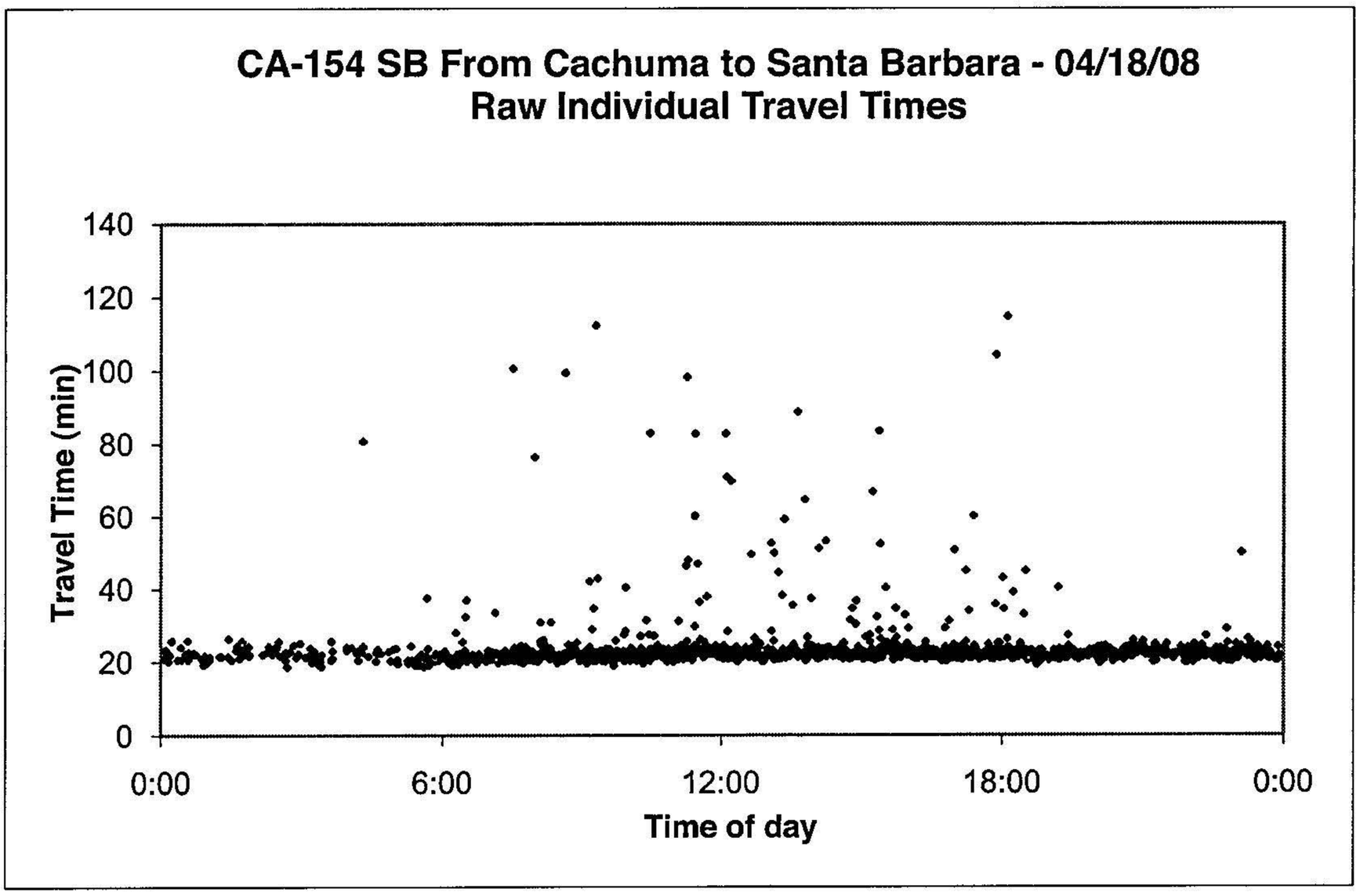

CA-154 NB From Cachuma to Santa Barbara - 05/11/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

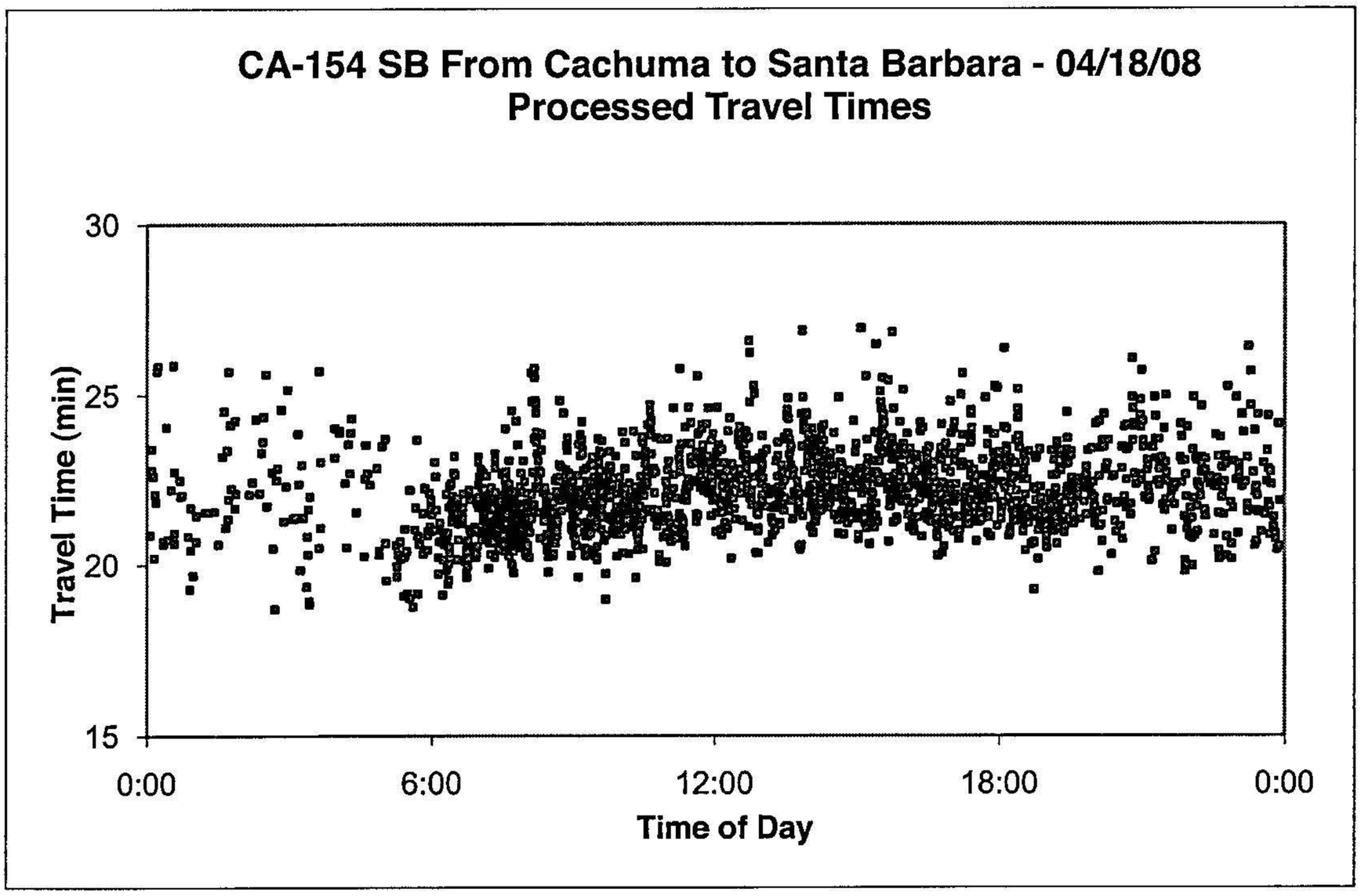

CA-154 NB From Cachuma to Santa Barbara - 05/12/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

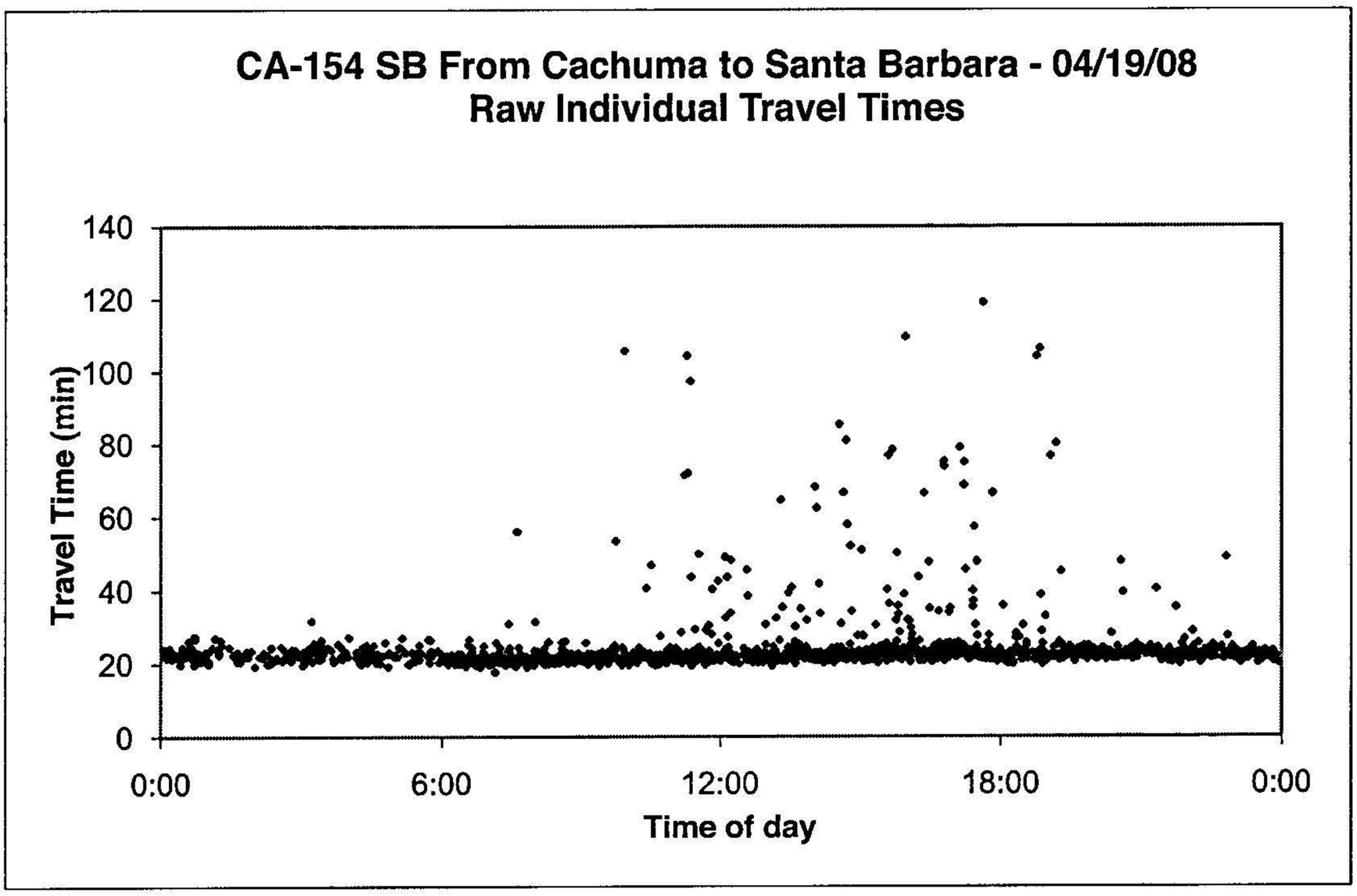

CA-154 NB From Cachuma to Santa Barbara - 05/12/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

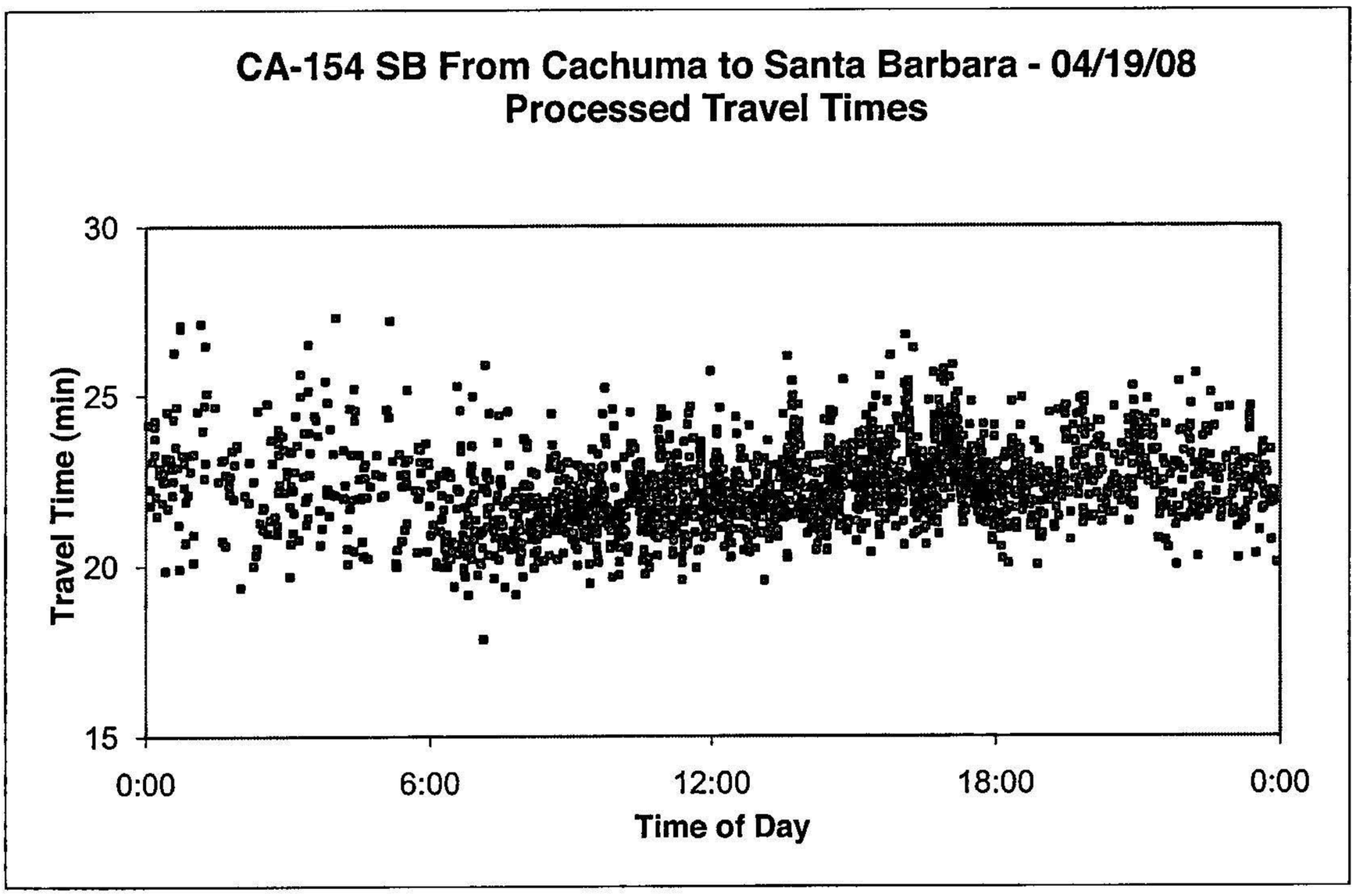

CA-154 SB From Cachuma to Santa Barbara - 04/17/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

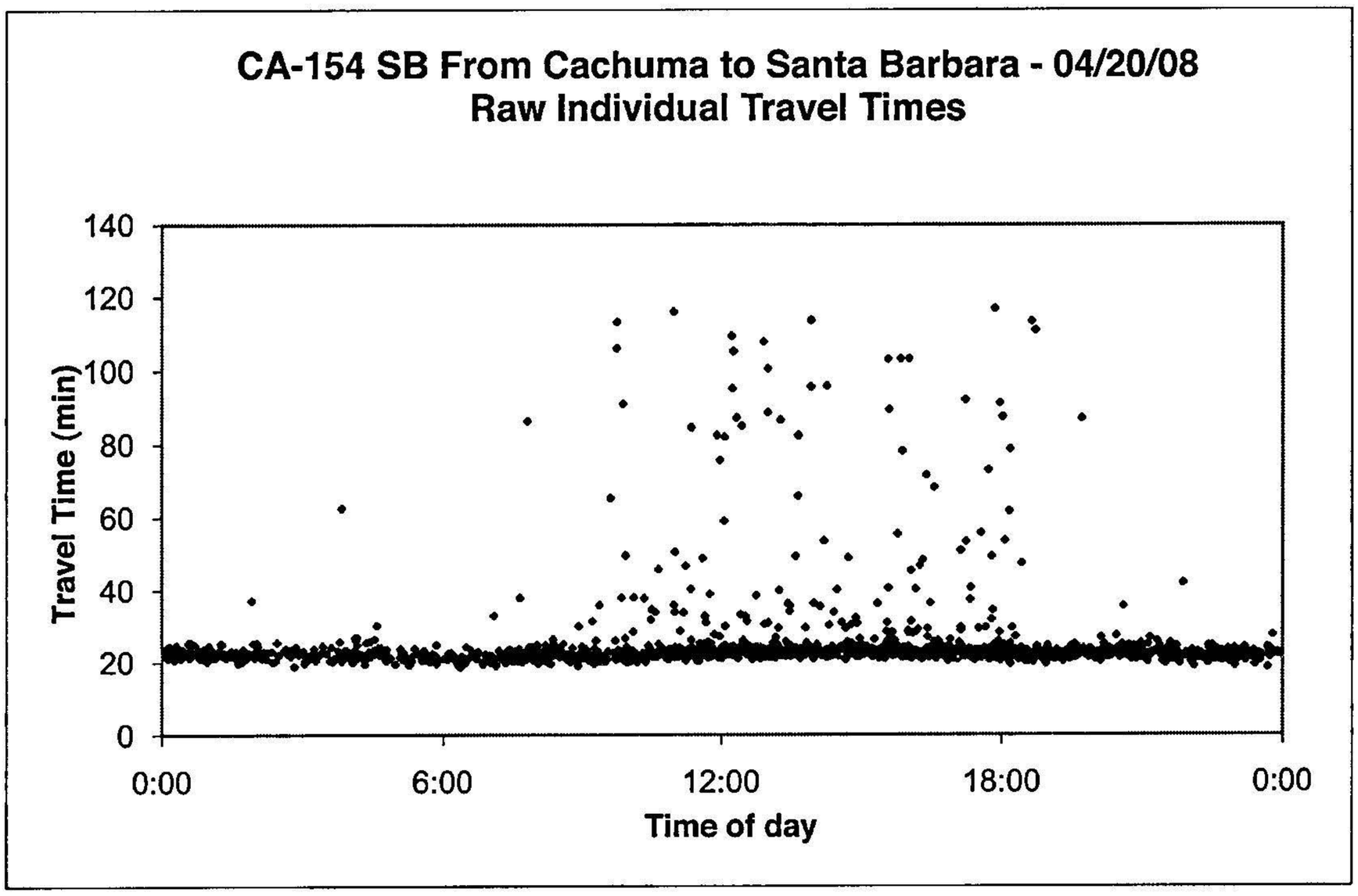

CA-154 SB From Cachuma to Santa Barbara - 04/17/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

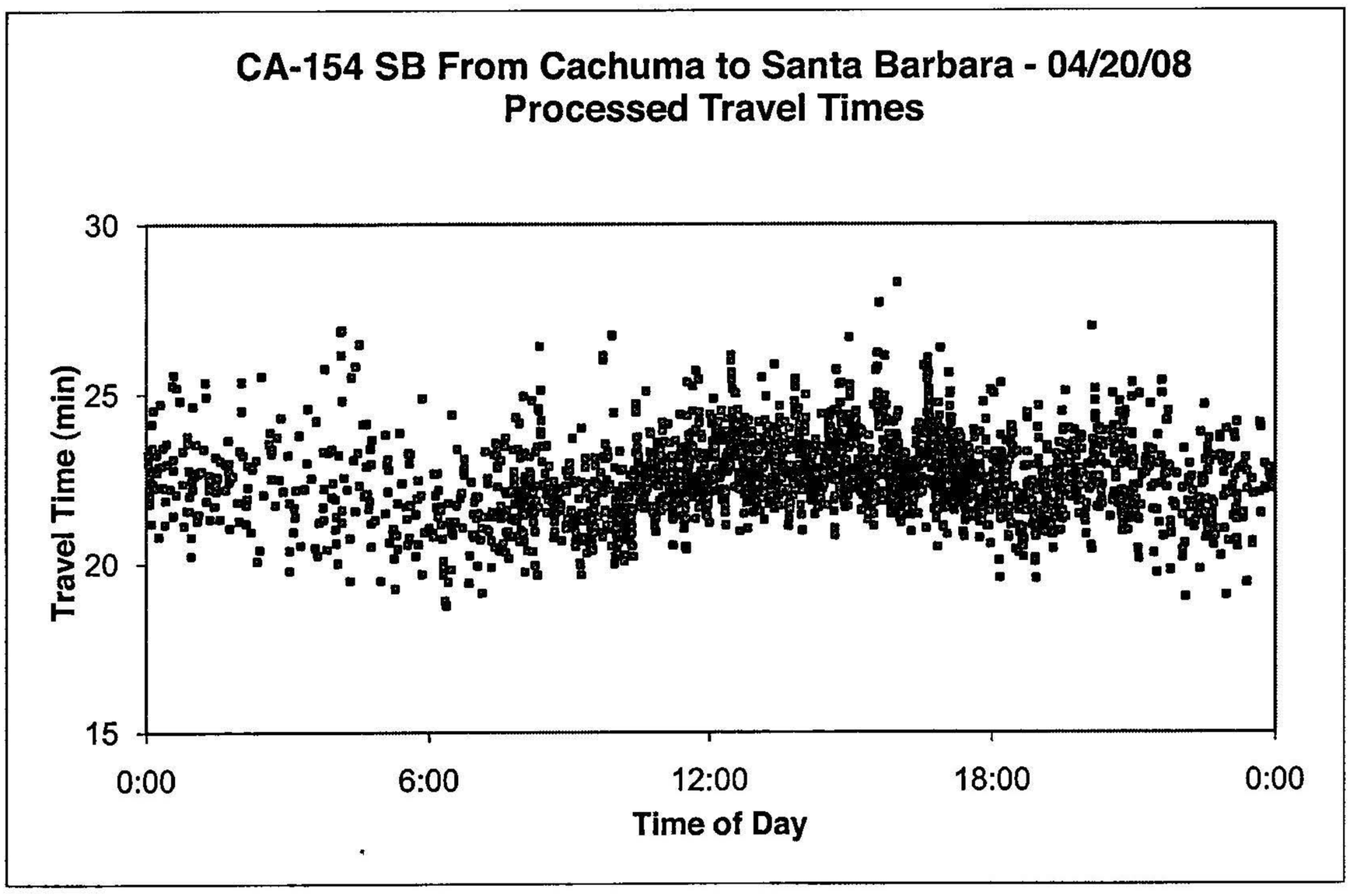

CA-154 SB From Cachuma to Santa Barbara - 04/18/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

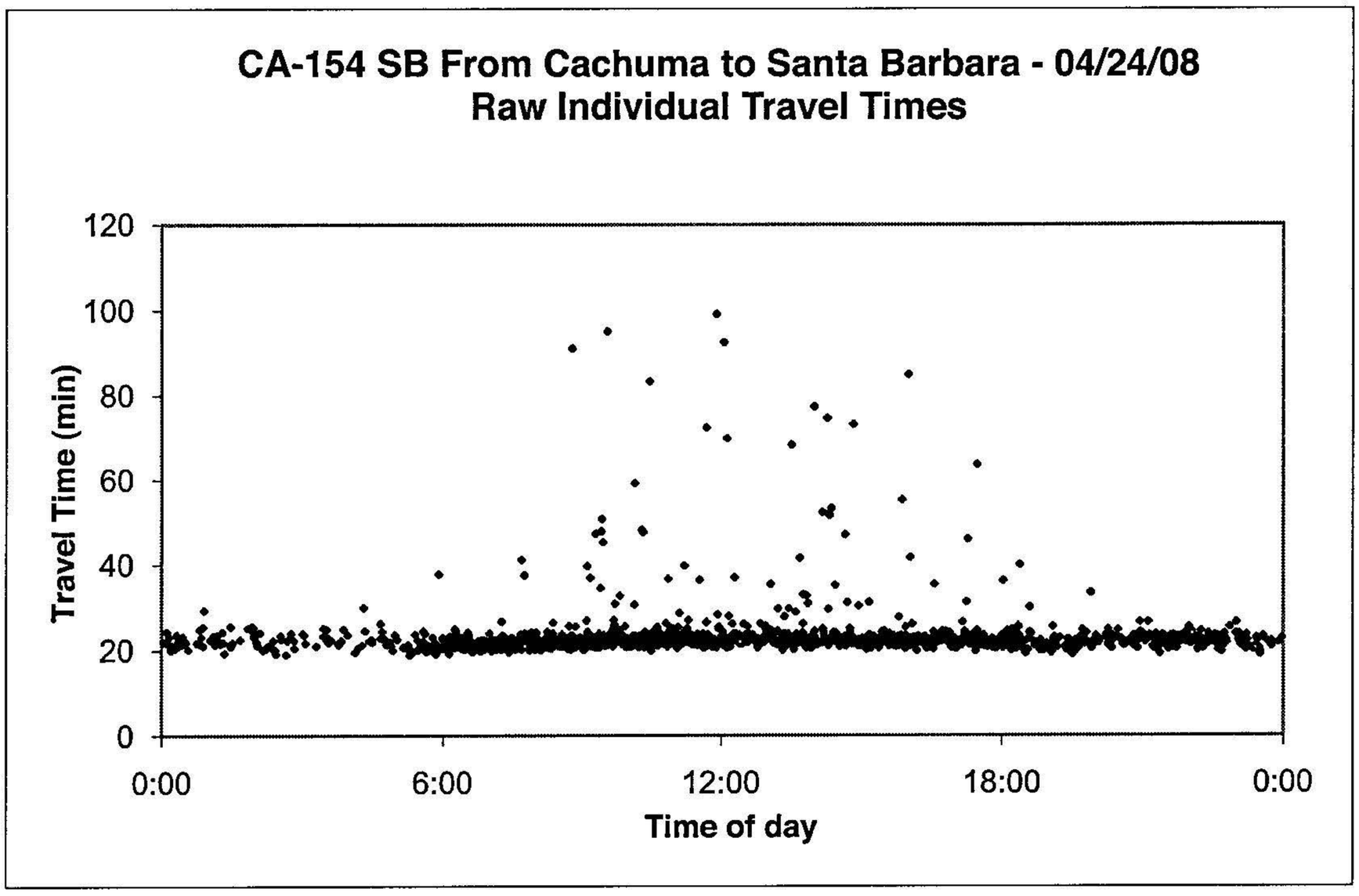

CA-154 SB From Cachuma to Santa Barbara - 04/18/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

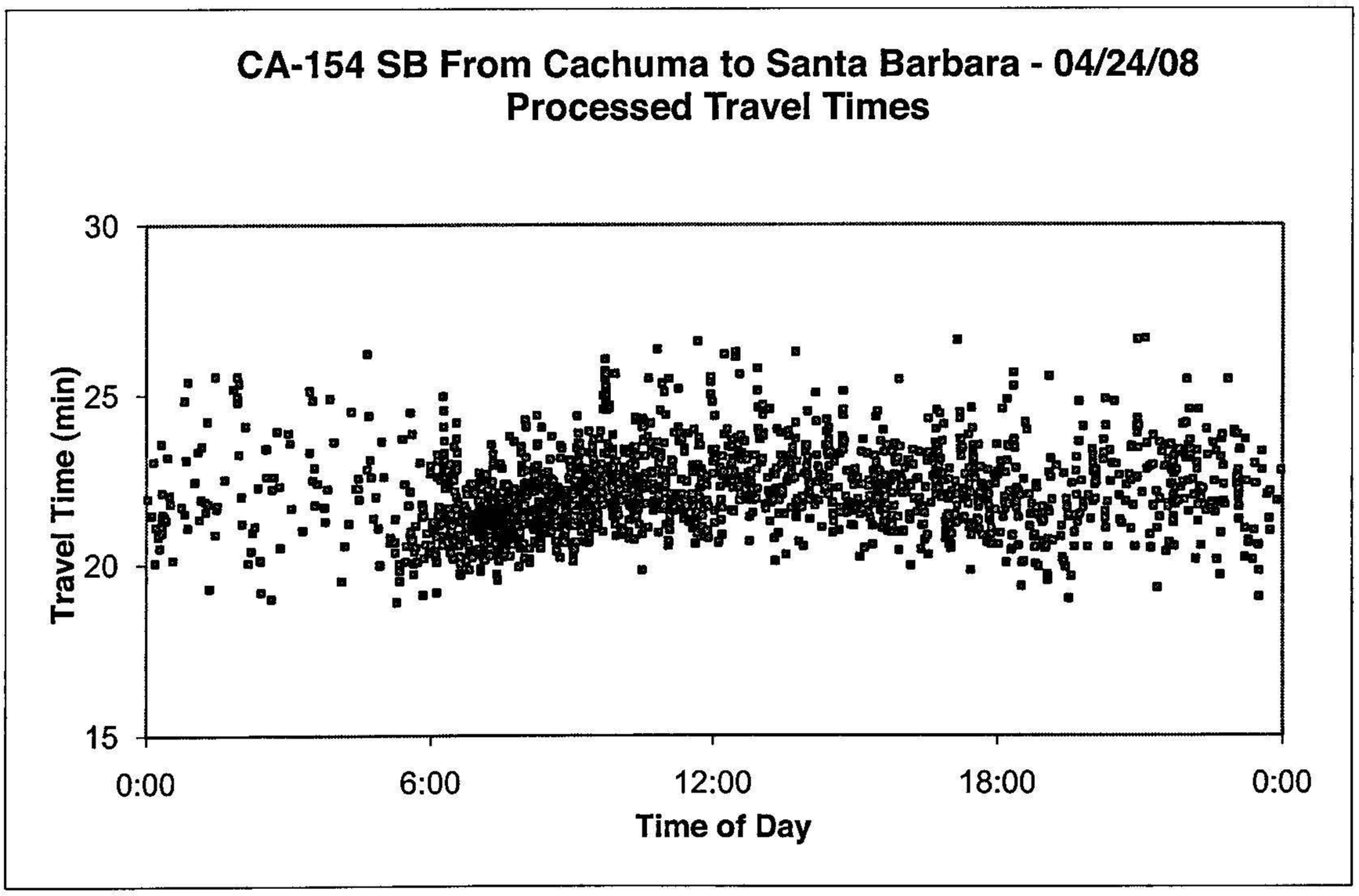

CA-154 SB From Cachuma to Santa Barbara - 04/19/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

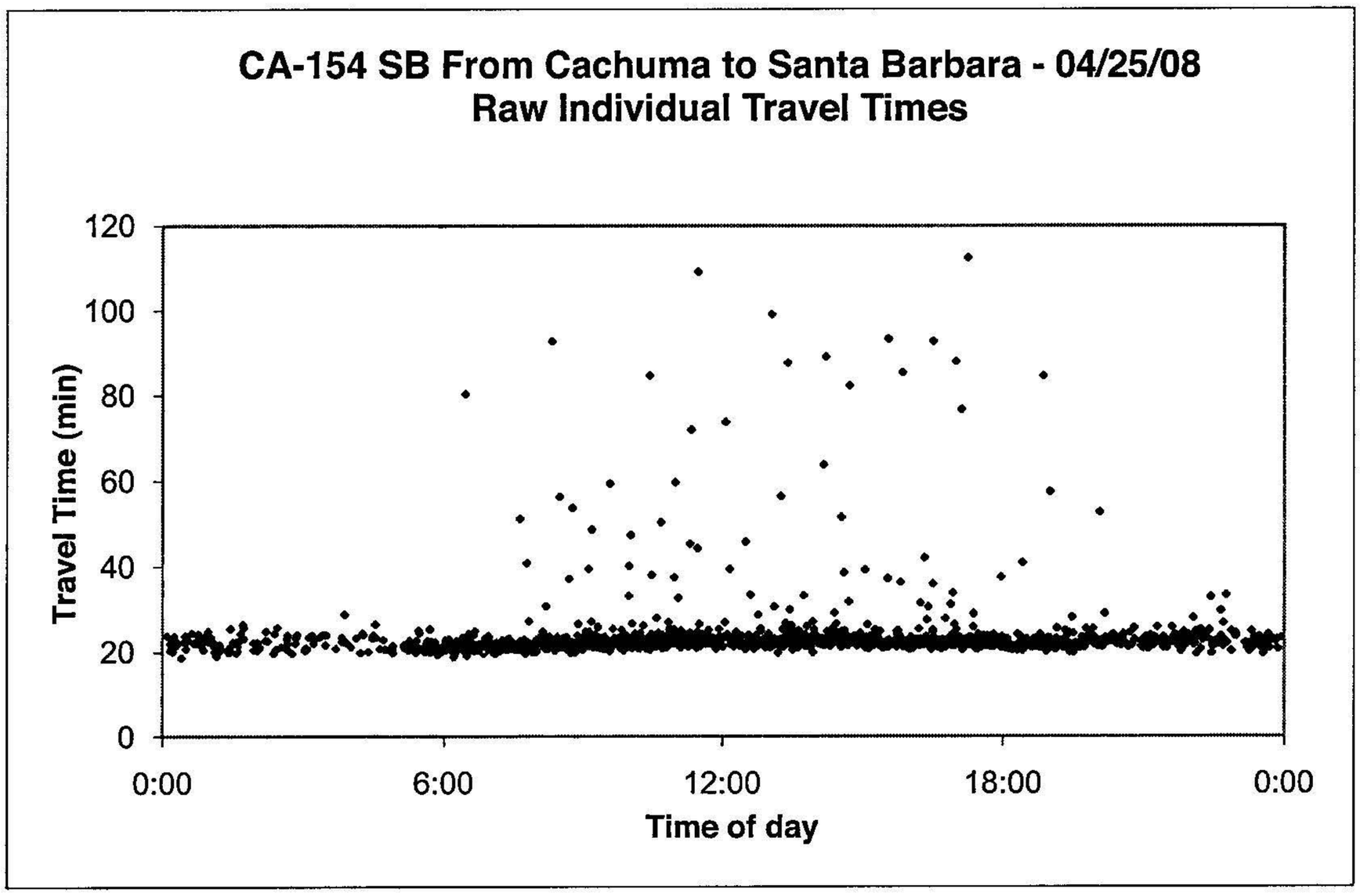

CA-154 SB From Cachuma to Santa Barbara - 04/19/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

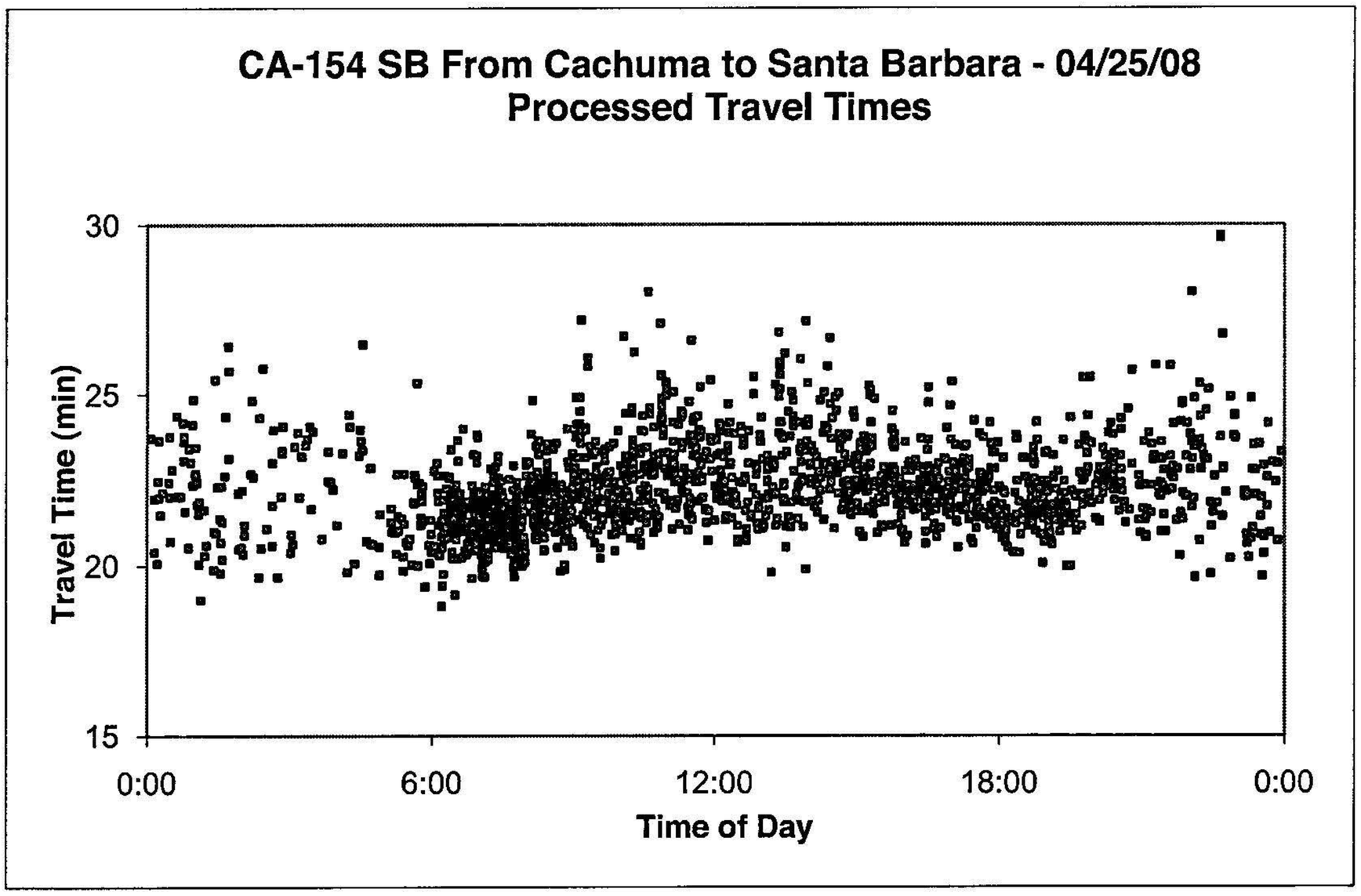

CA-154 SB From Cachuma to Santa Barbara - 04/20/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

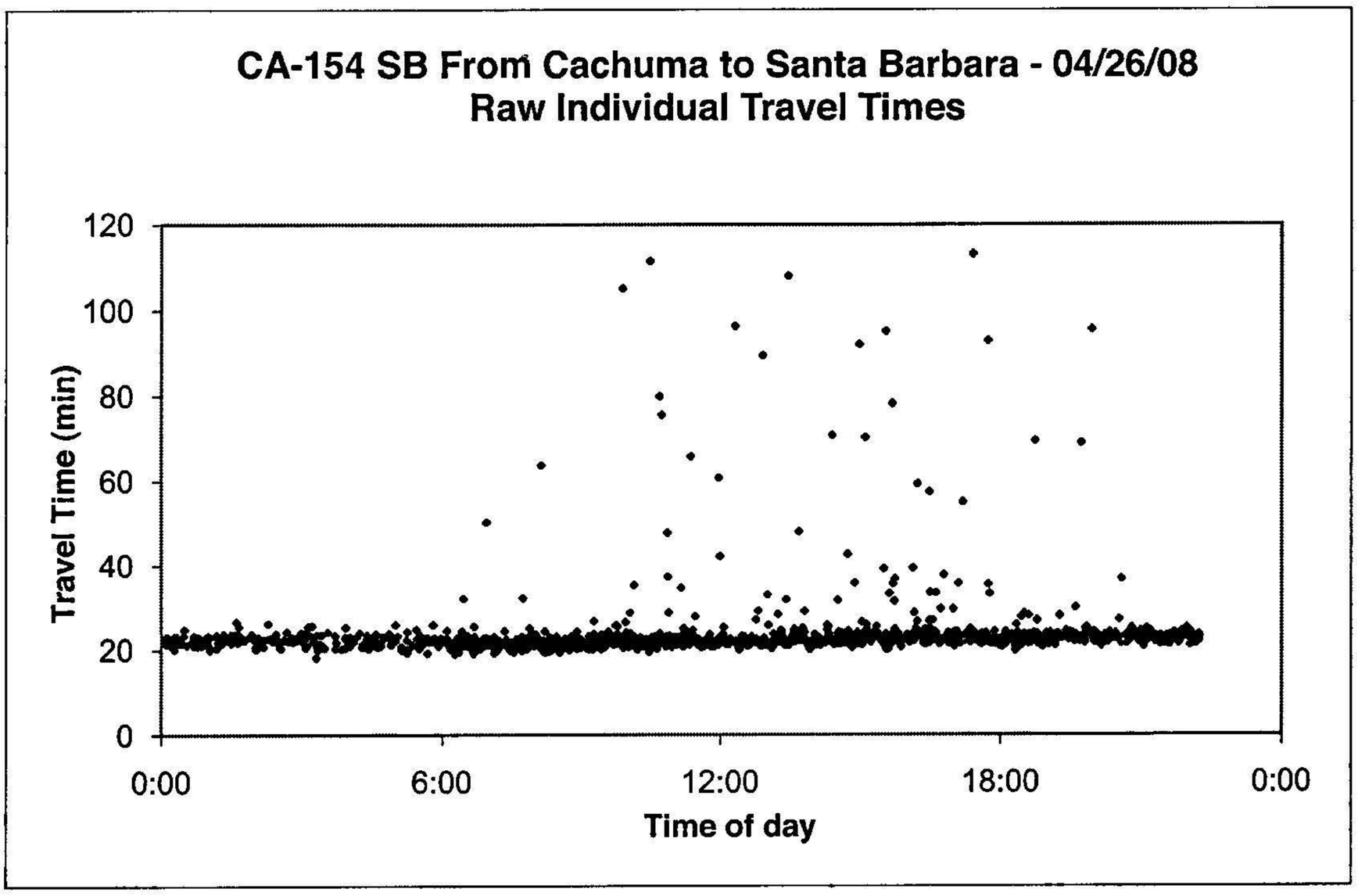

CA-154 SB From Cachuma to Santa Barbara - 04/20/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

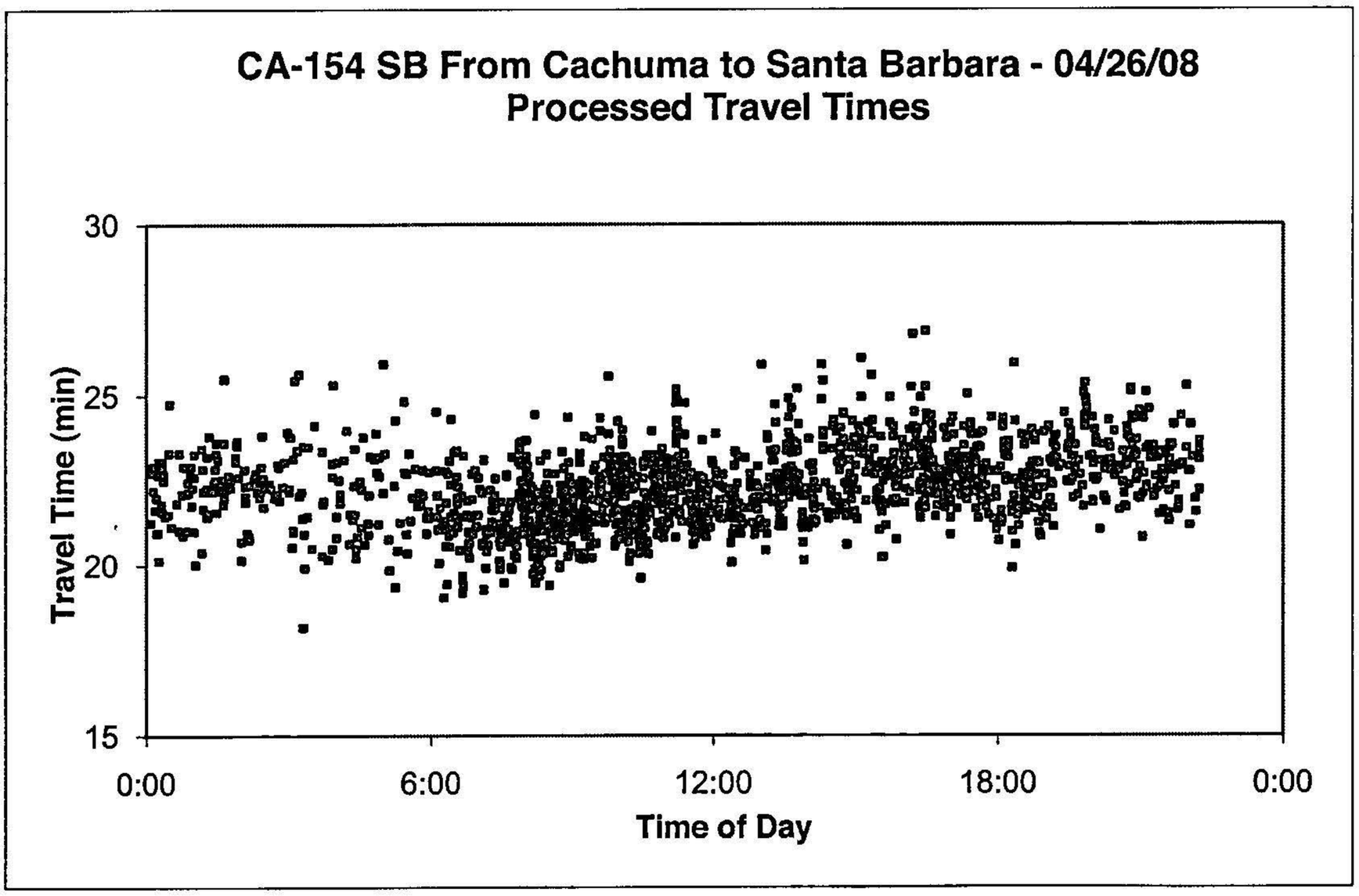

CA-154 SB From Cachuma to Santa Barbara - 04/24/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

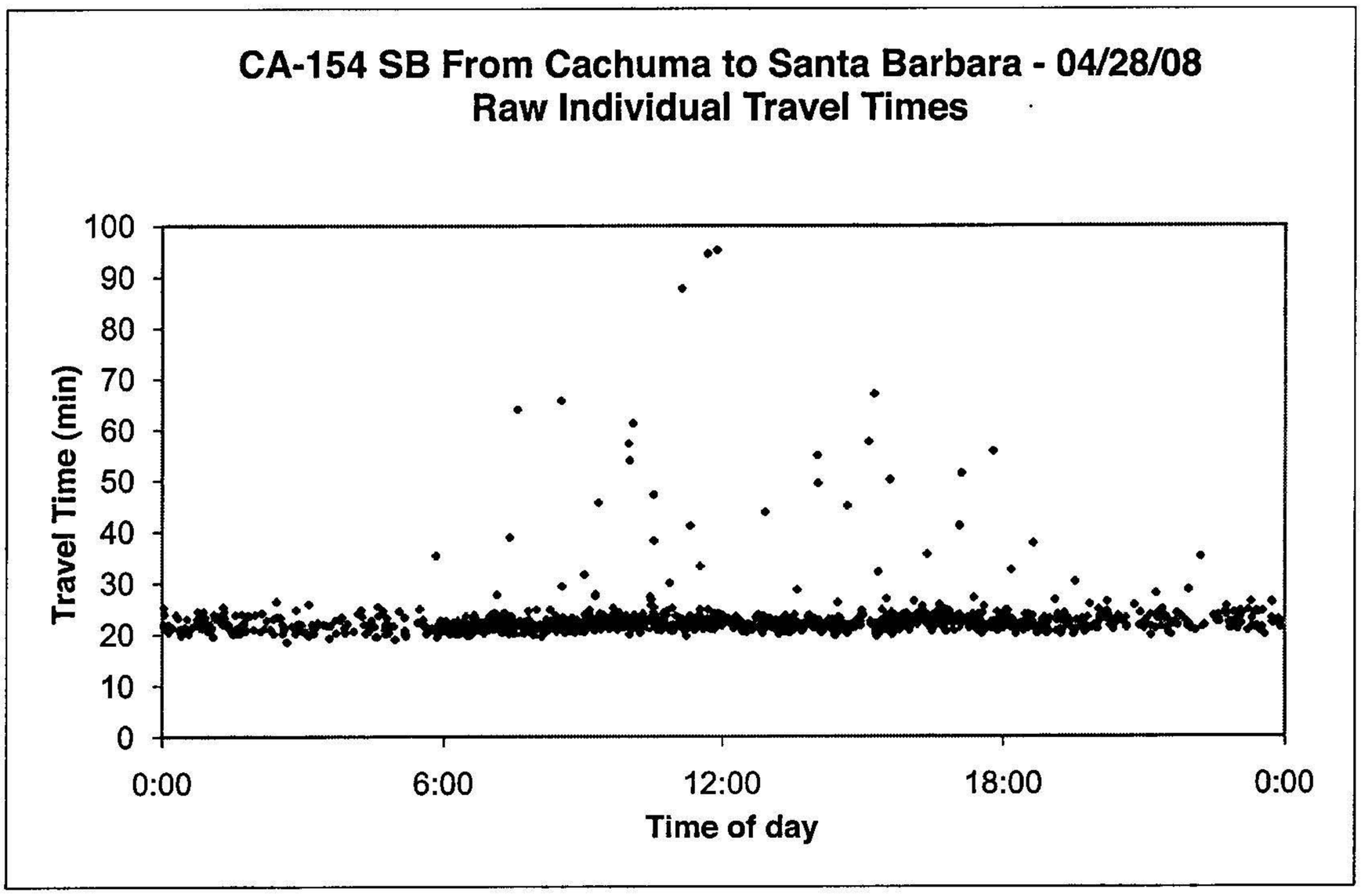

CA-154 SB From Cachuma to Santa Barbara - 04/24/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

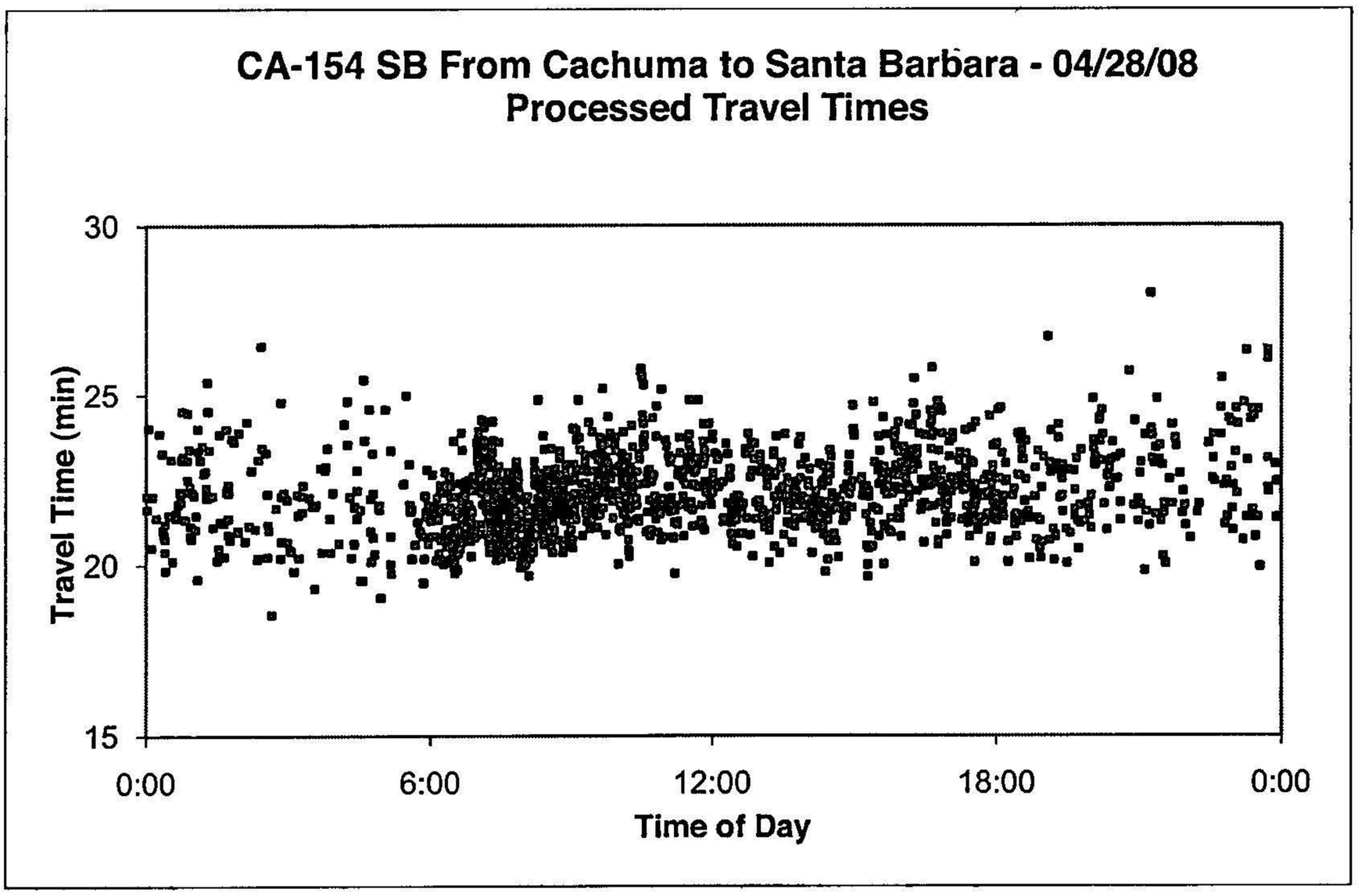

CA-154 SB From Cachuma to Santa Barbara - 04/25/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


CA-154 SB From Cachuma to Santa Barbara - 04/25/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

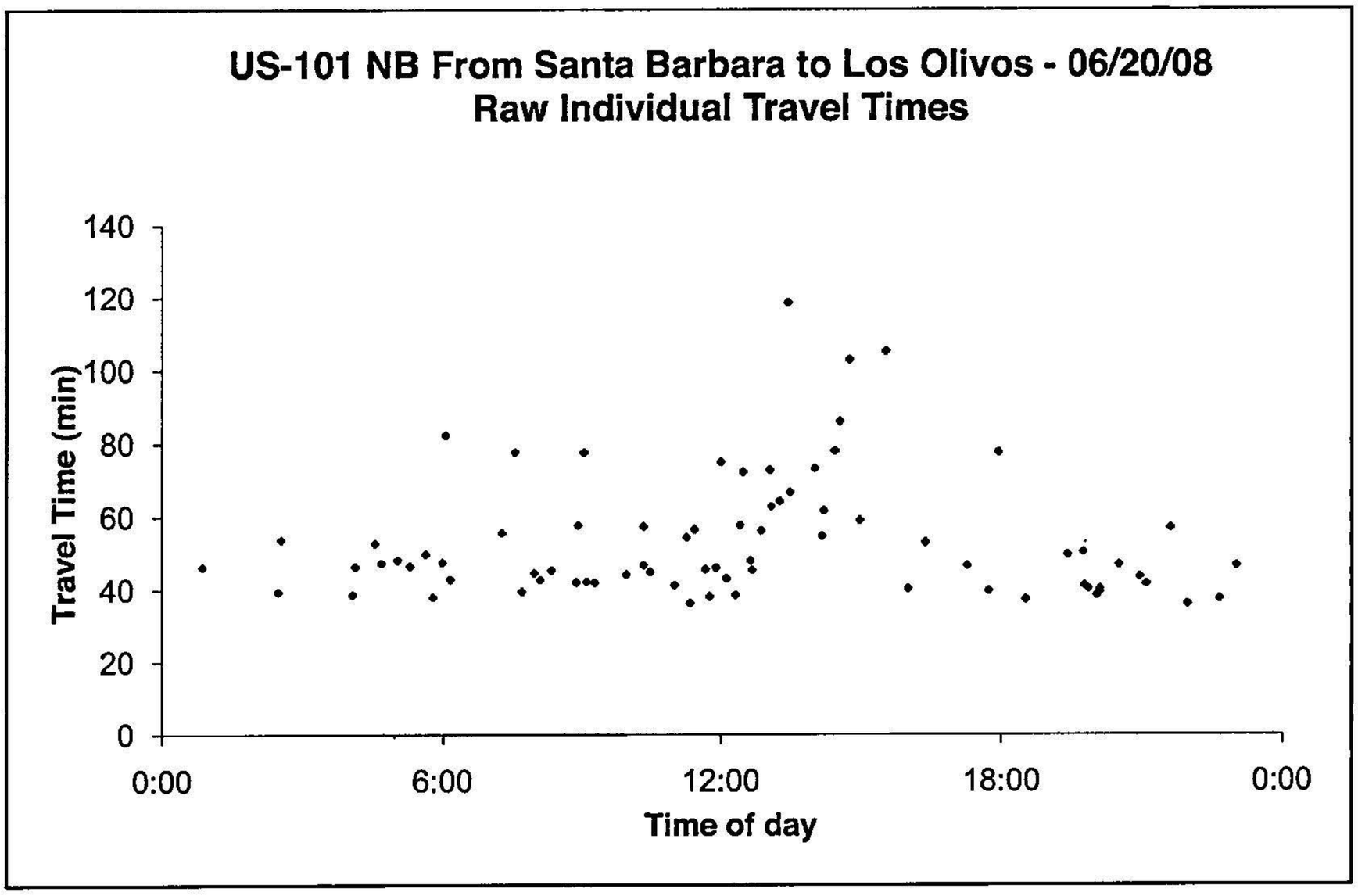

CA-154 SB From Cachuma to Santa Barbara - 04/26/08
Raw Individual Travel Times
Travel Time (min)
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100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

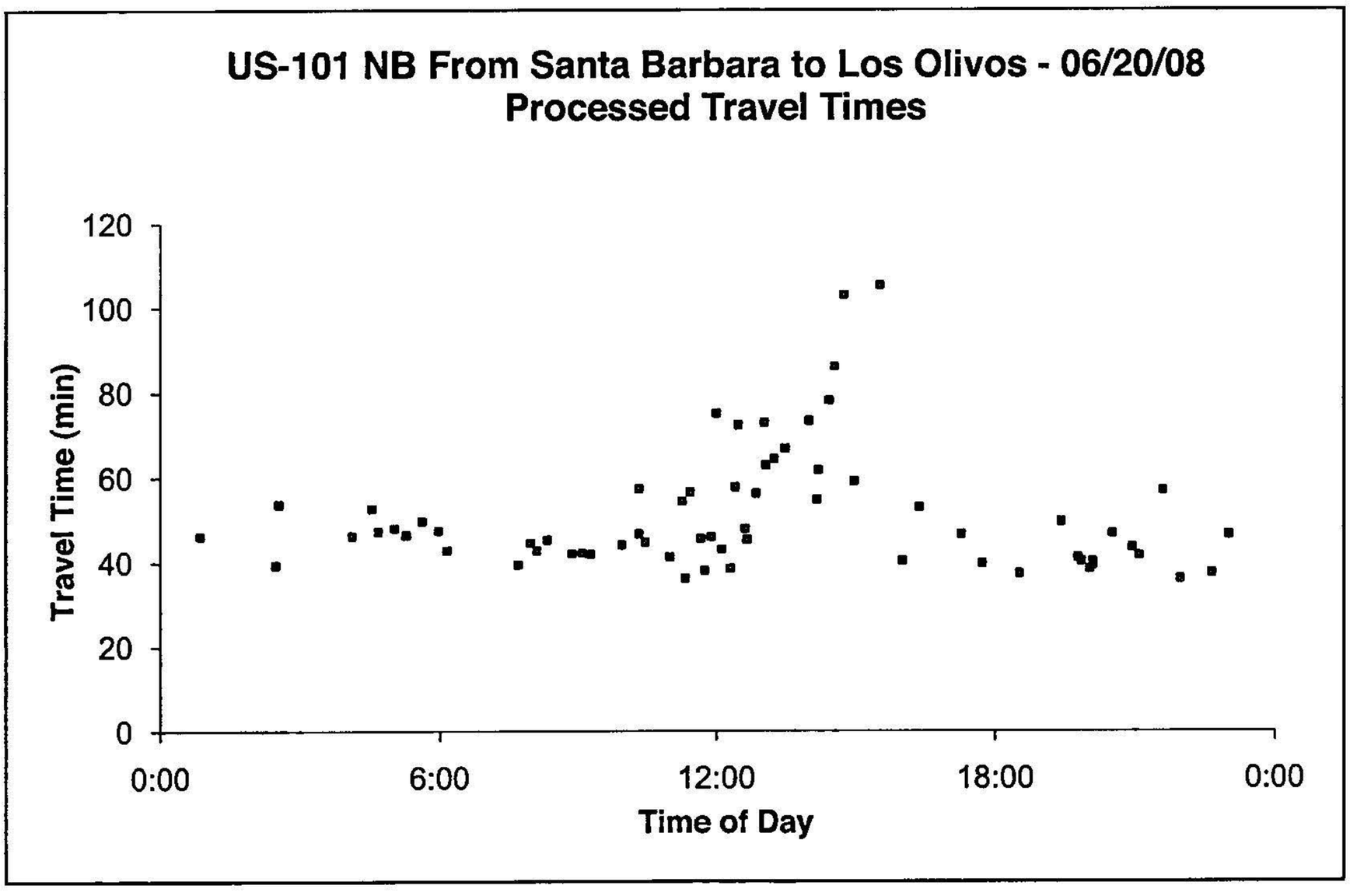

CA-154 SB From Cachuma to Santa Barbara - 04/26/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

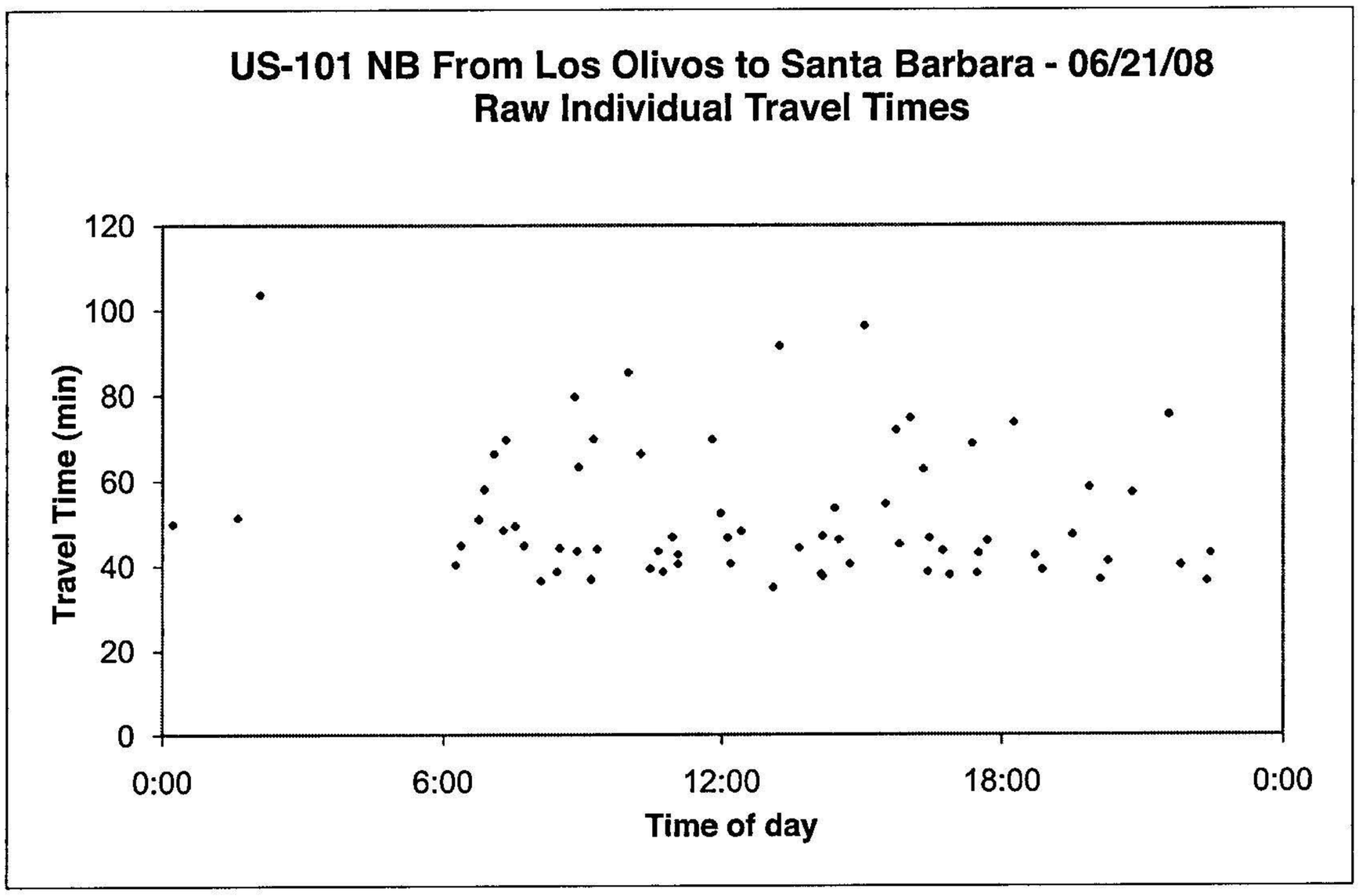

CA-154 SB From Cachuma to Santa Barbara - 04/28/08
Raw Individual Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

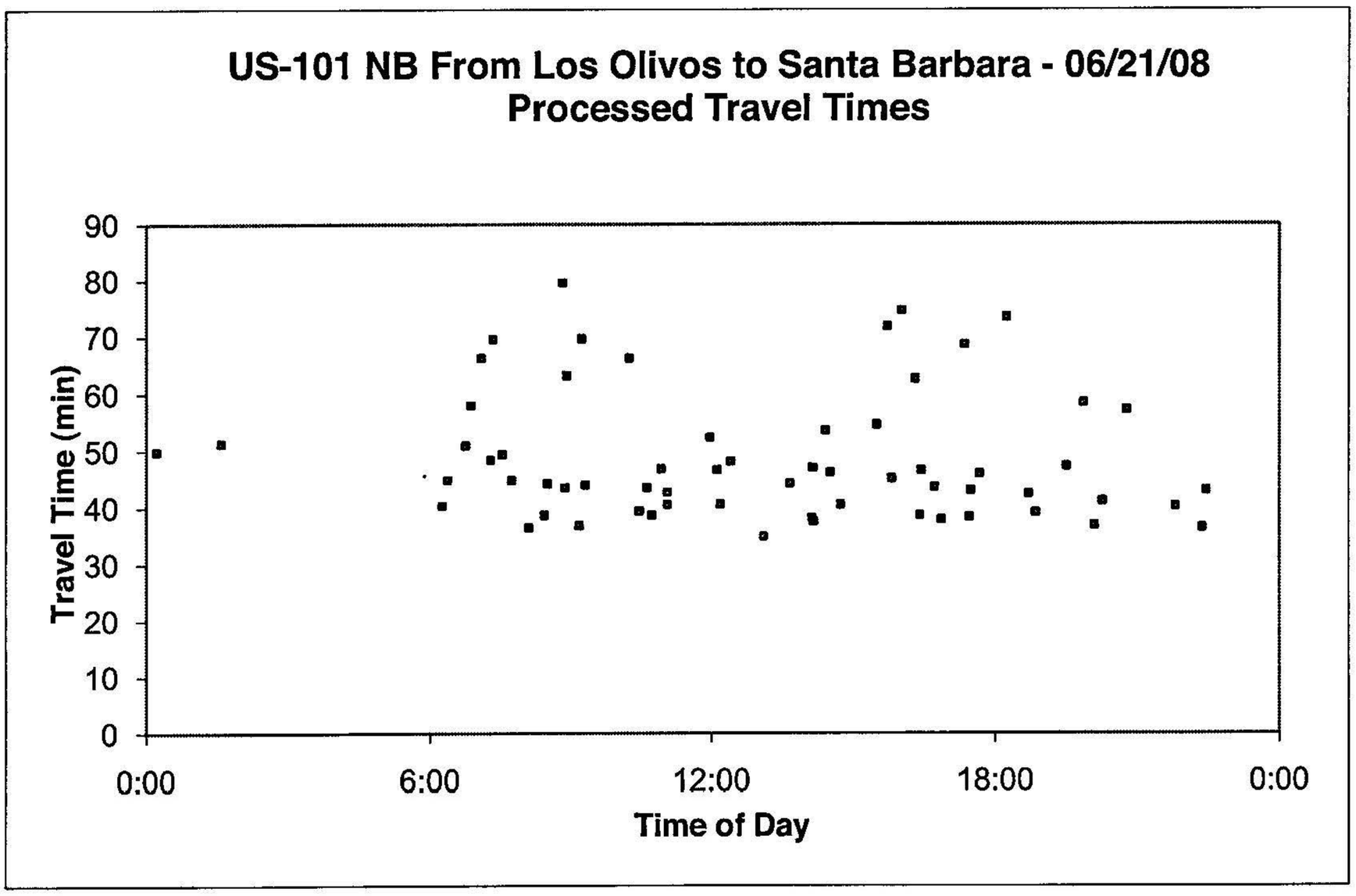

CA-154 SB From Cachuma to Santa Barbara - 04/28/08
Processed Travel Times
Travel Time (min)
30
25
20
15
0:00
6:00
12:00
18:00
0:00
Time of Day

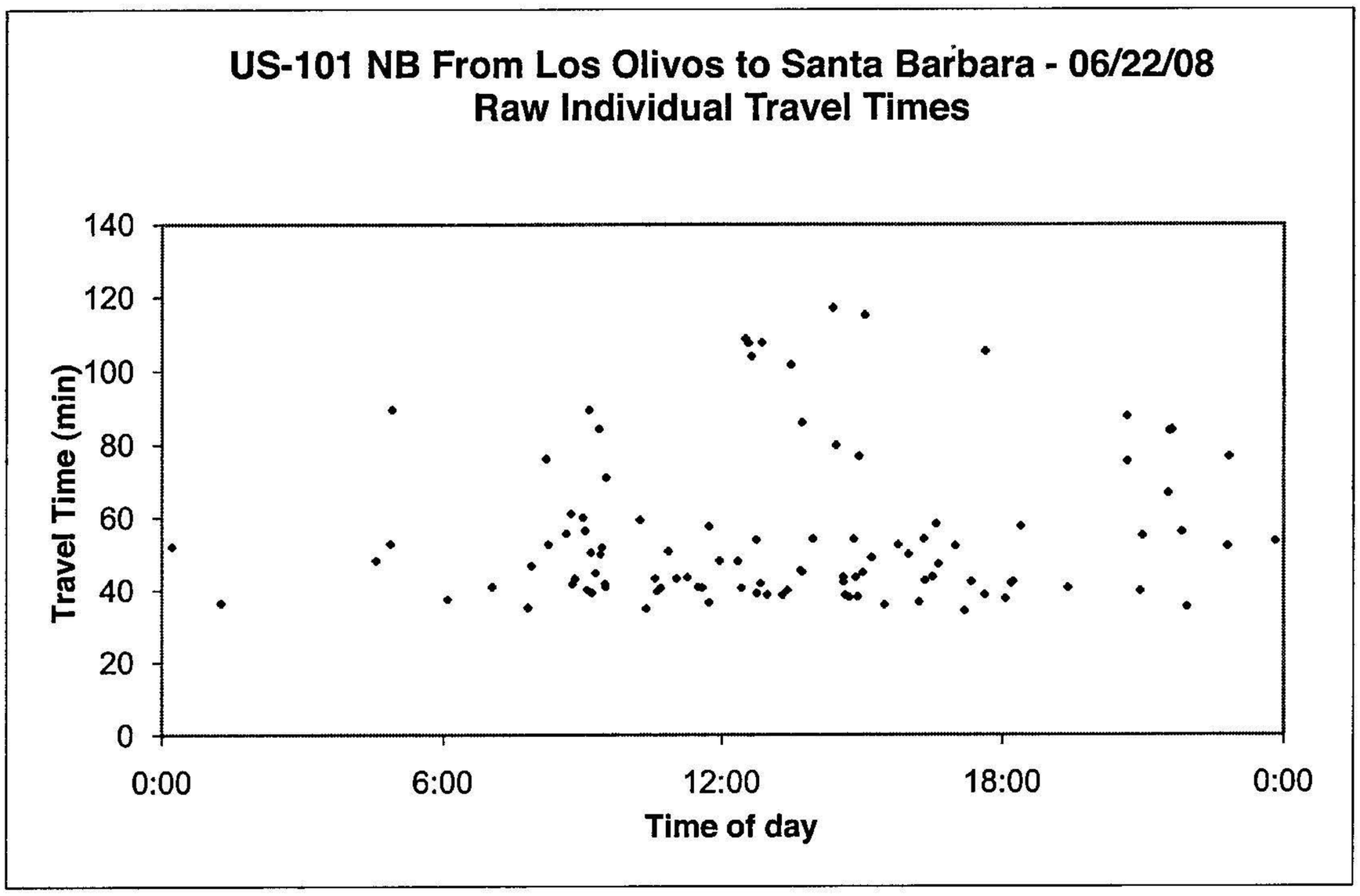
C.4 US-101 From Los Olivos to Santa Barbara Travel Time Distribution

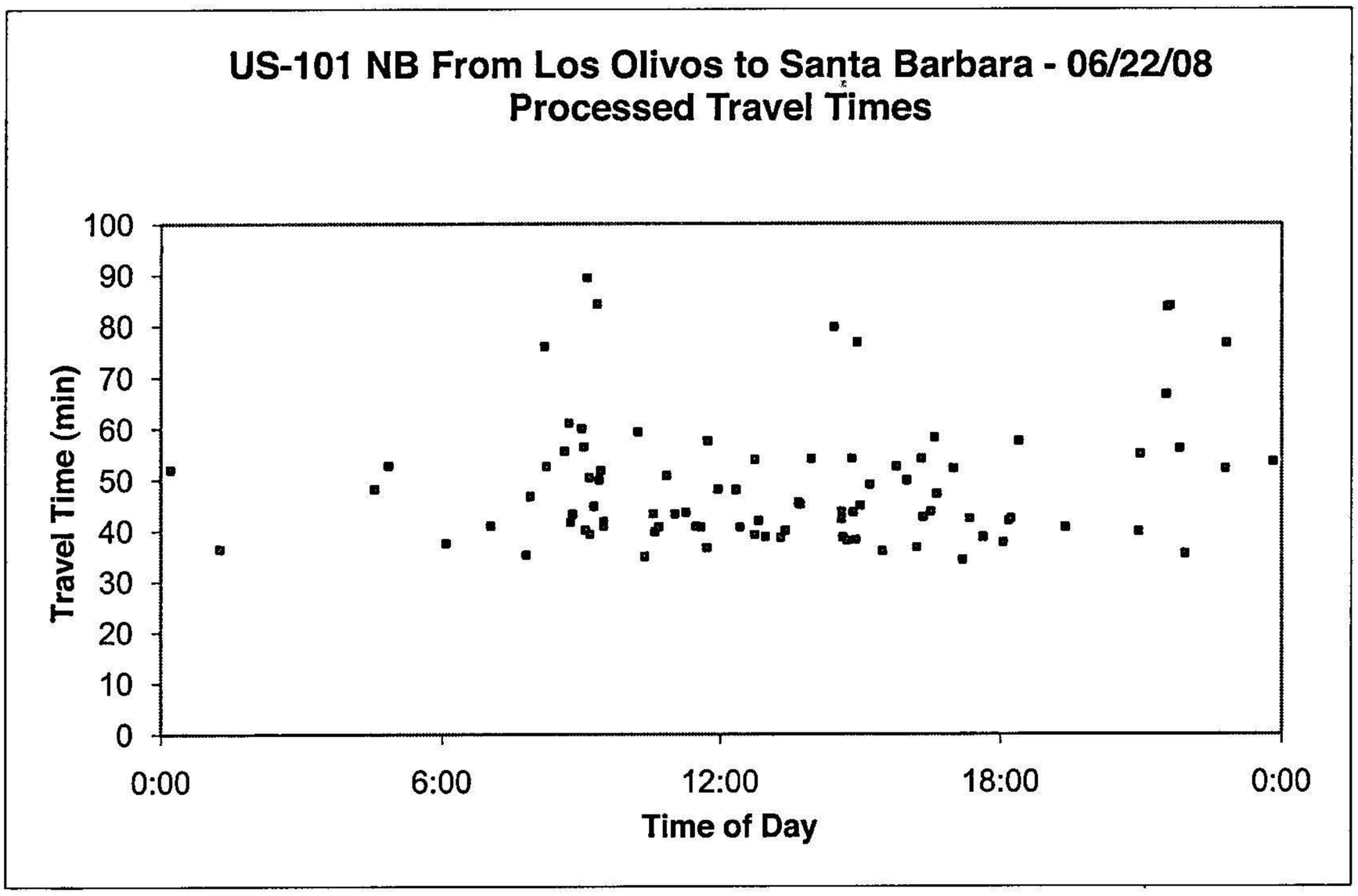


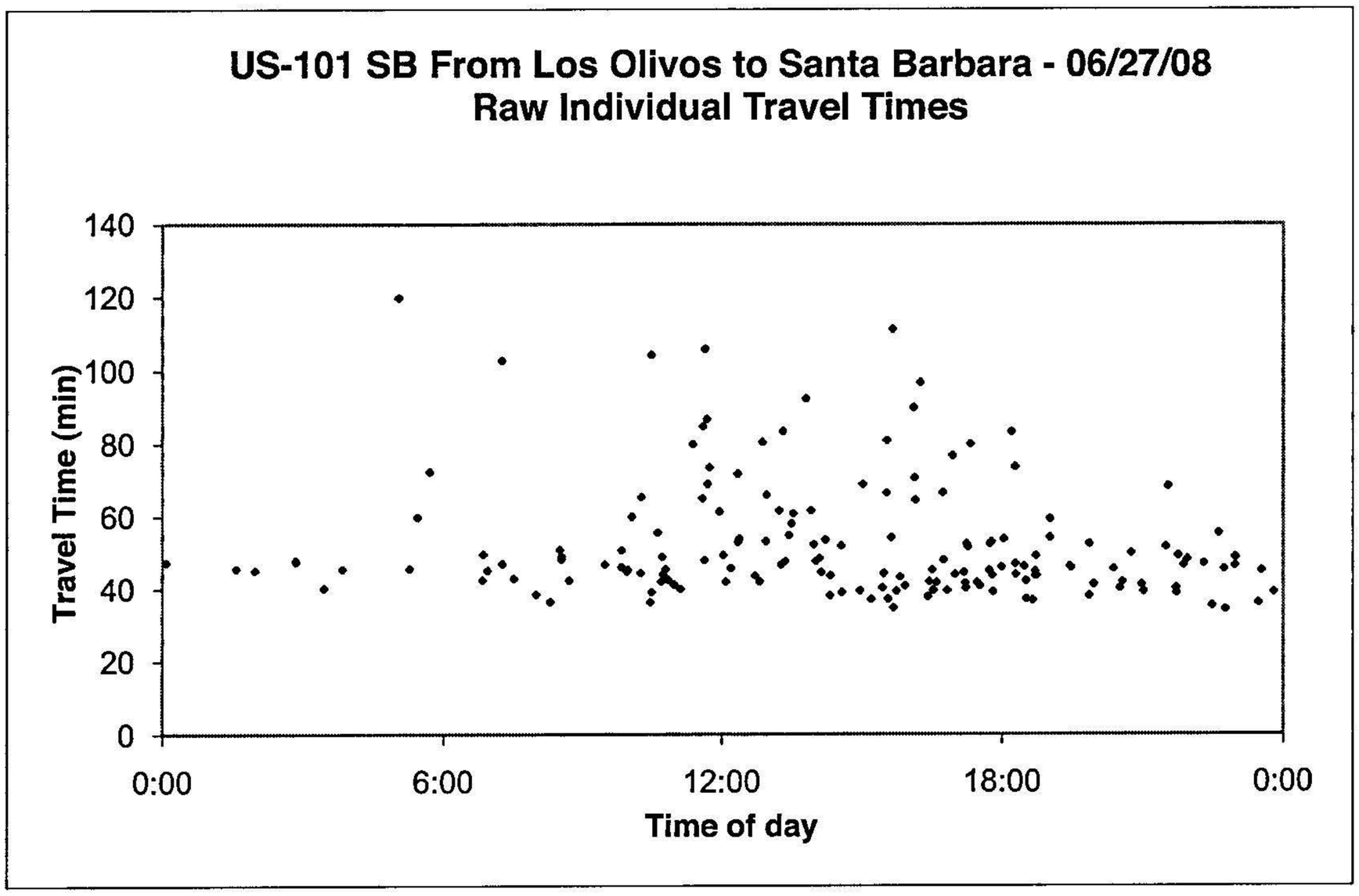


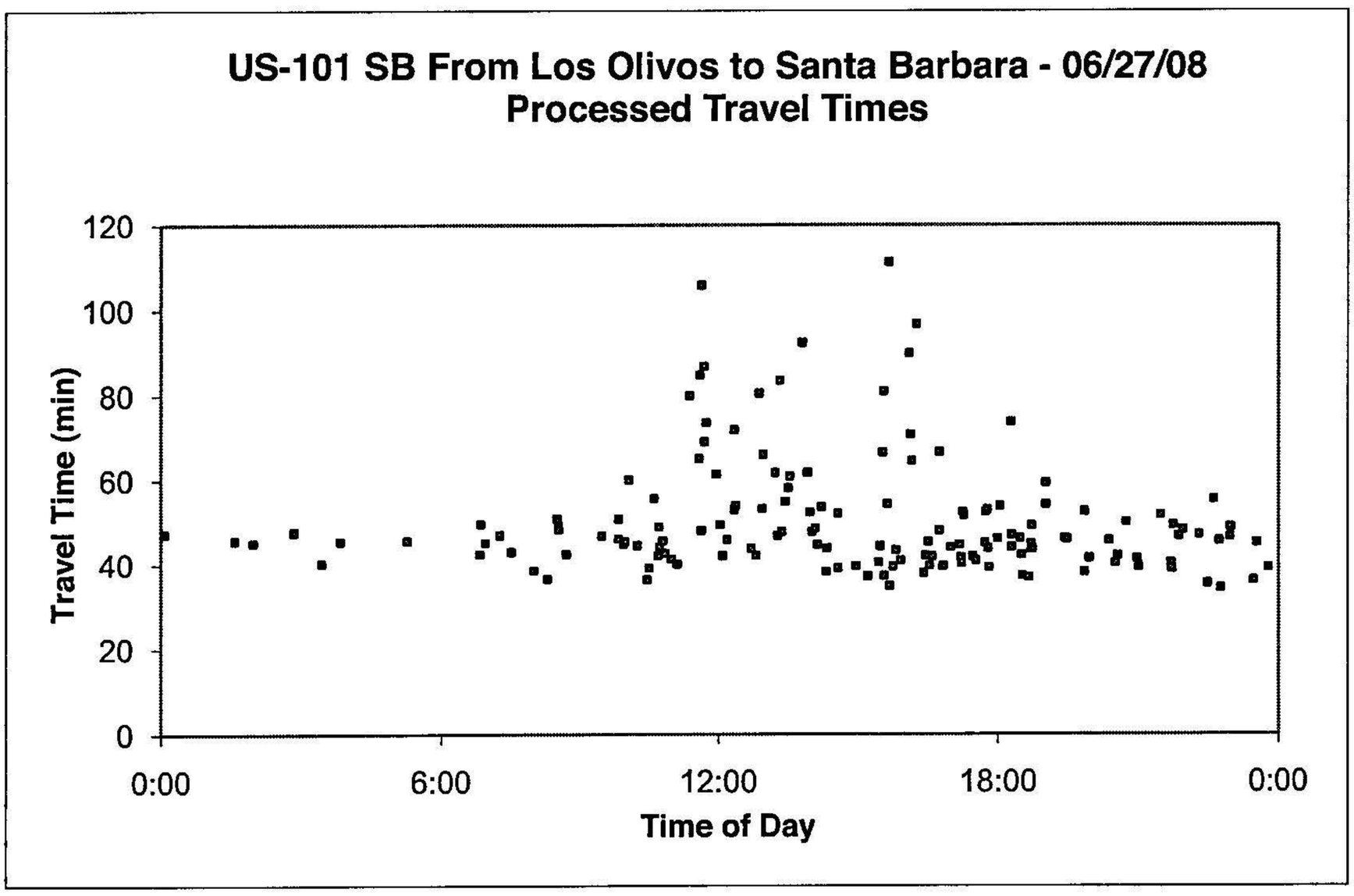

US-101 NB From Los Olivos to Santa Barbara - 06/21/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

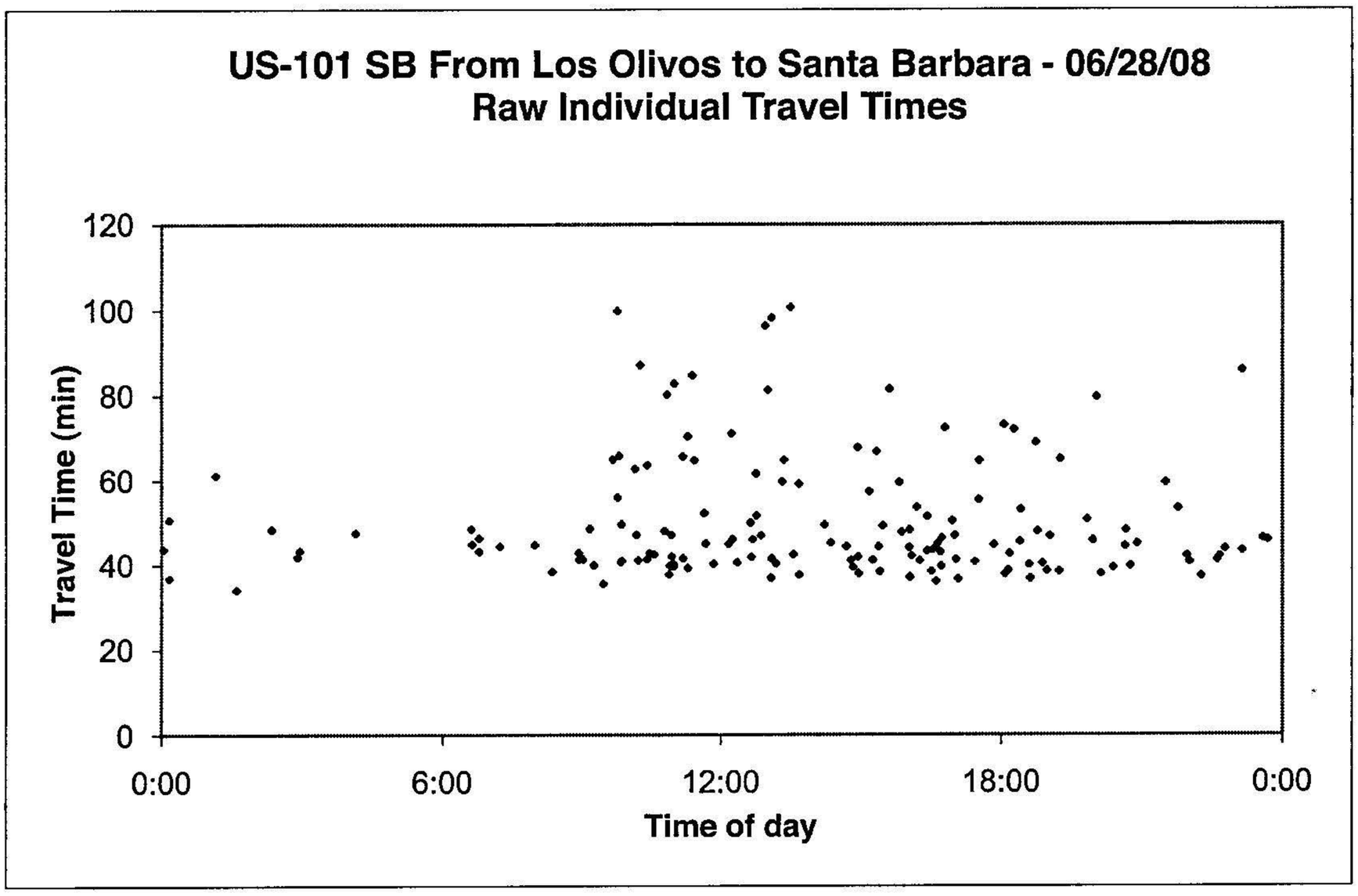

US-101 NB From Los Olivos to Santa Barbara - 06/21/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

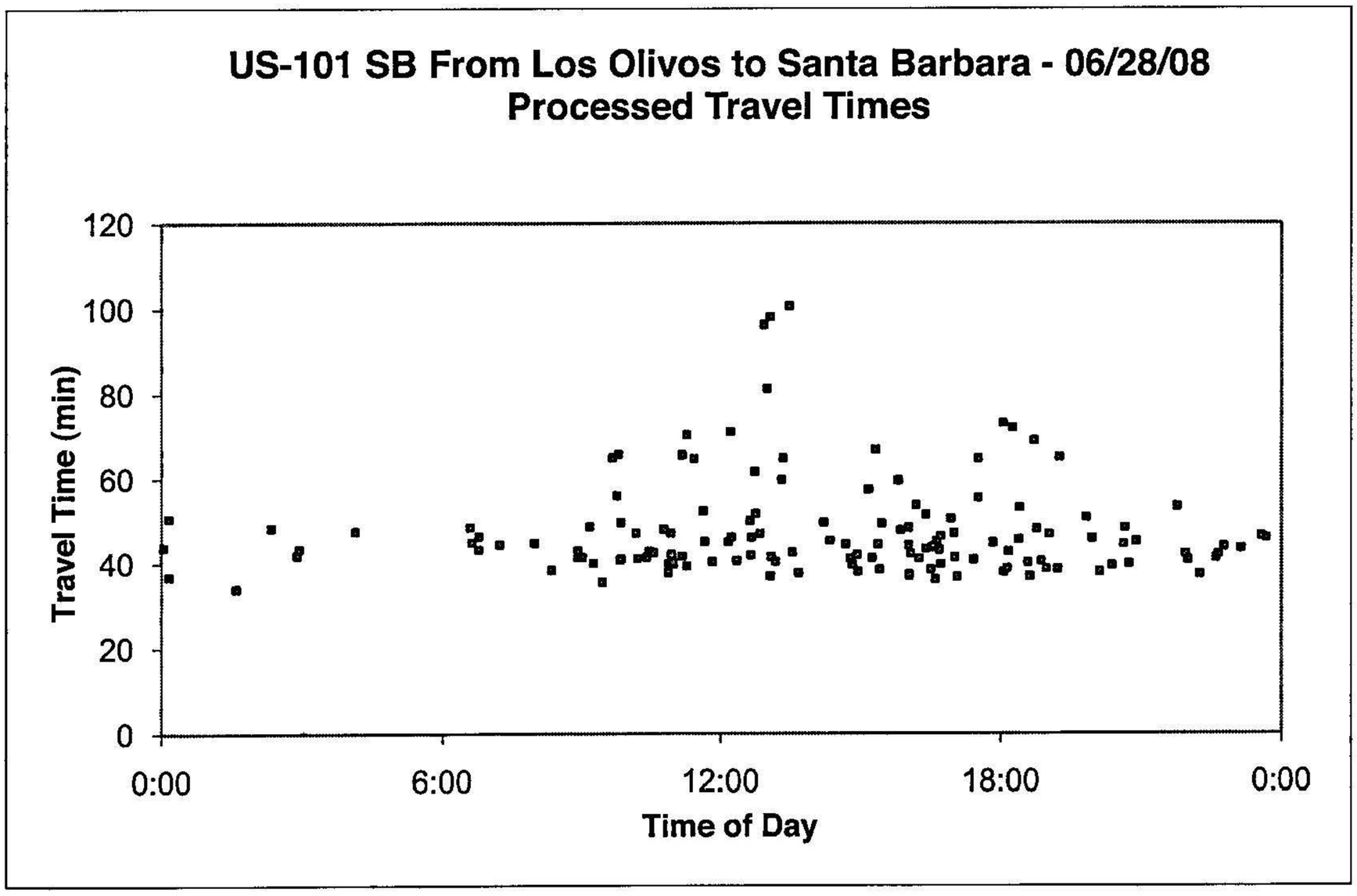

US-101 NB From Los Olivos to Santa Barbara - 06/22/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

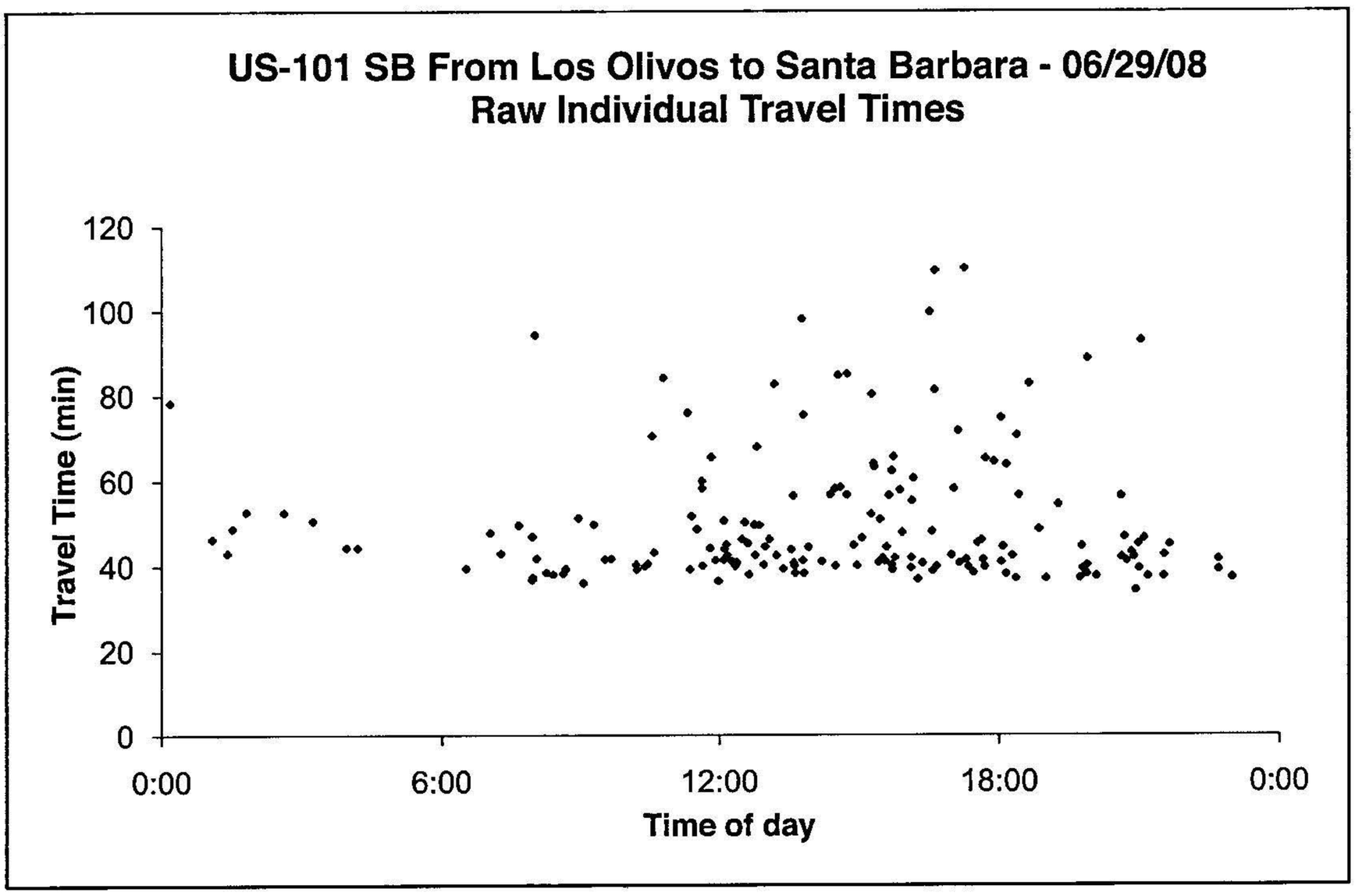

US-101 NB From Los Olivos to Santa Barbara - 06/22/08
Processed Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

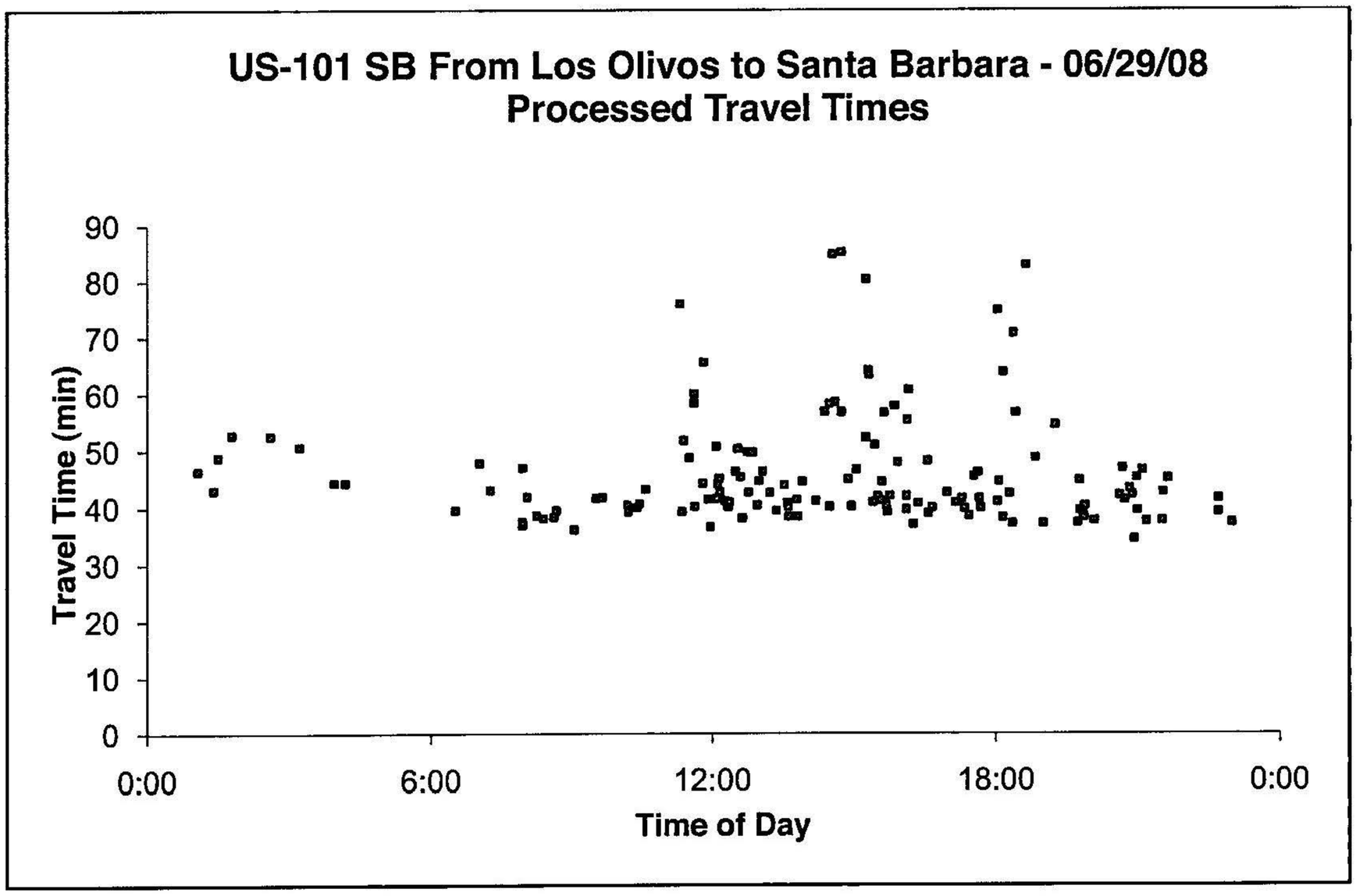

US-101 SB From Los Olivos to Santa Barbara - 06/27/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Los Olivos to Santa Barbara - 06/27/08
Processed Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of Day

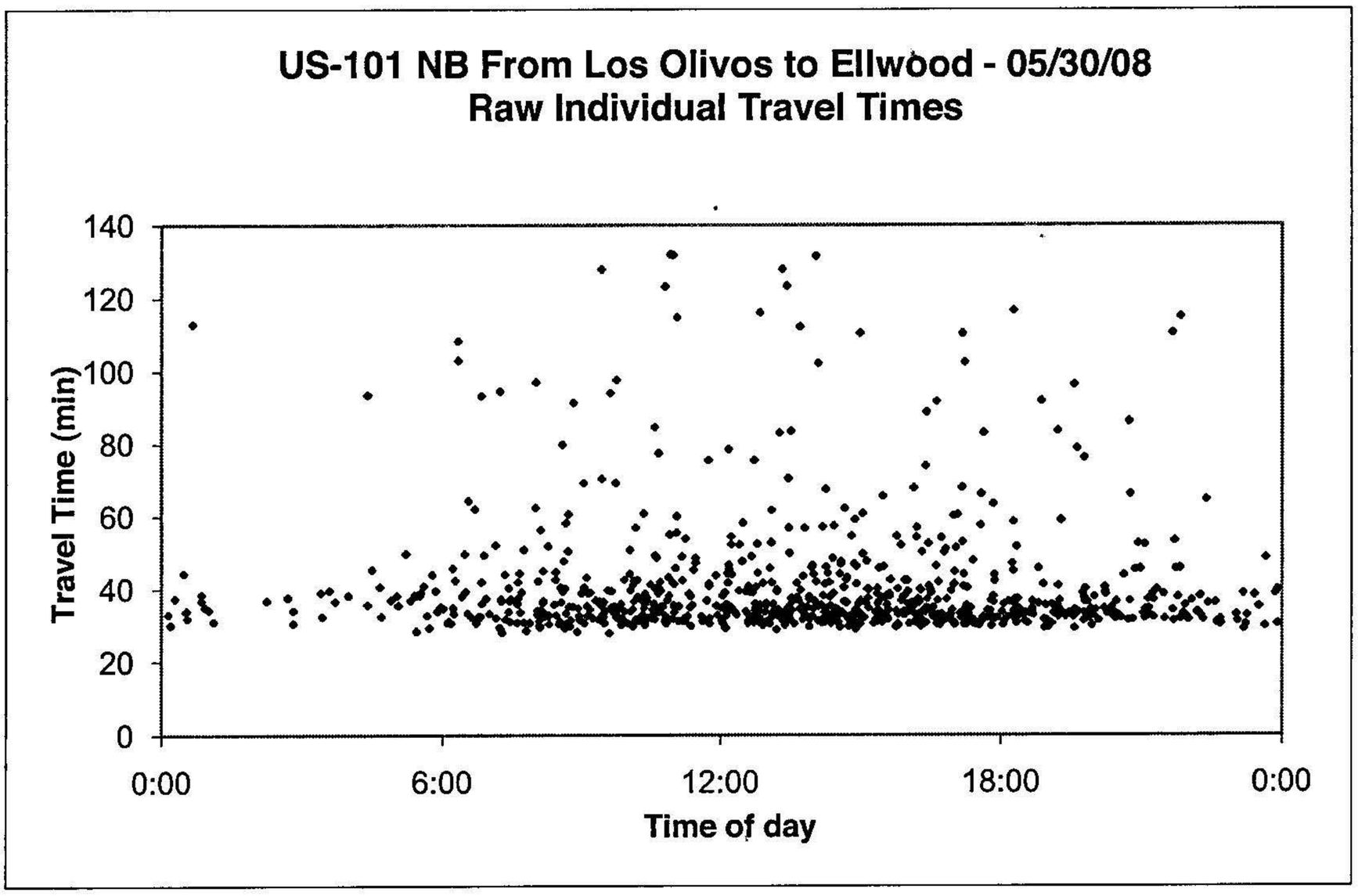

US-101 SB From Los Olivos to Santa Barbara - 06/28/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

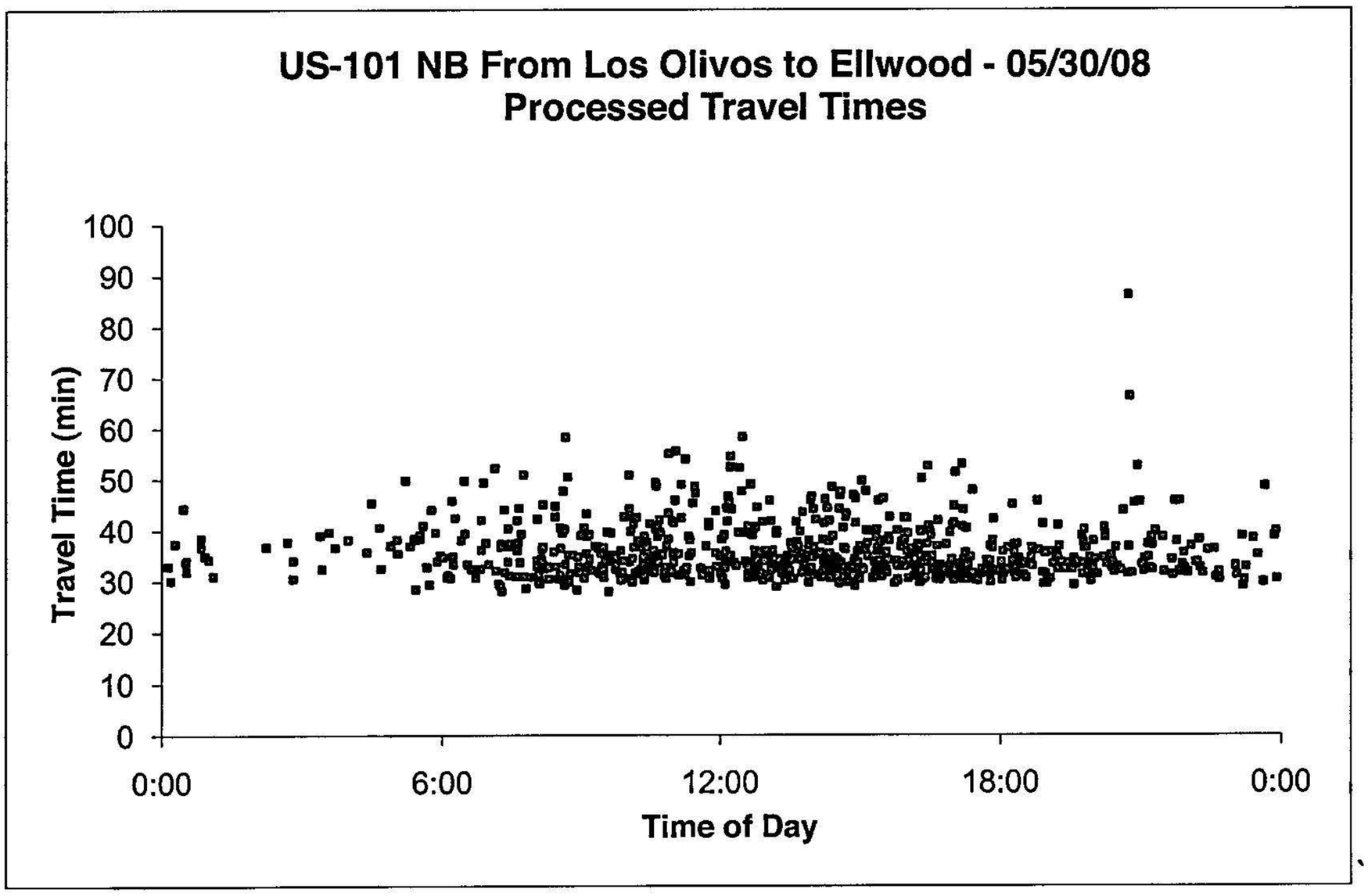

US-101 SB From Los Olivos to Santa Barbara - 06/28/08
Processed Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of Day

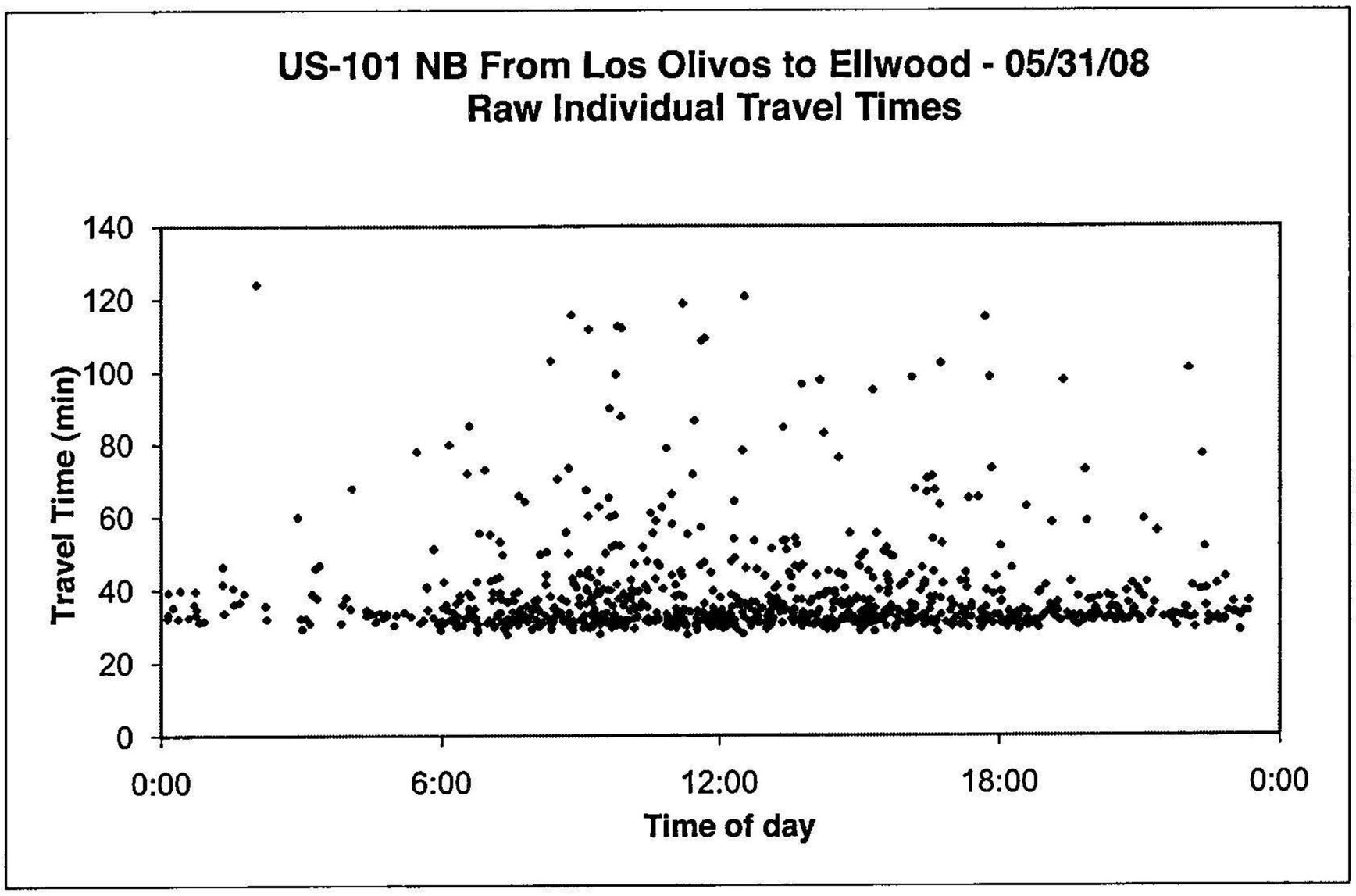

US-101 SB From Los Olivos to Santa Barbara - 06/29/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

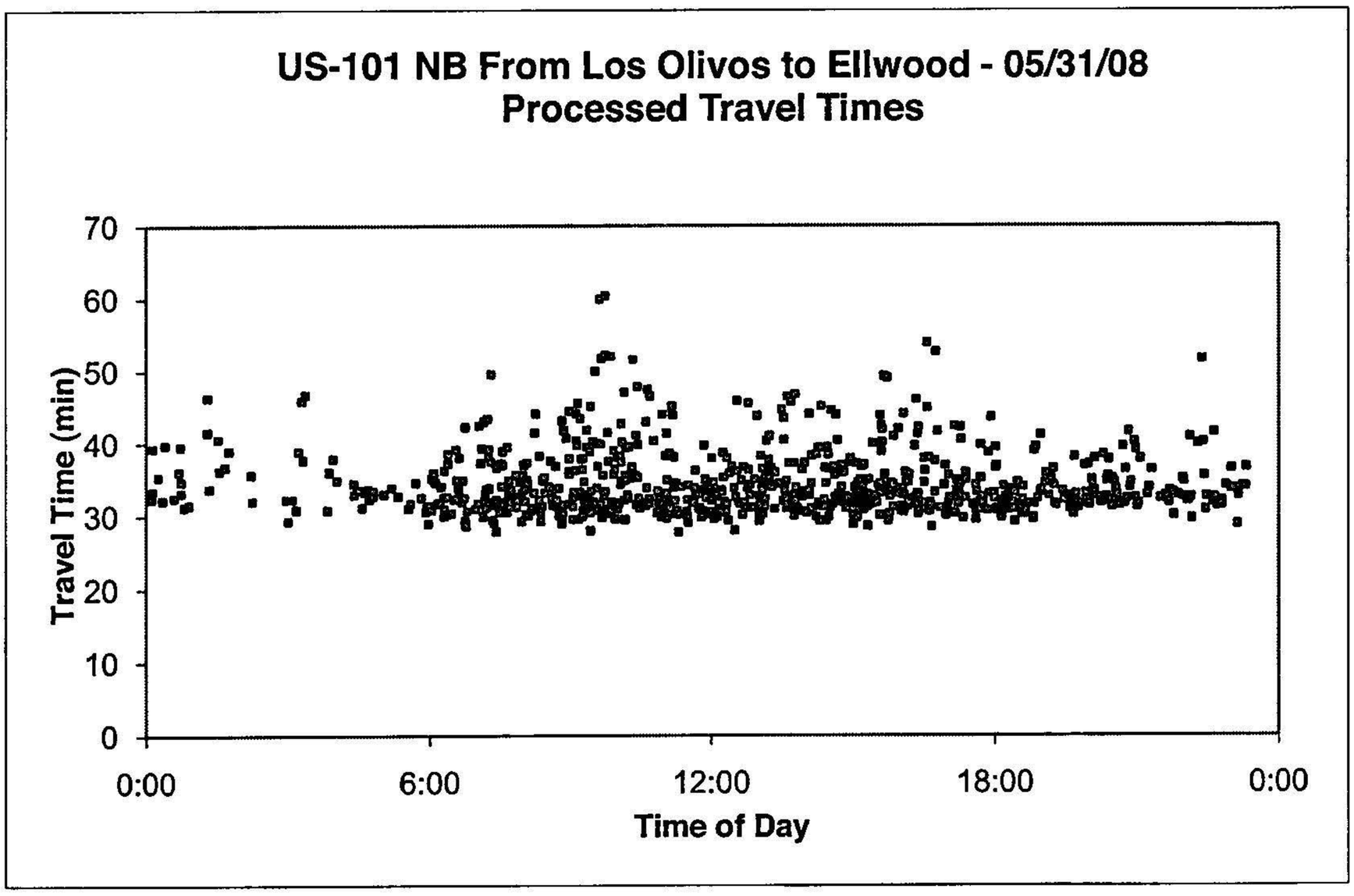

US-101 SB From Los Olivos to Santa Barbara - 06/29/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

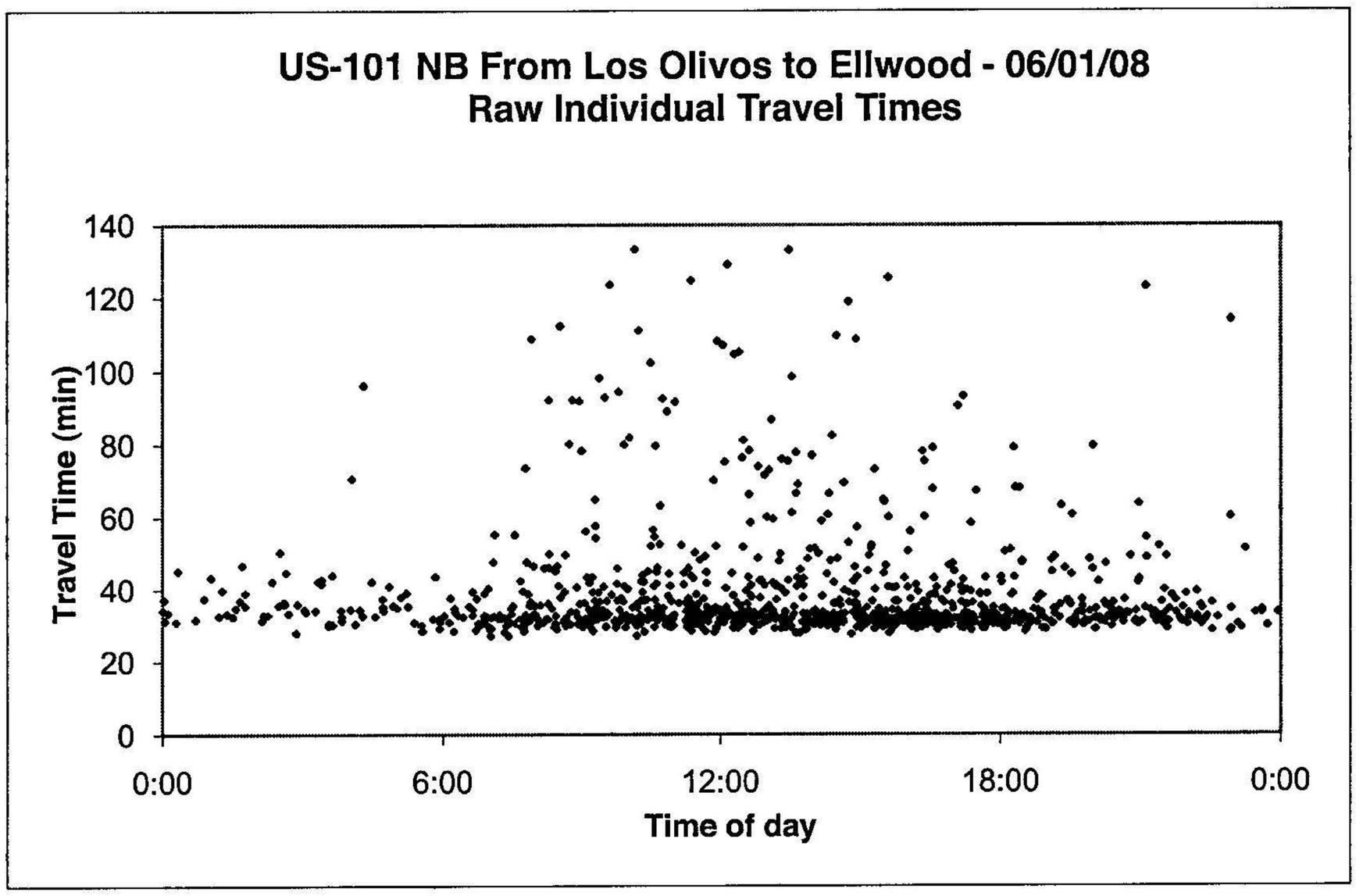
C.5 US-101 From Los Olivos to Ellwood Travel Time Distribution

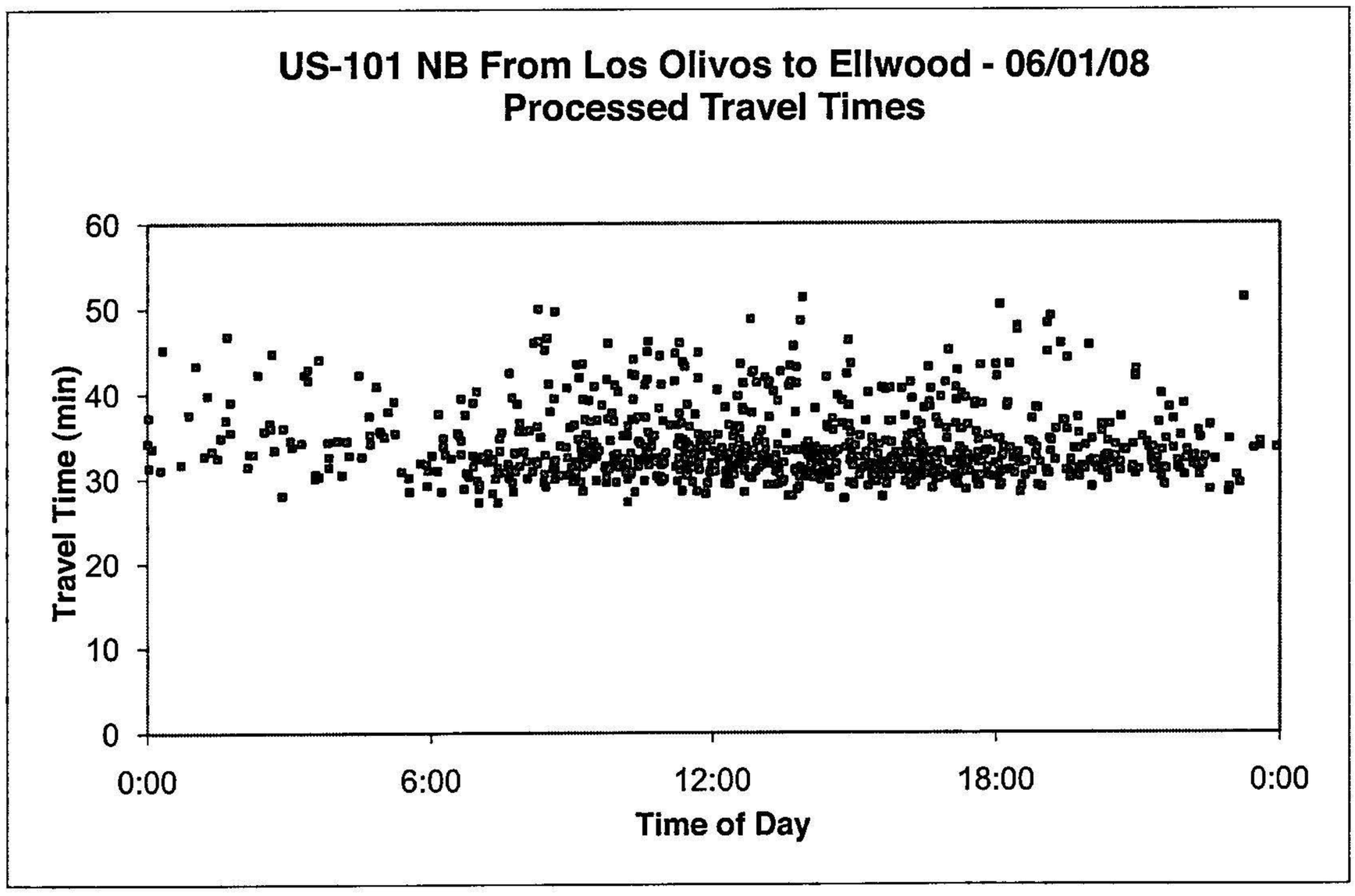


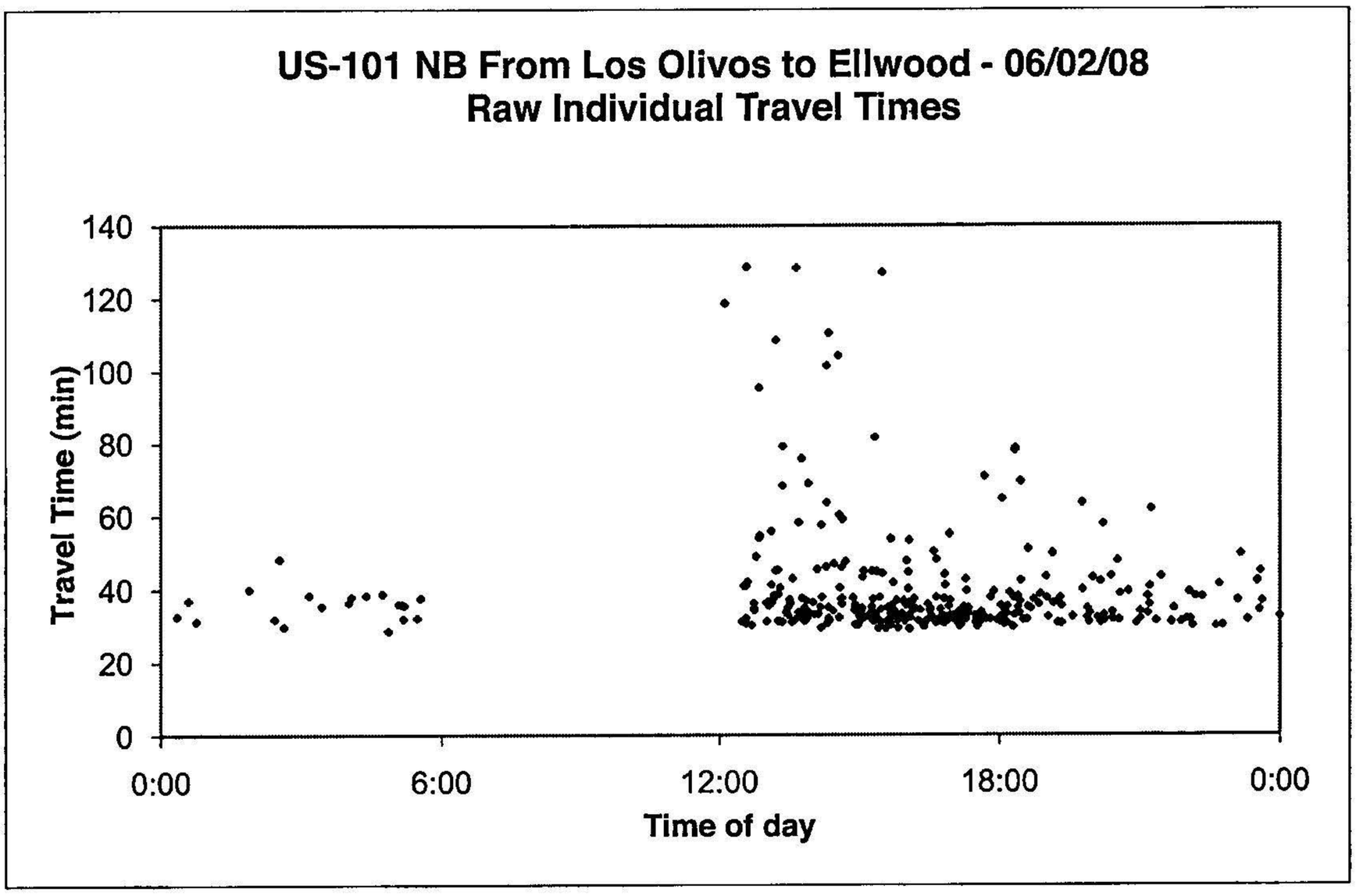


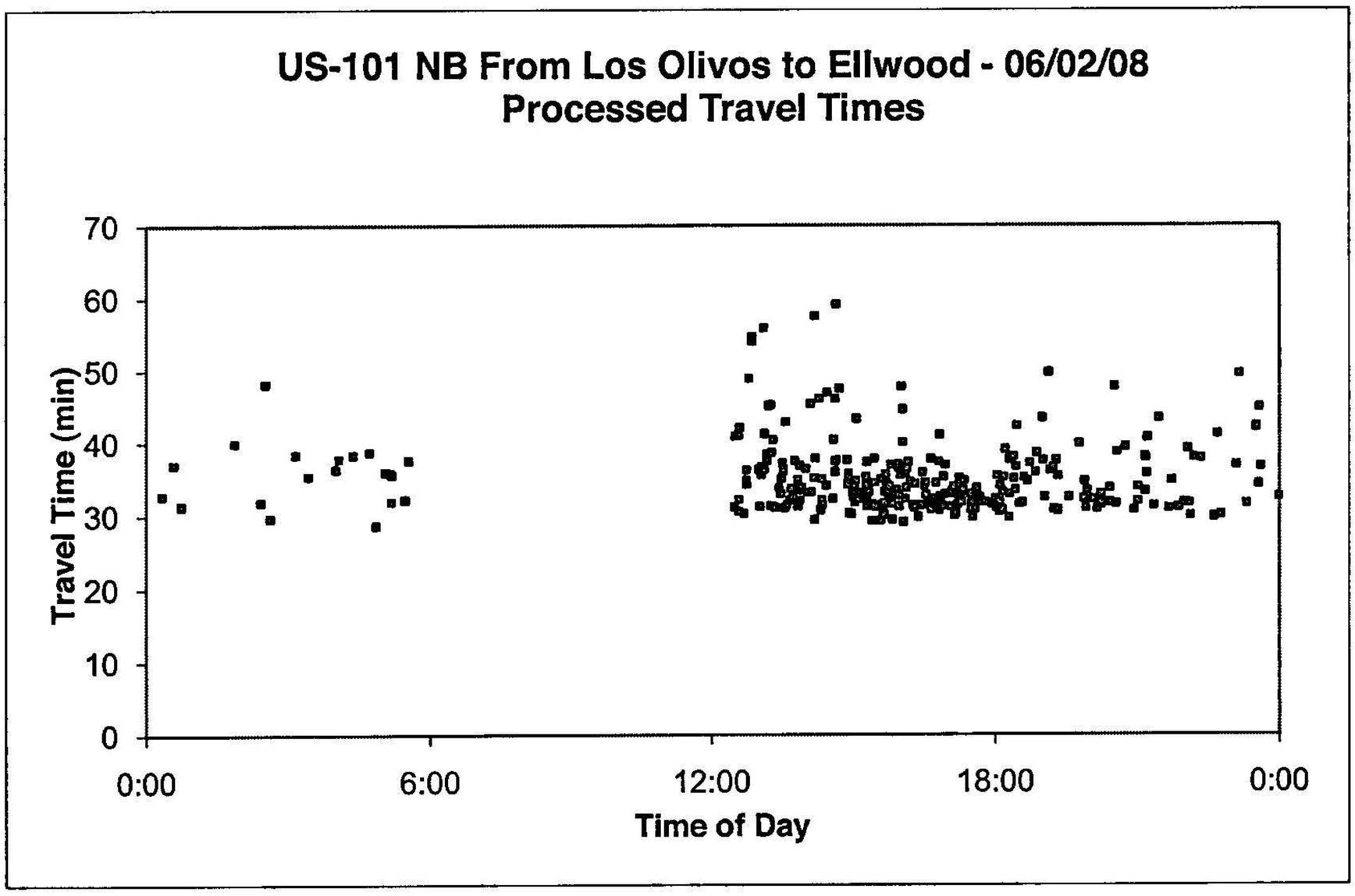

US-101 NB From Los Olivos to Ellwood - 05/31/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

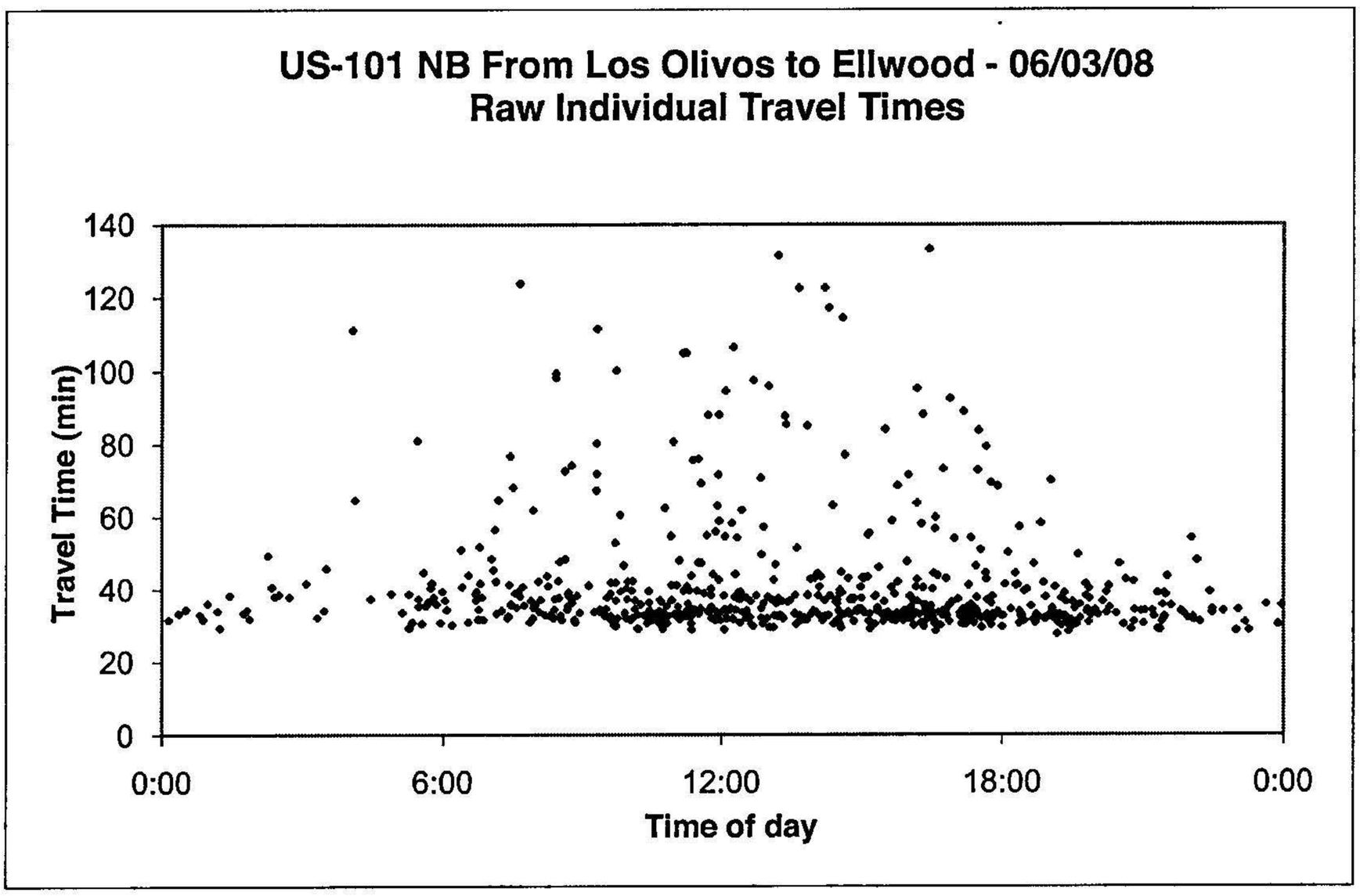

US-101 NB From Los Olivos to Ellwood - 05/31/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

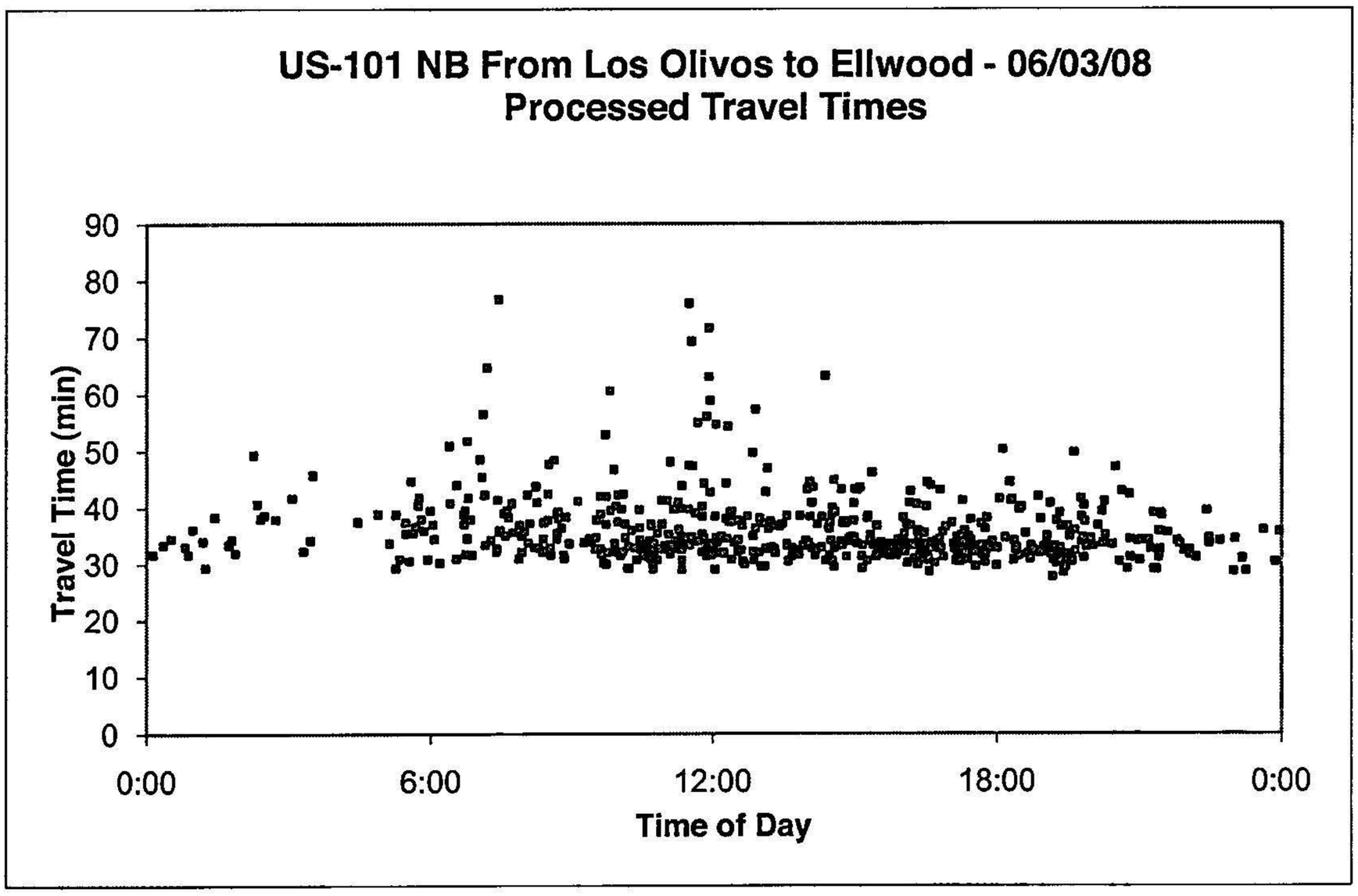

US-101 NB From Los Olivos to Ellwood - 06/01/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

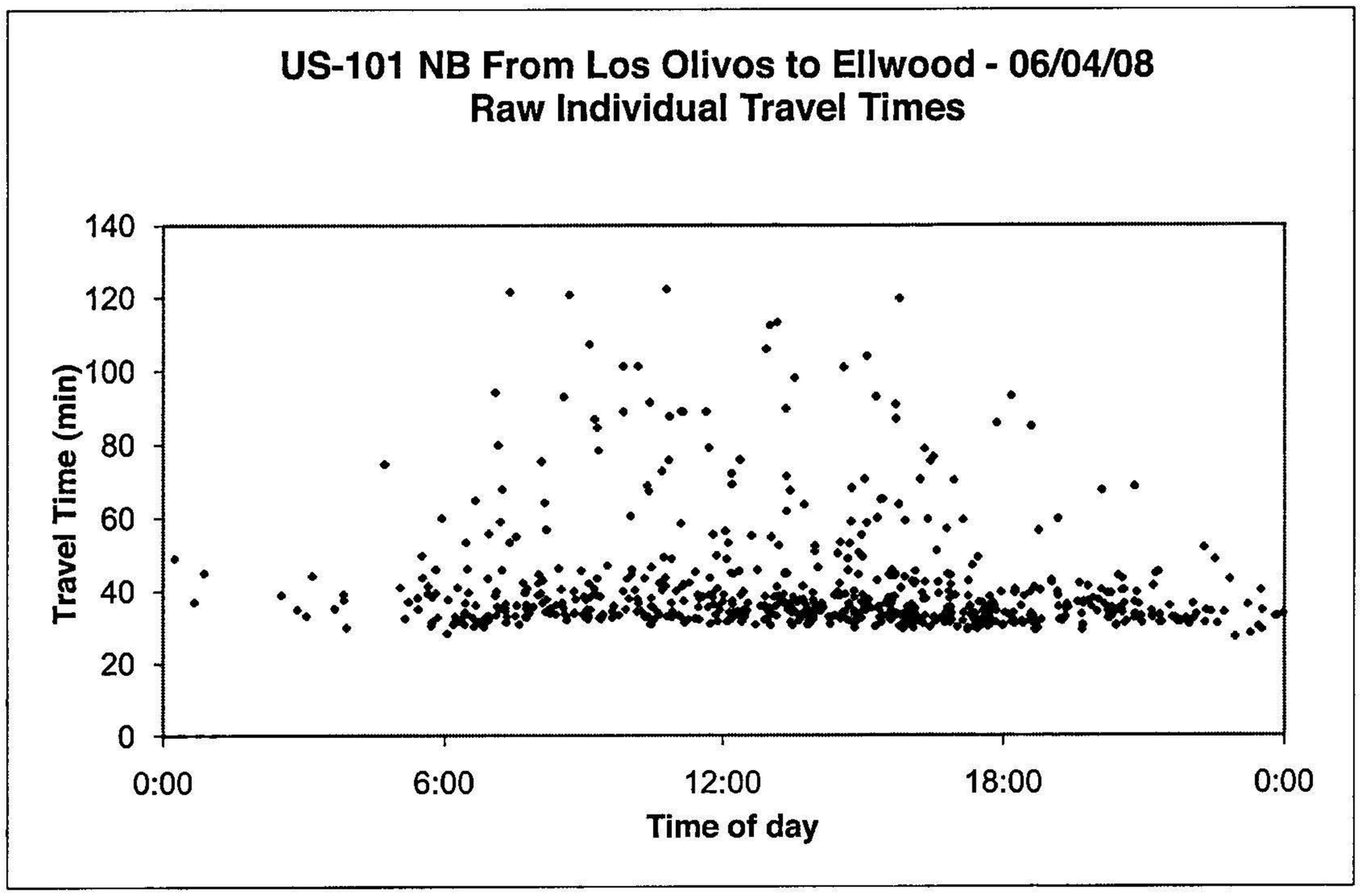

US-101 NB From Los Olivos to Ellwood - 06/01/08
Processed Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

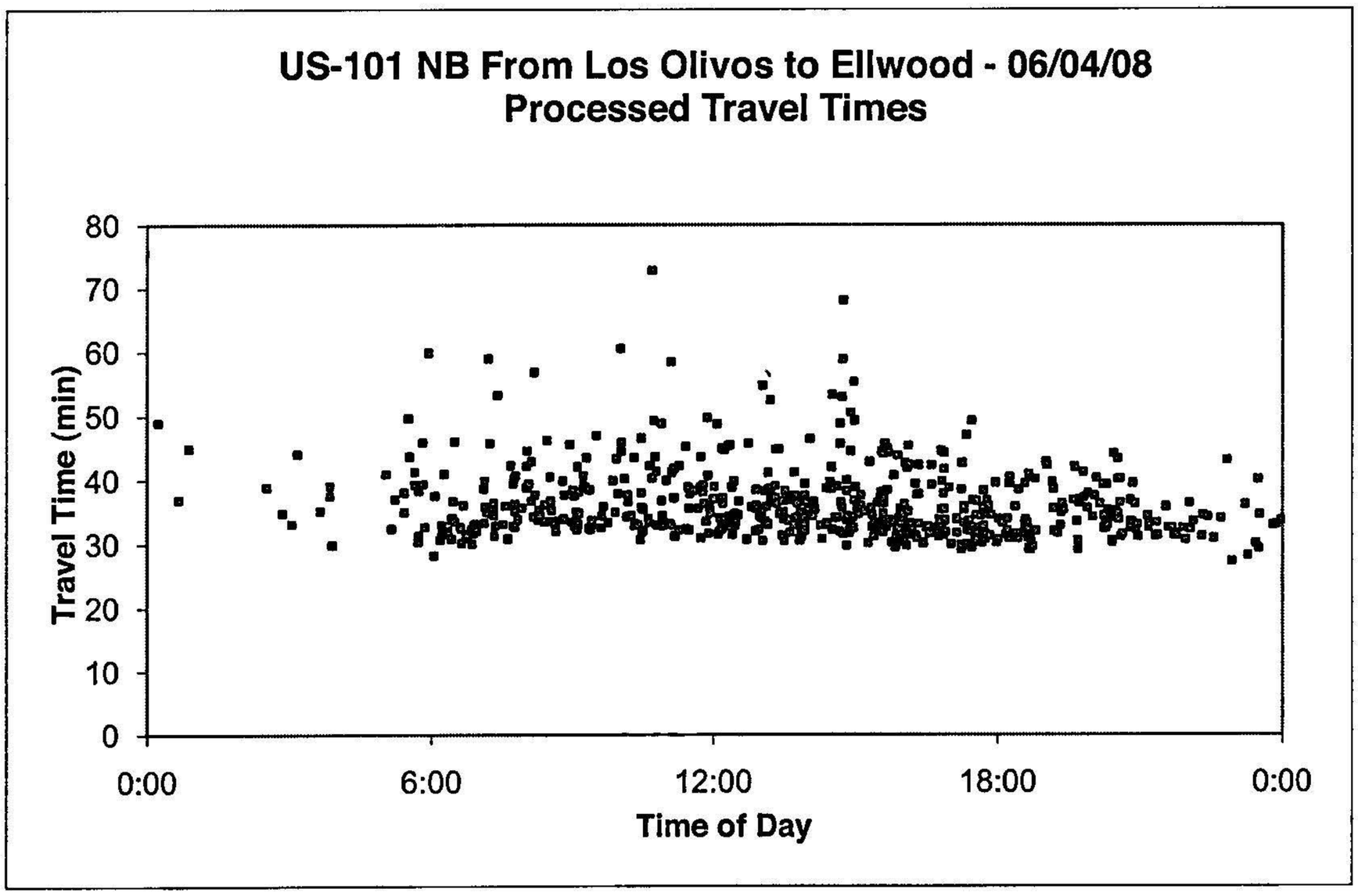

US-101 NB From Los Olivos to Ellwood - 06/02/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

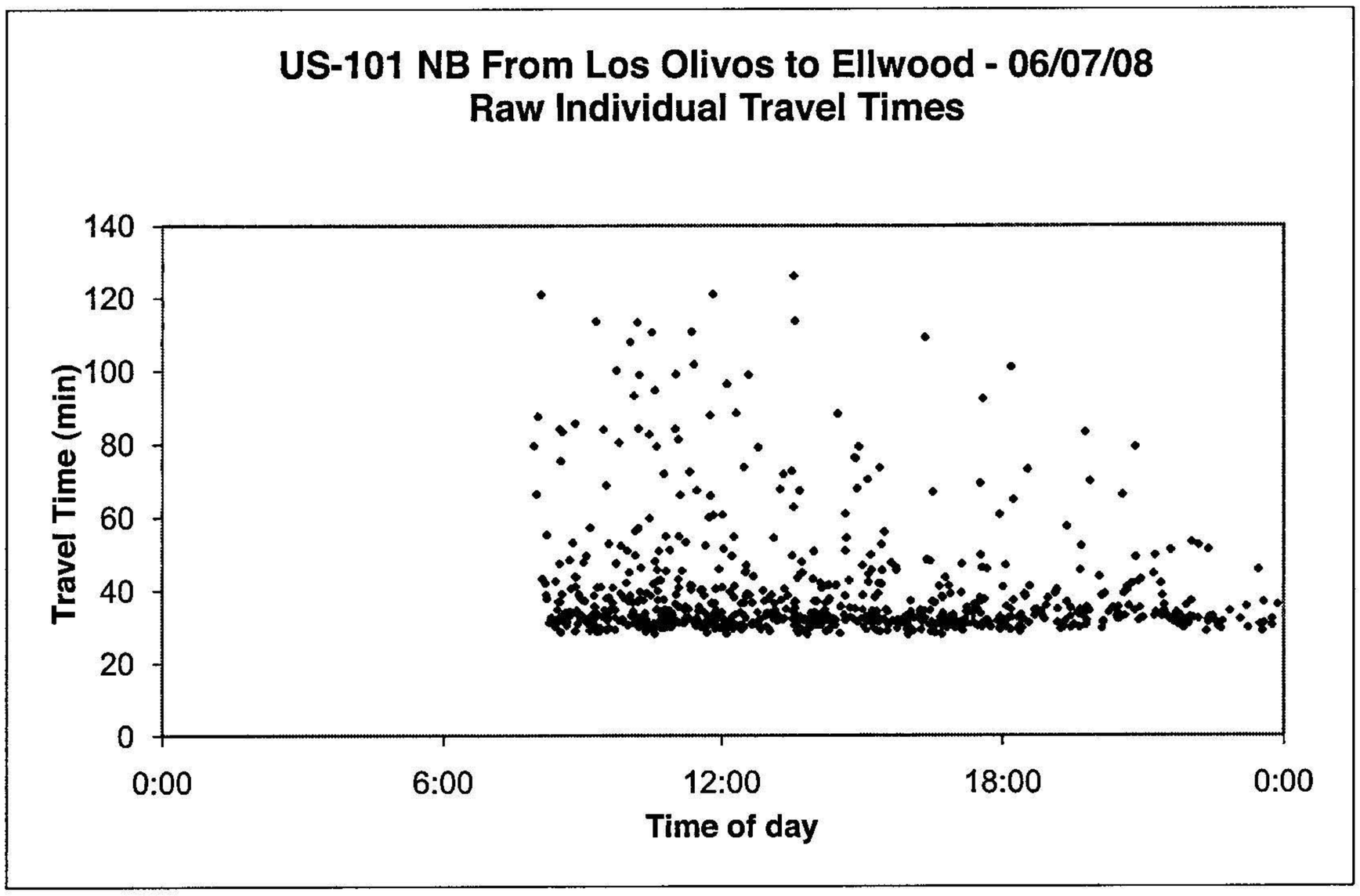

US-101 NB From Los Olivos to Ellwood - 06/02/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

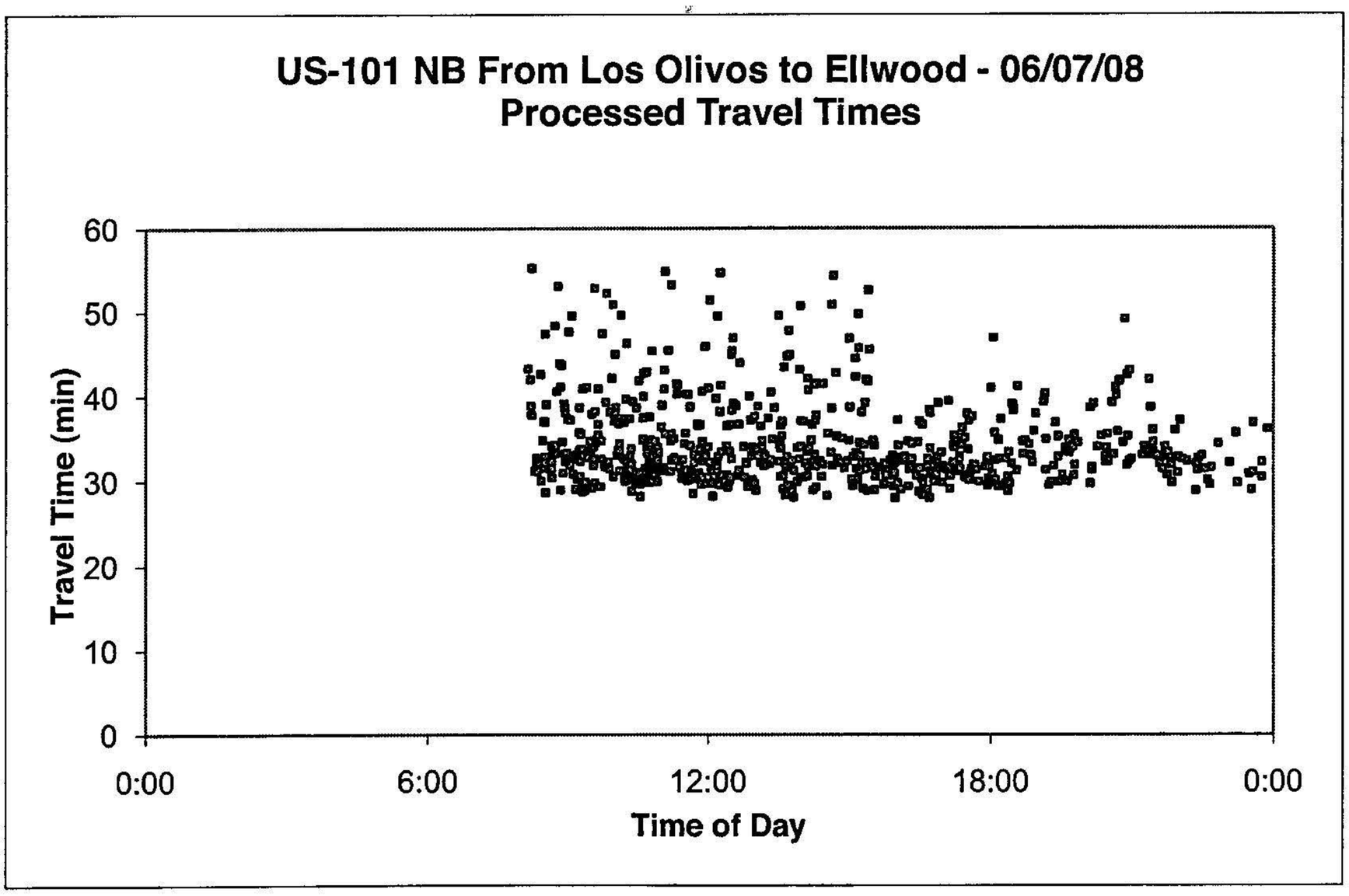

US-101 NB From Los Olivos to Ellwood - 06/03/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

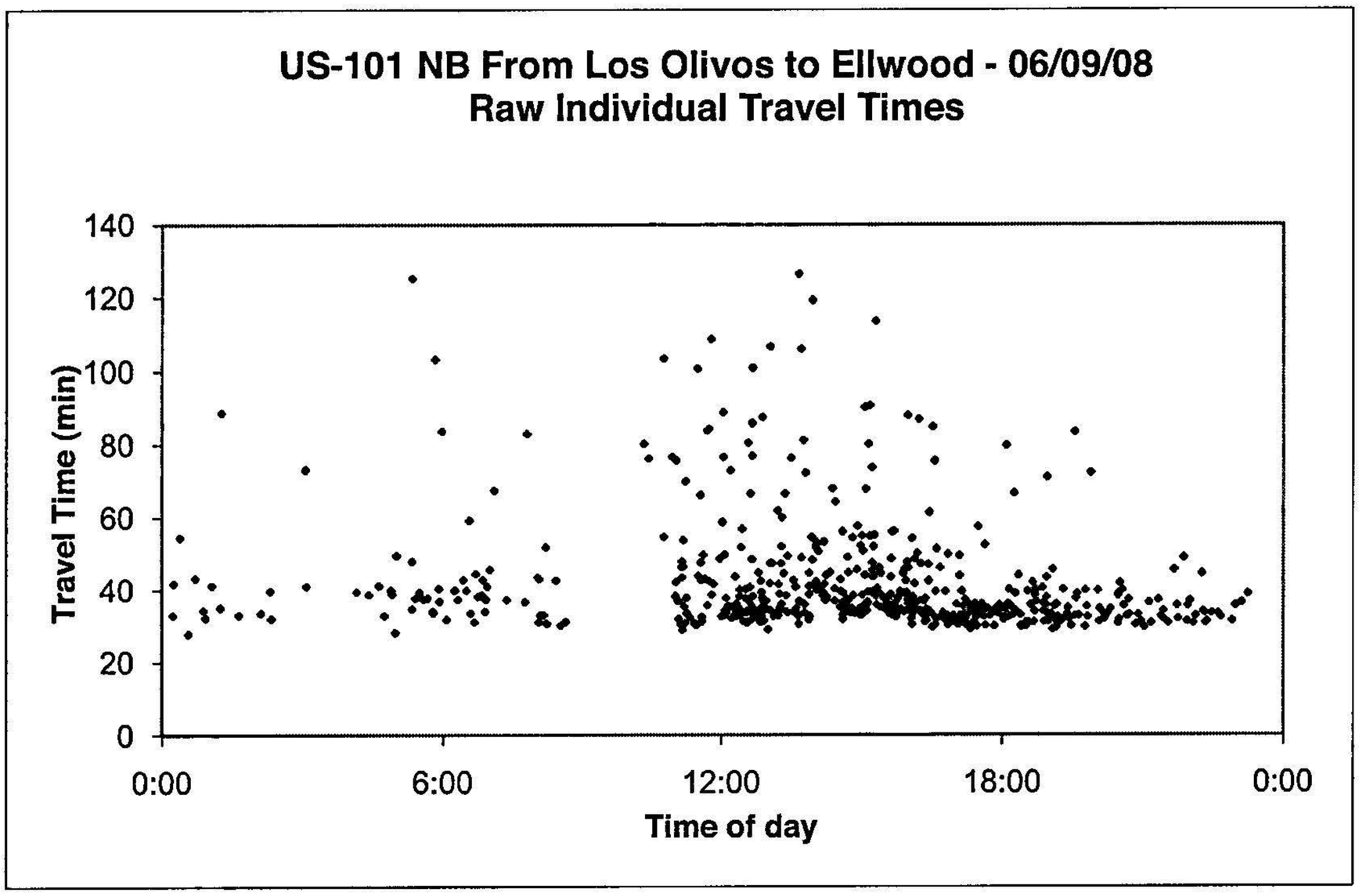

US-101 NB From Los Olivos to Ellwood - 06/03/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

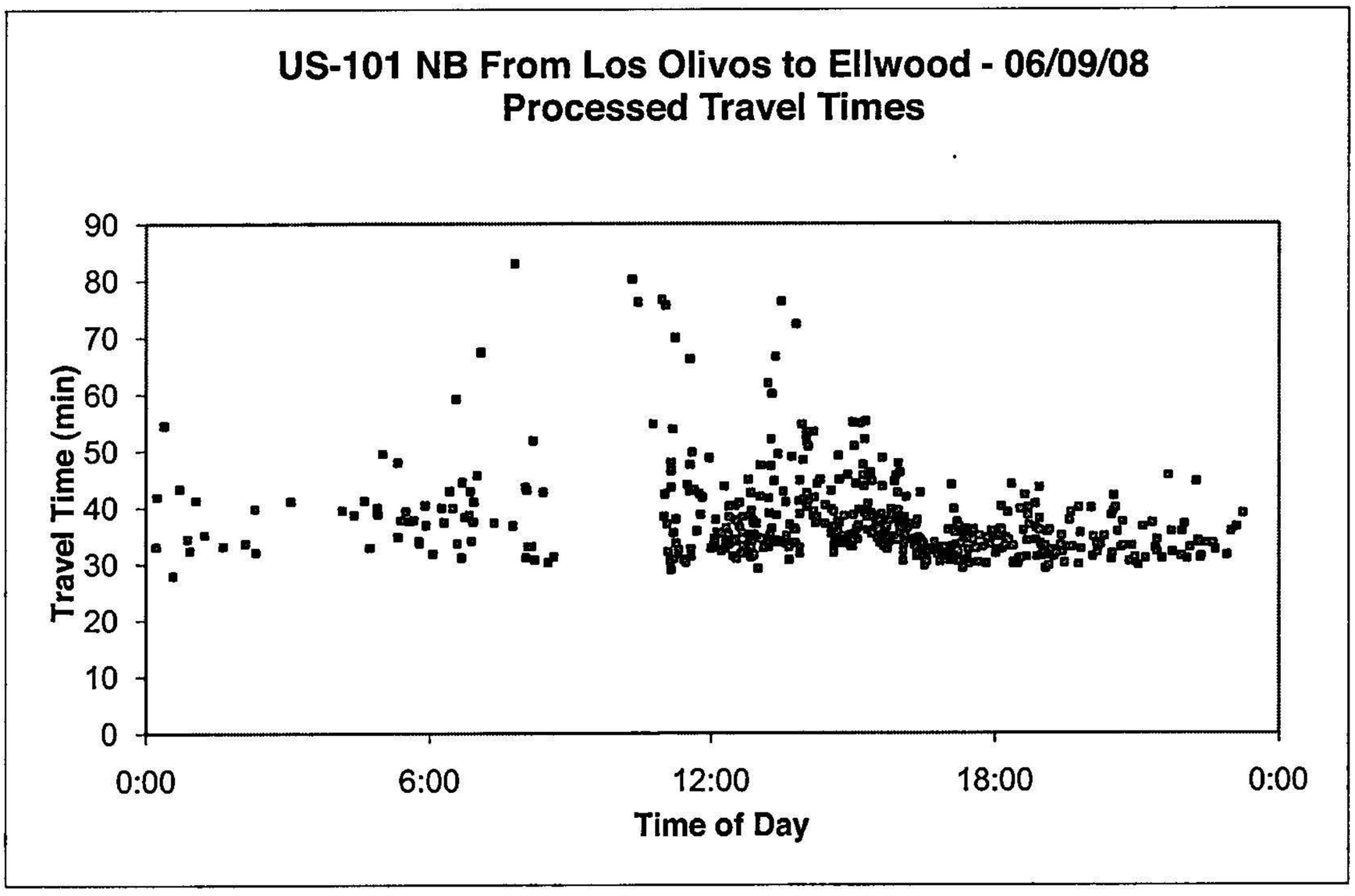

US-101 NB From Los Olivos to Ellwood - 06/04/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

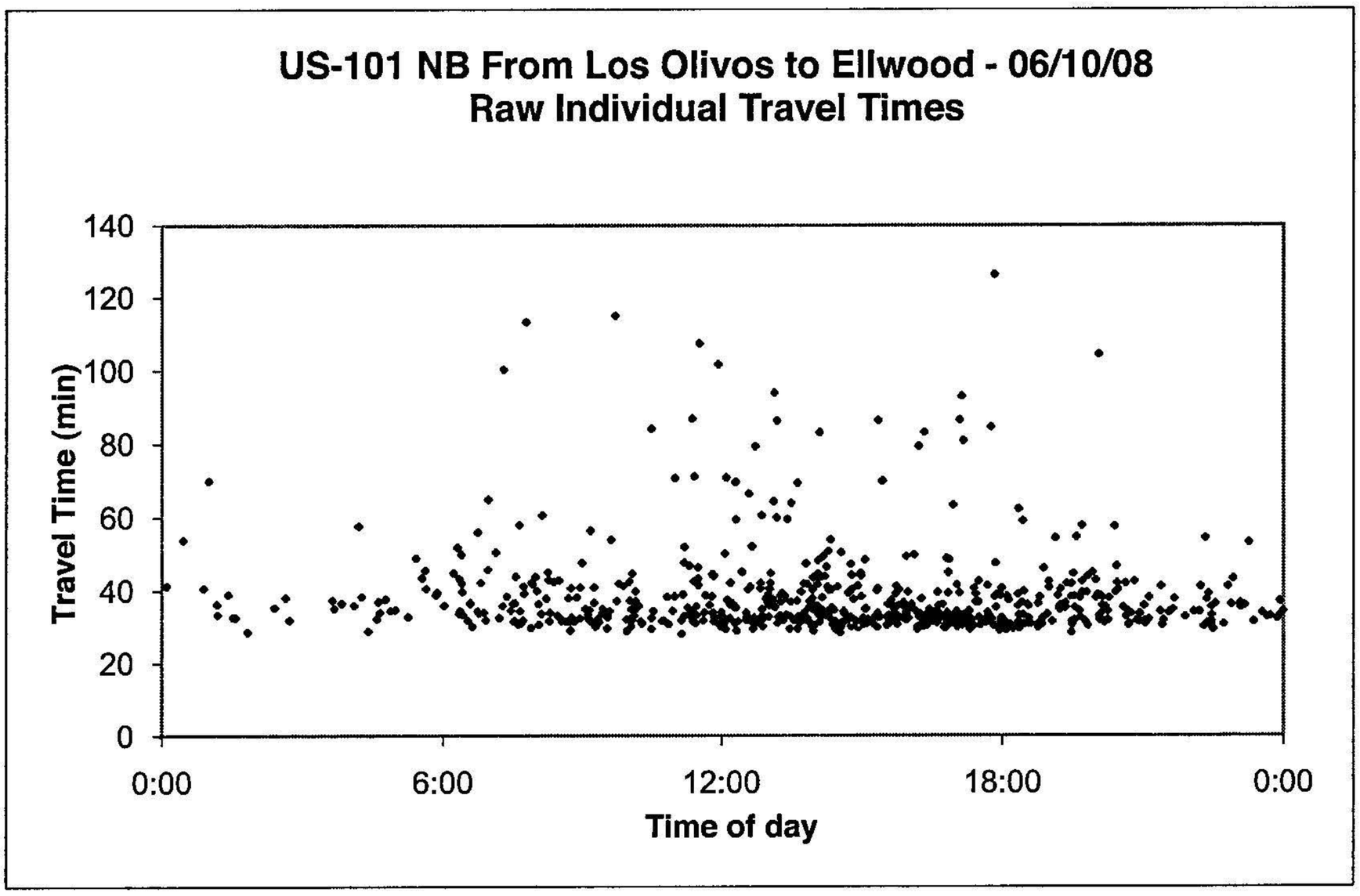

US-101 NB From Los Olivos to Ellwood - 06/04/08
Processed Travel Times
Travel Time (min)
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

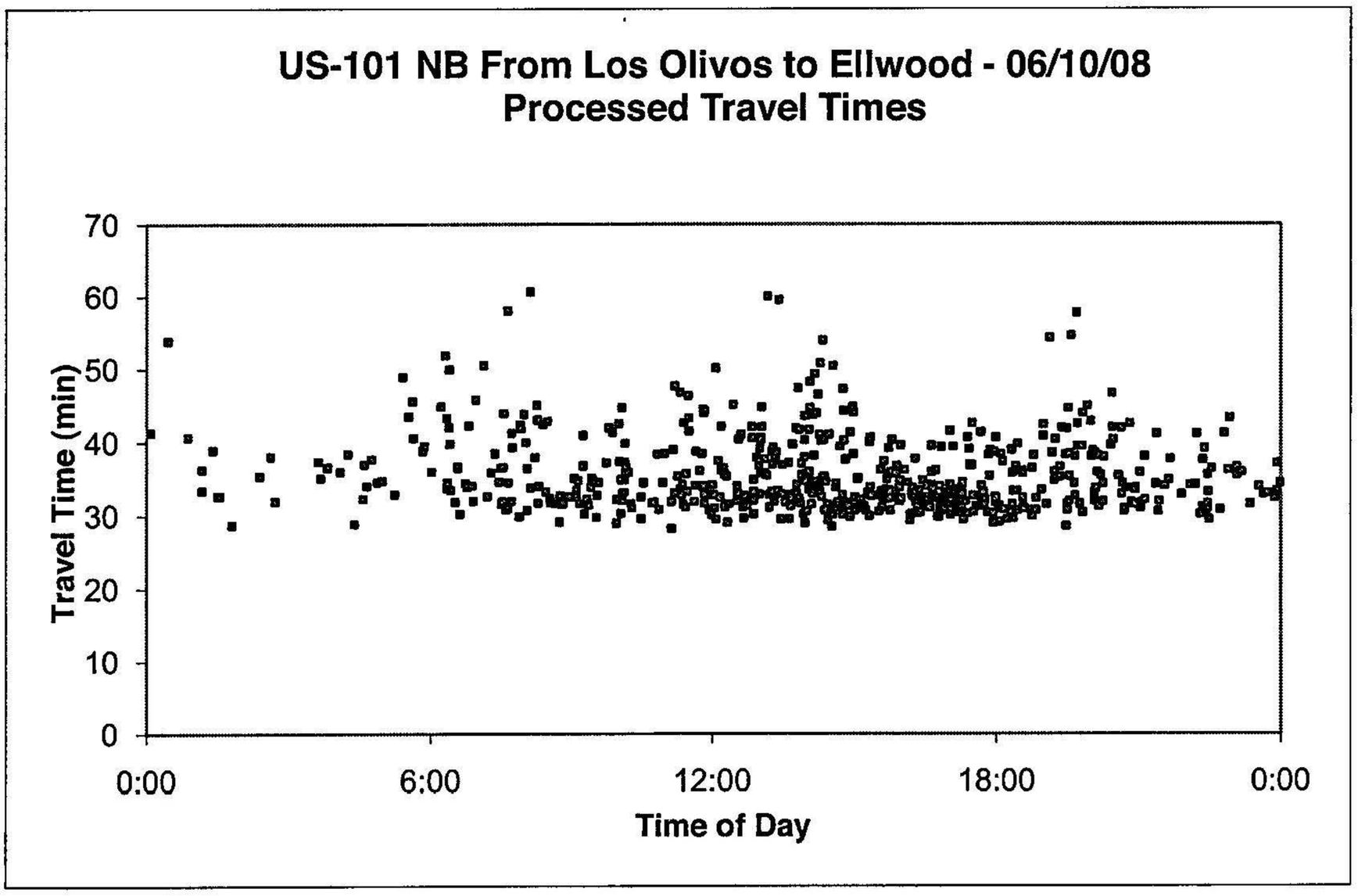

US-101 NB From Los Olivos to Ellwood - 06/07/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

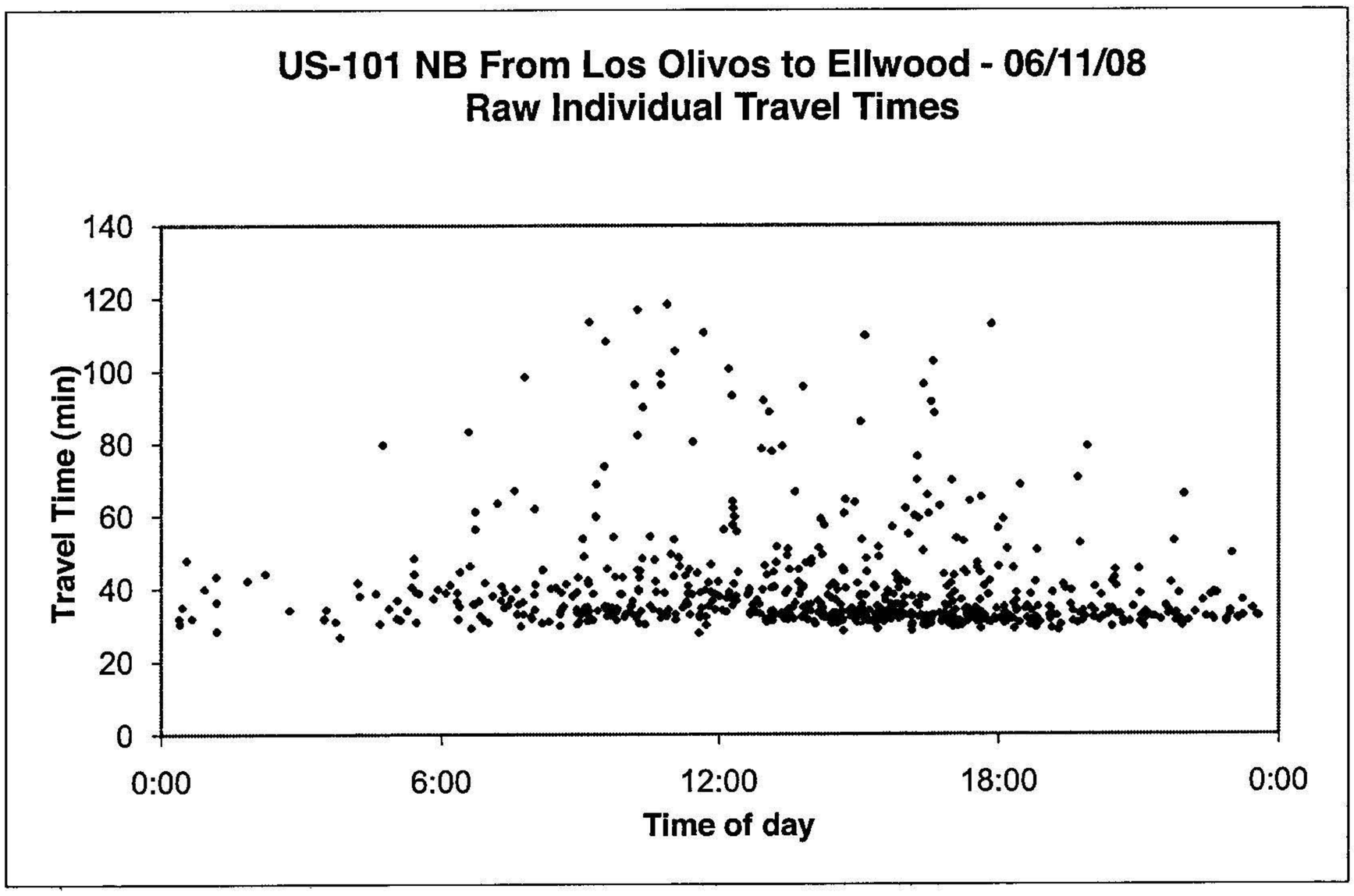

US-101 NB From Los Olivos to Ellwood - 06/07/08
Processed Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

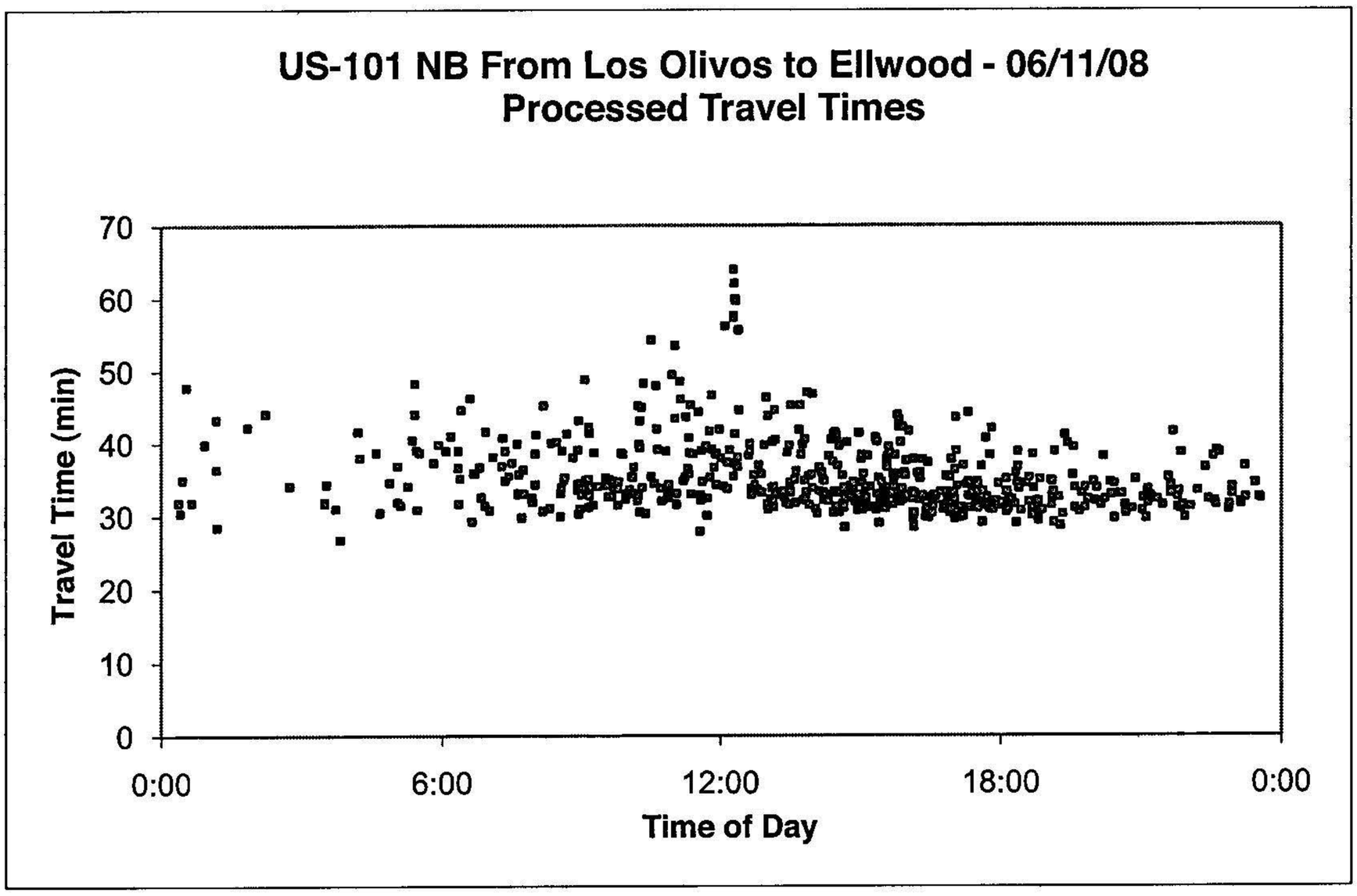

US-101 NB From Los Olivos to Ellwood - 06/09/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

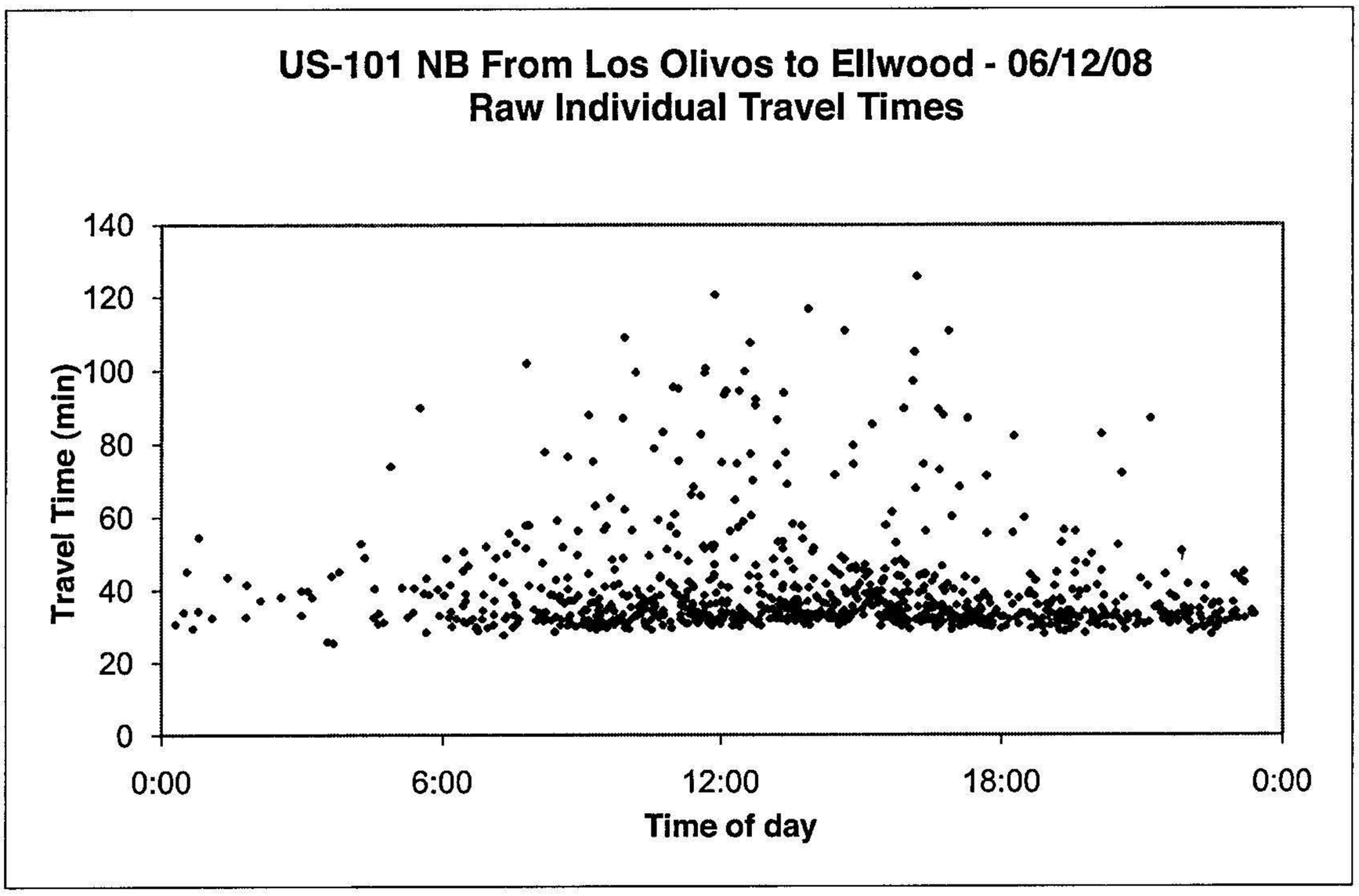

US-101 NB From Los Olivos to Ellwood - 06/09/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

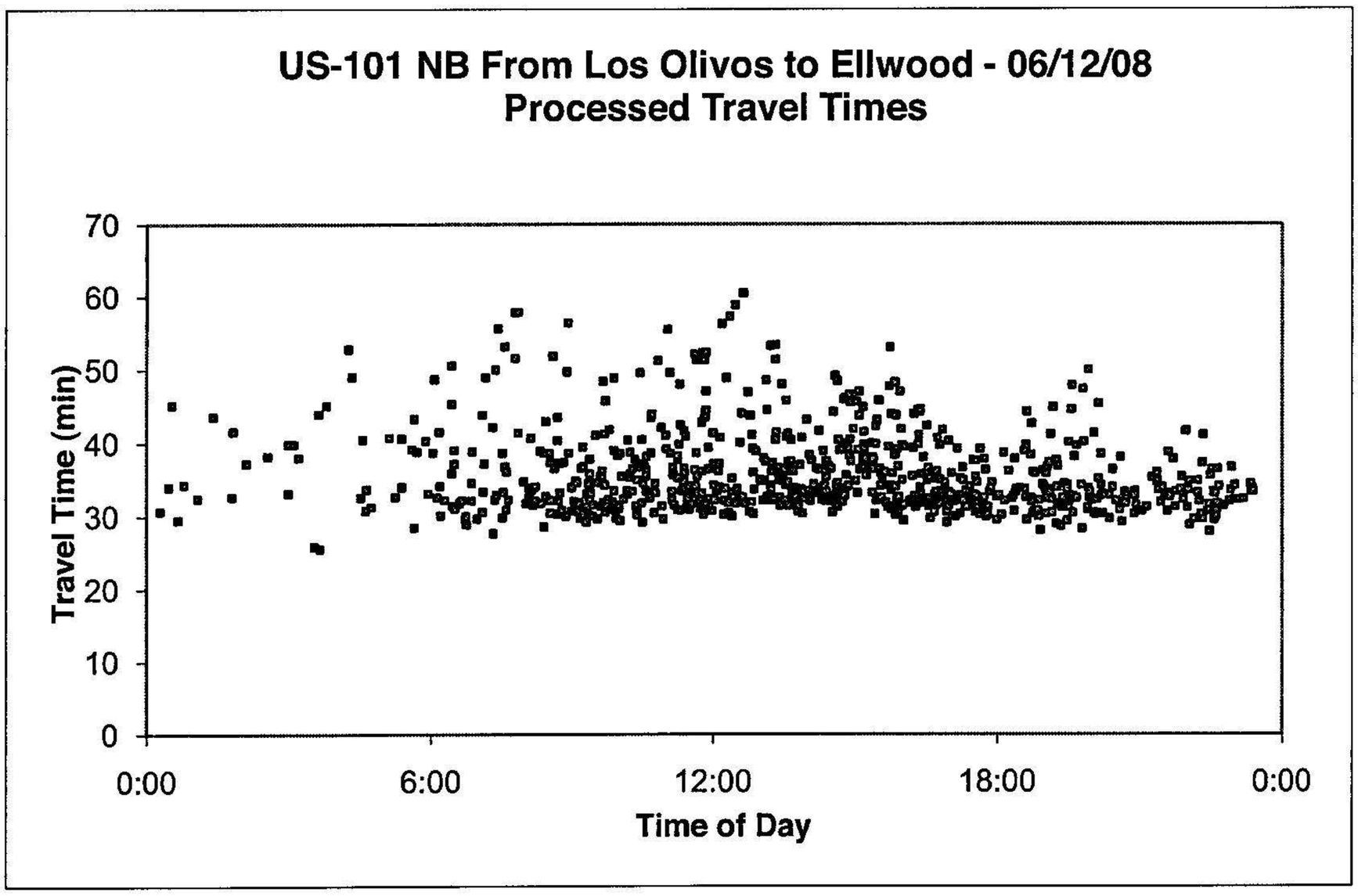

US-101 NB From Los Olivos to Ellwood - 06/10/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

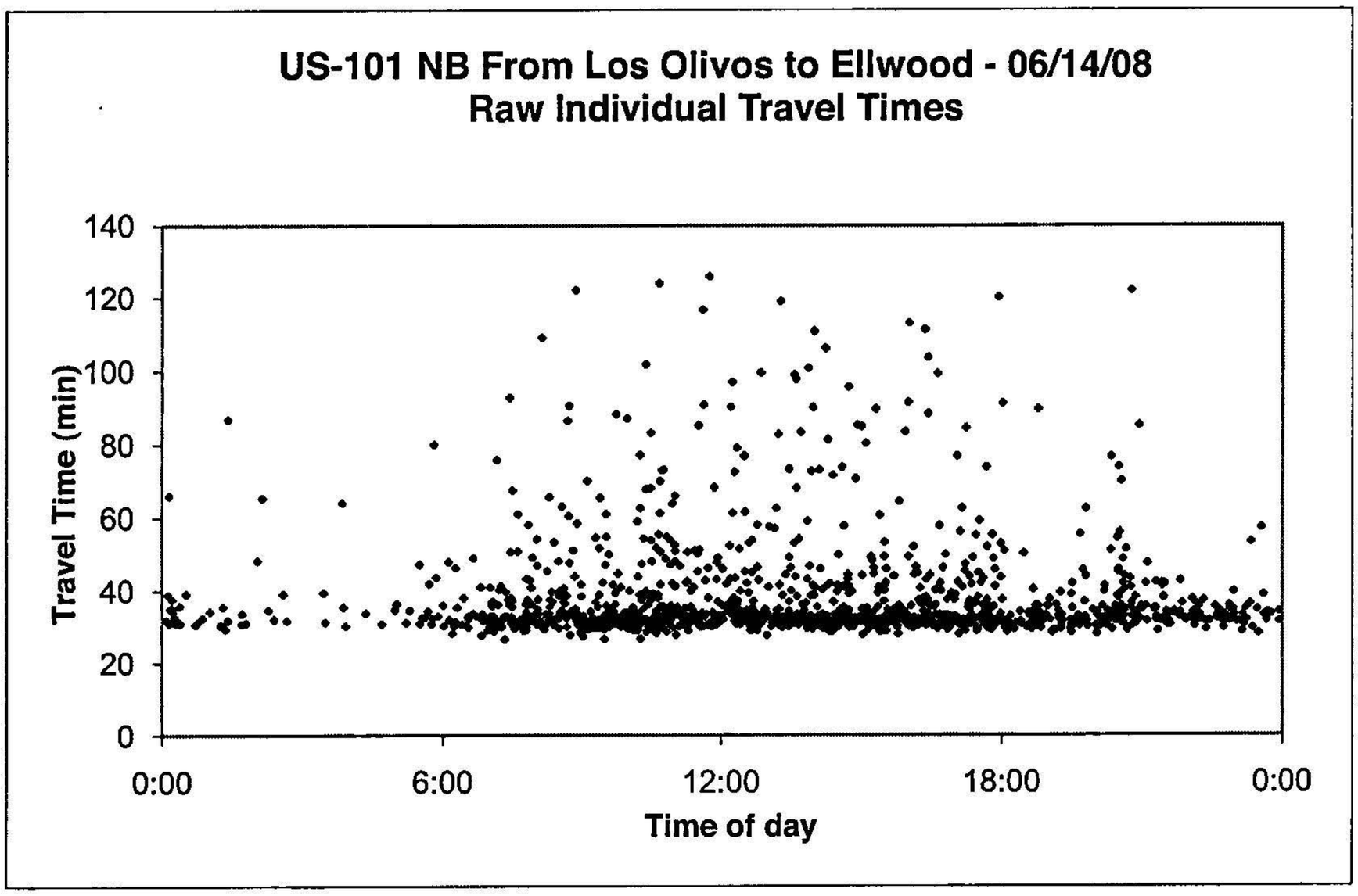

US-101 NB From Los Olivos to Ellwood - 06/10/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

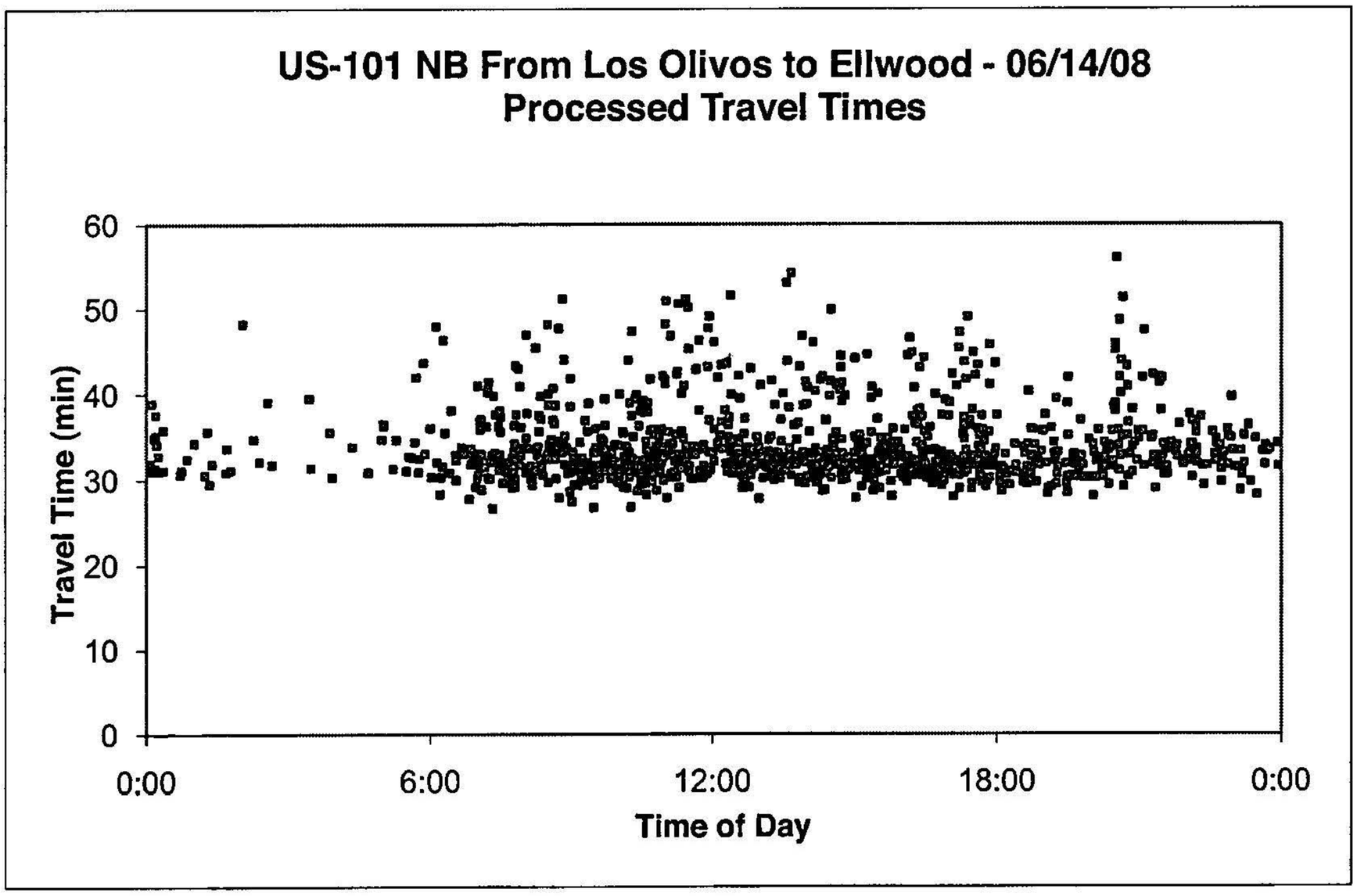

US-101 NB From Los Olivos to Ellwood - 06/11/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

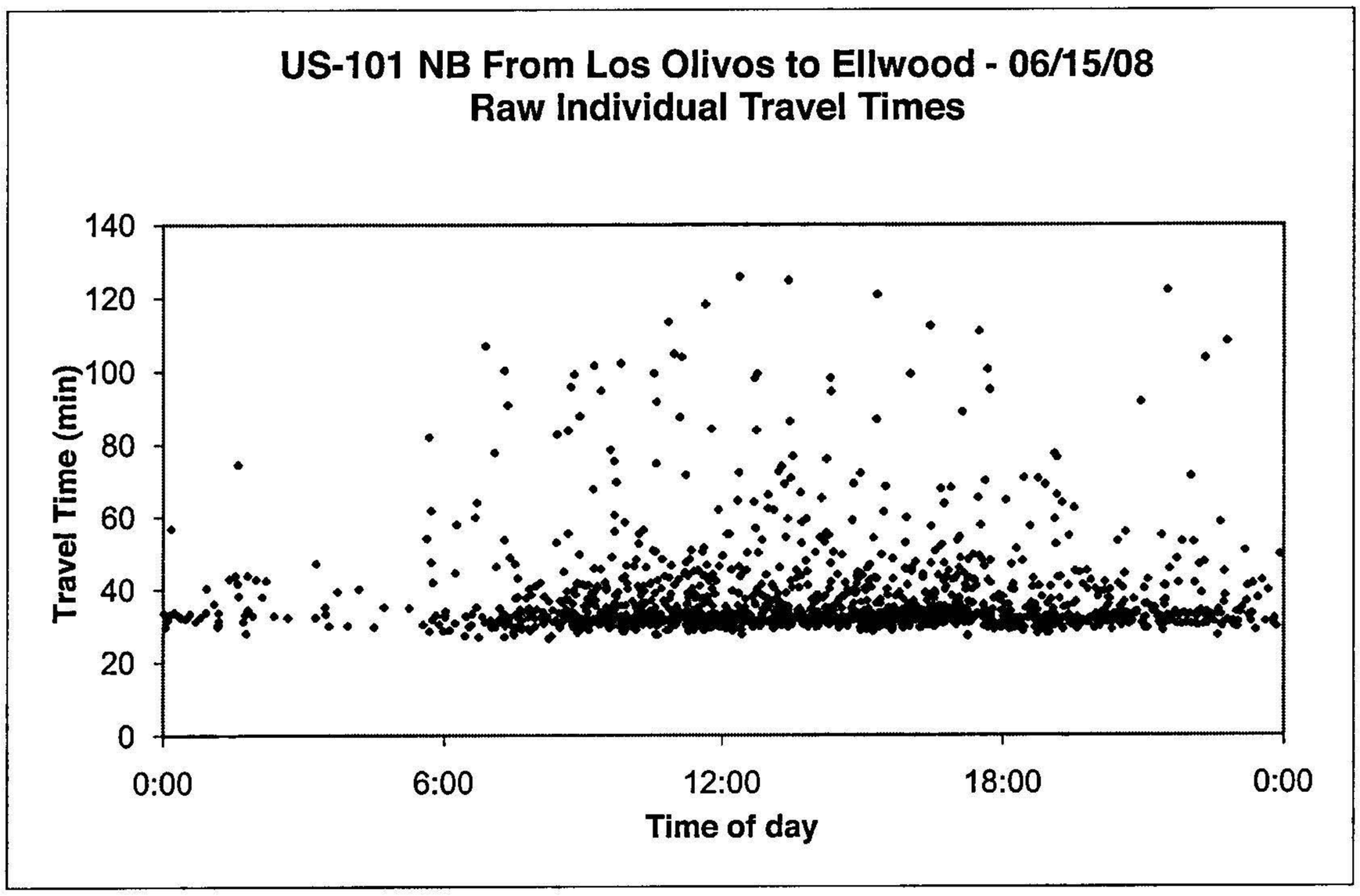

US-101 NB From Los Olivos to Ellwood - 06/11/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

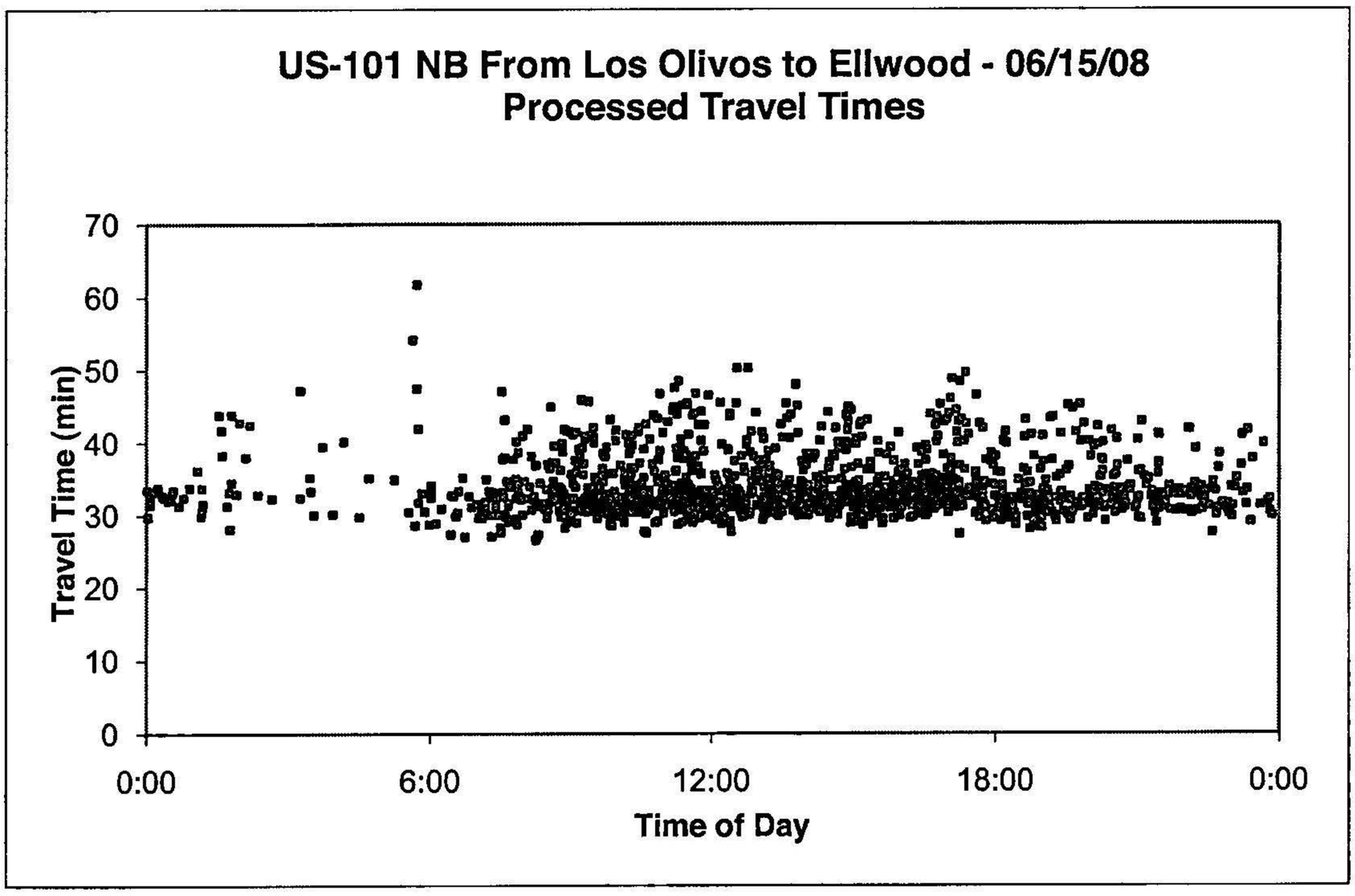

US-101 NB From Los Olivos to Ellwood - 06/12/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

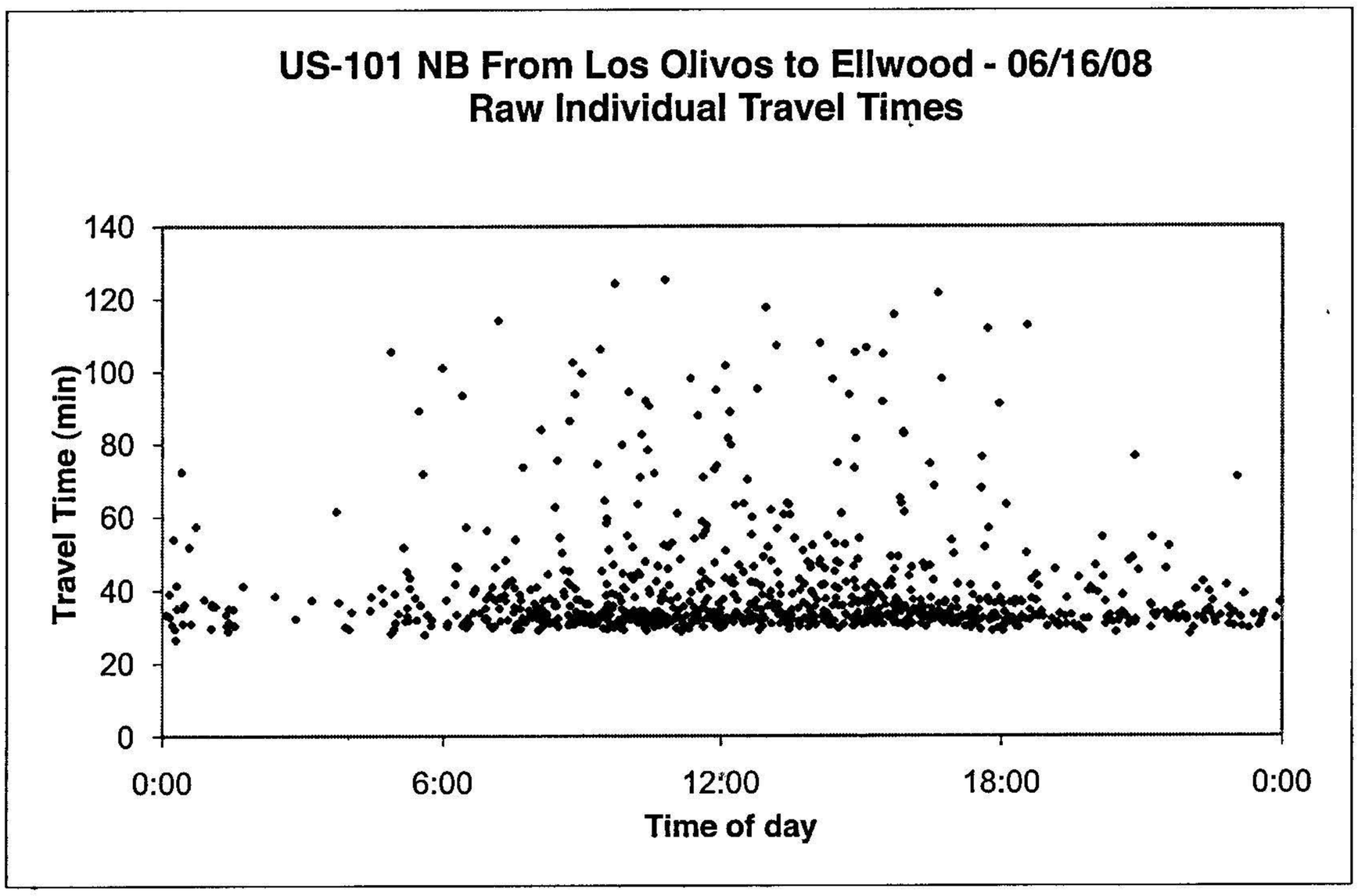

US-101 NB From Los Olivos to Ellwood - 06/12/08
Processed Travel Times
Travel Time (min)
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60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

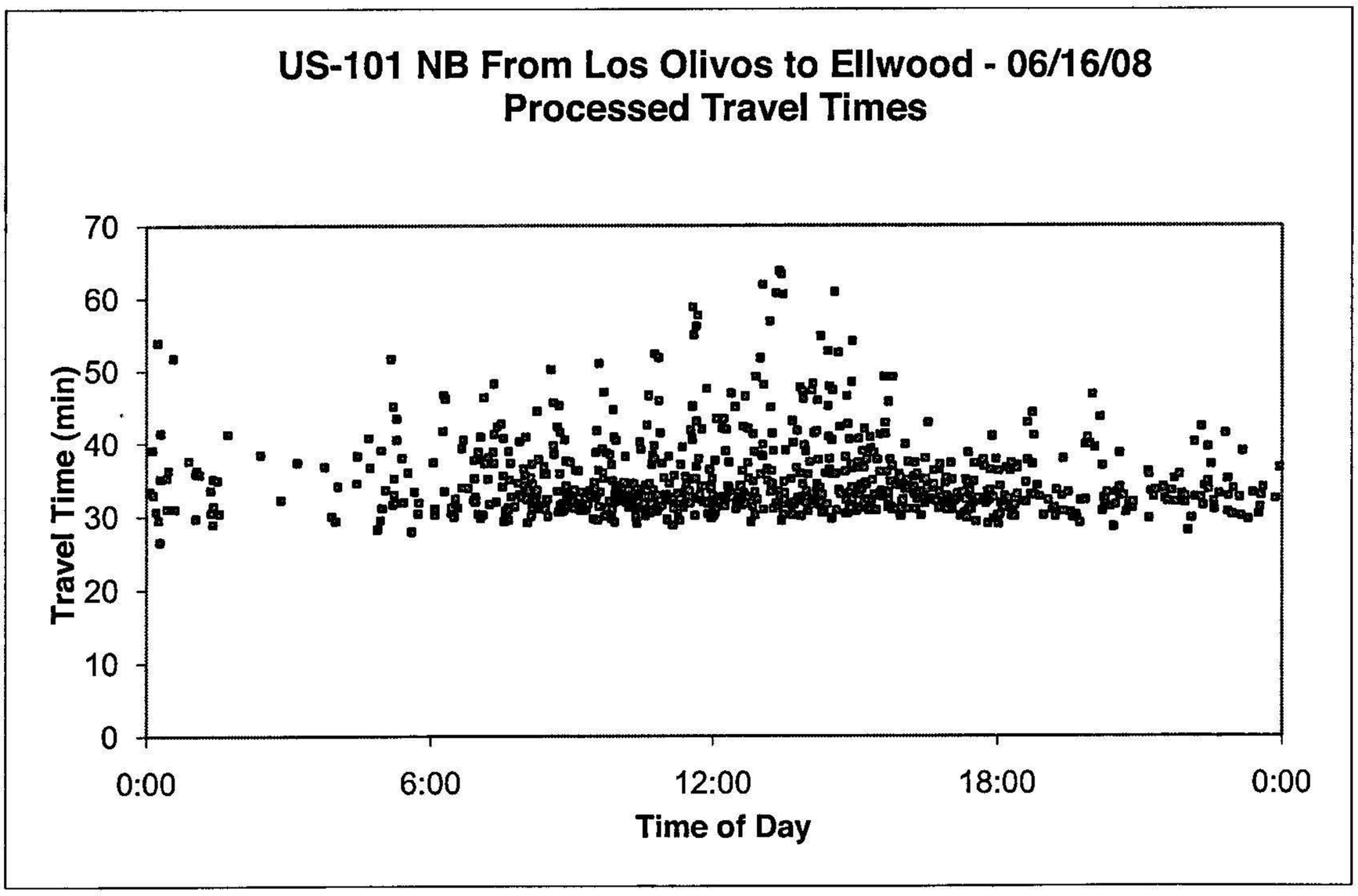

US-101 NB From Los Olivos to Ellwood - 06/14/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

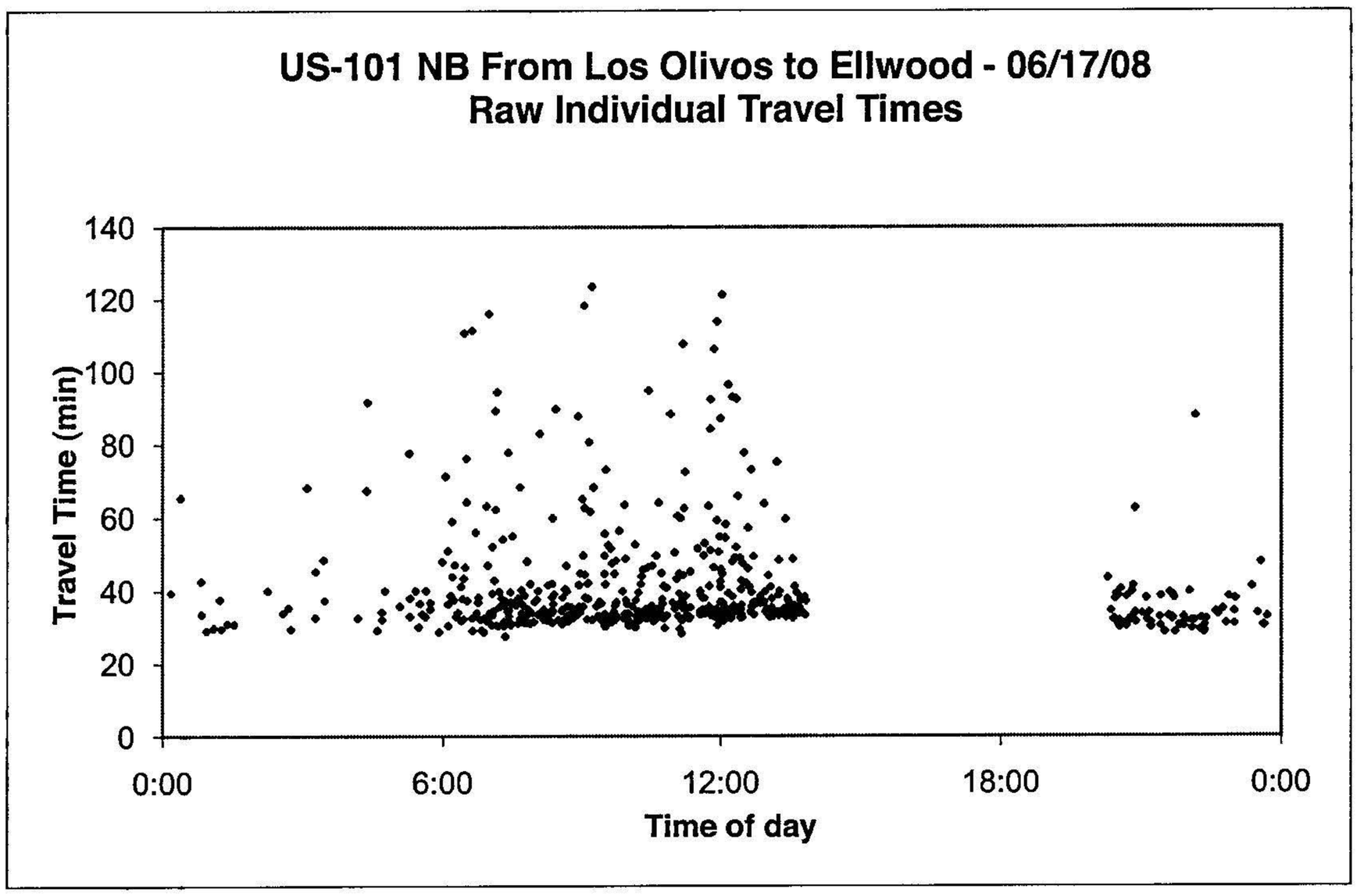

US-101 NB From Los Olivos to Ellwood - 06/14/08
Processed Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

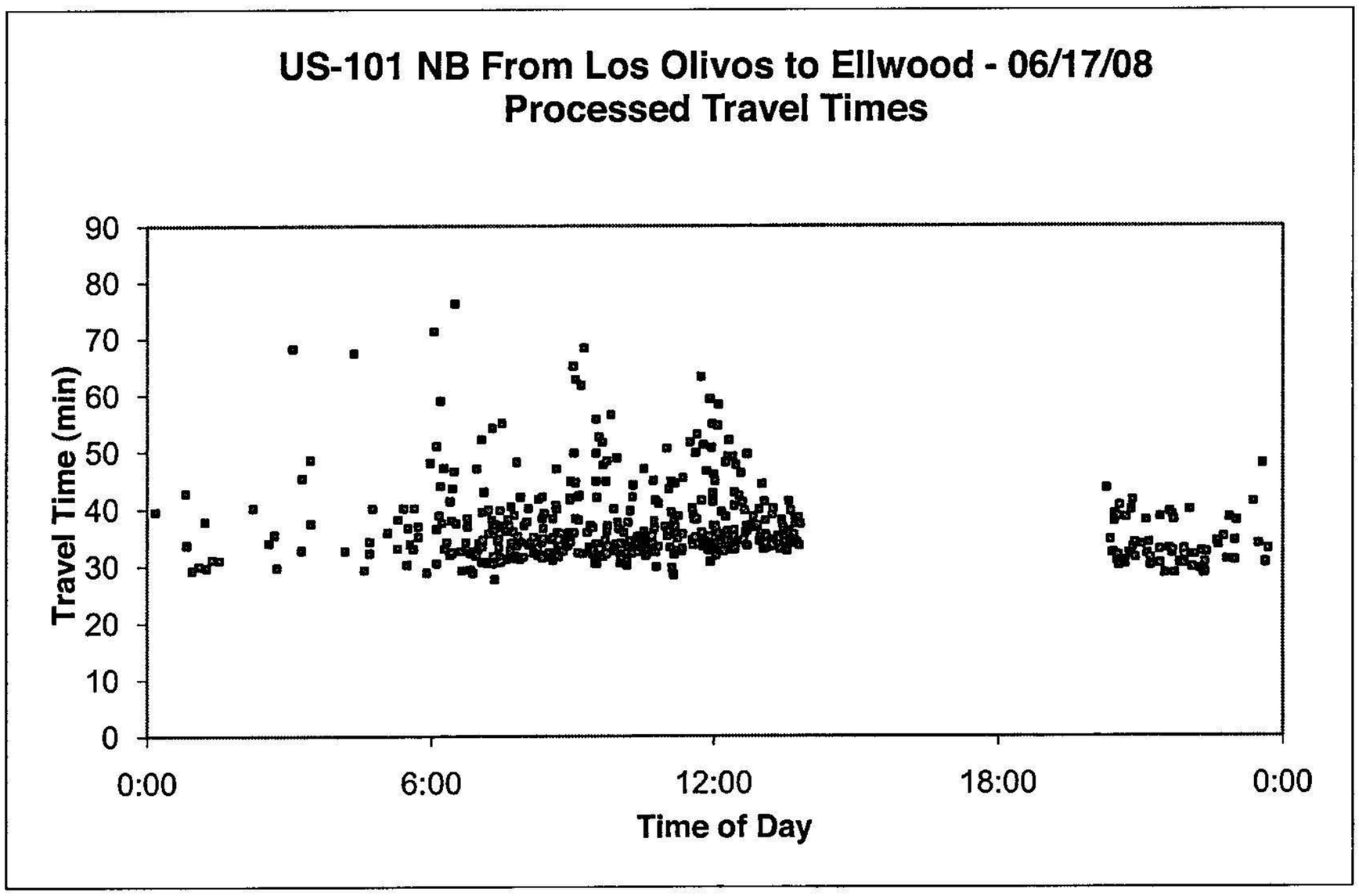

US-101 NB From Los Olivos to Ellwood - 06/15/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

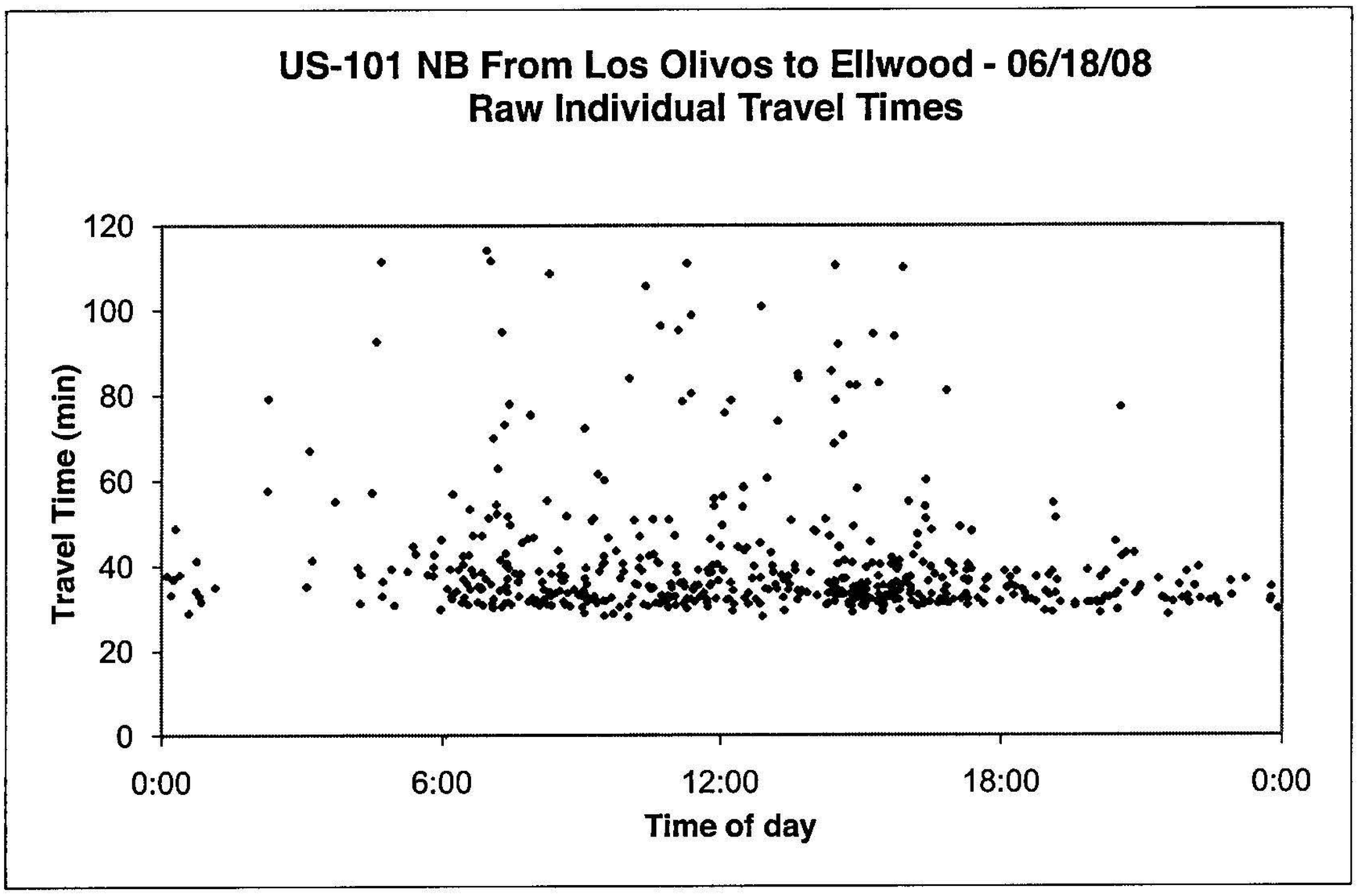

US-101 NB From Los Olivos to Ellwood - 06/15/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

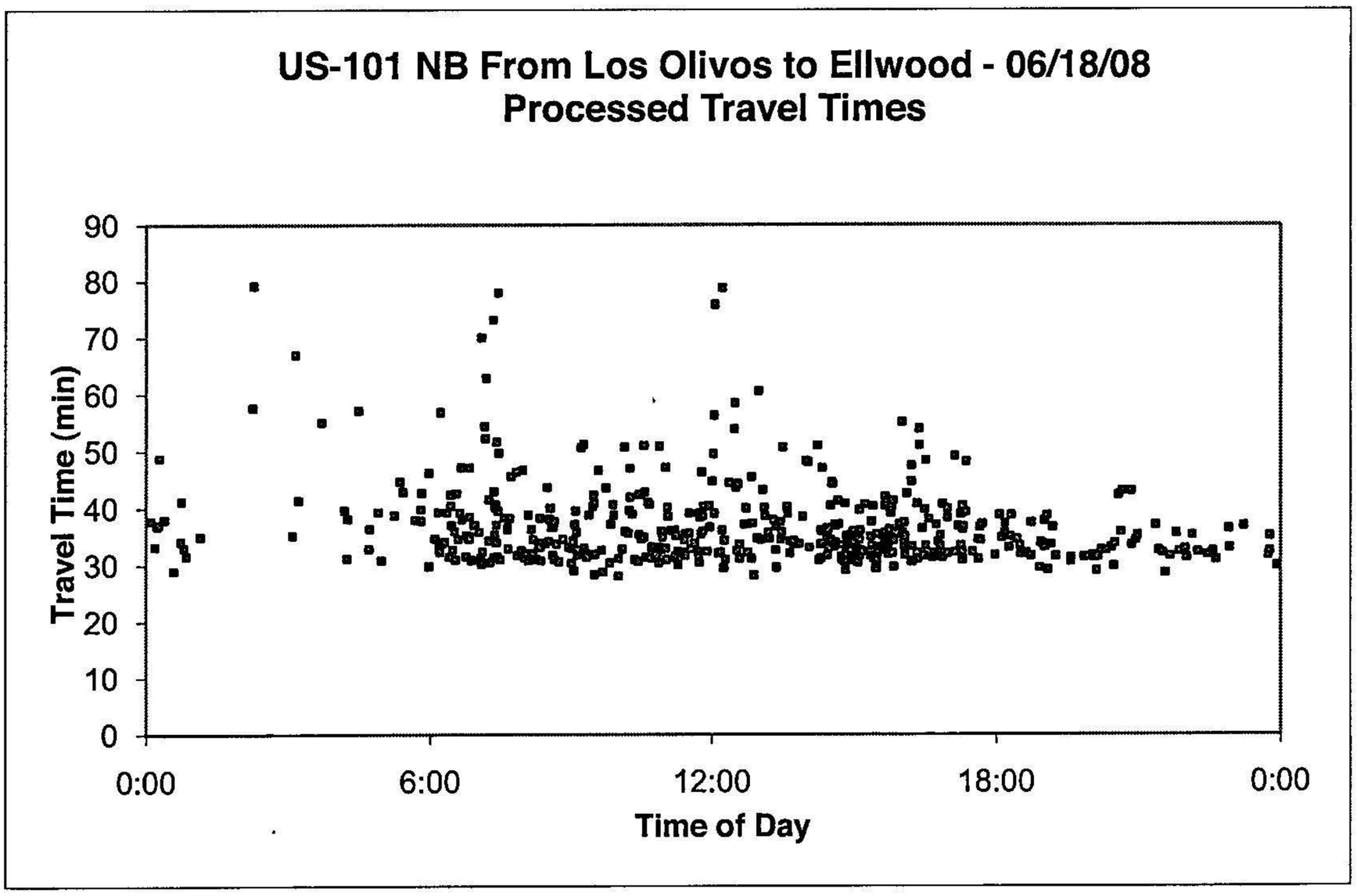

US-101 NB From Los Olivos to Ellwood - 06/16/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

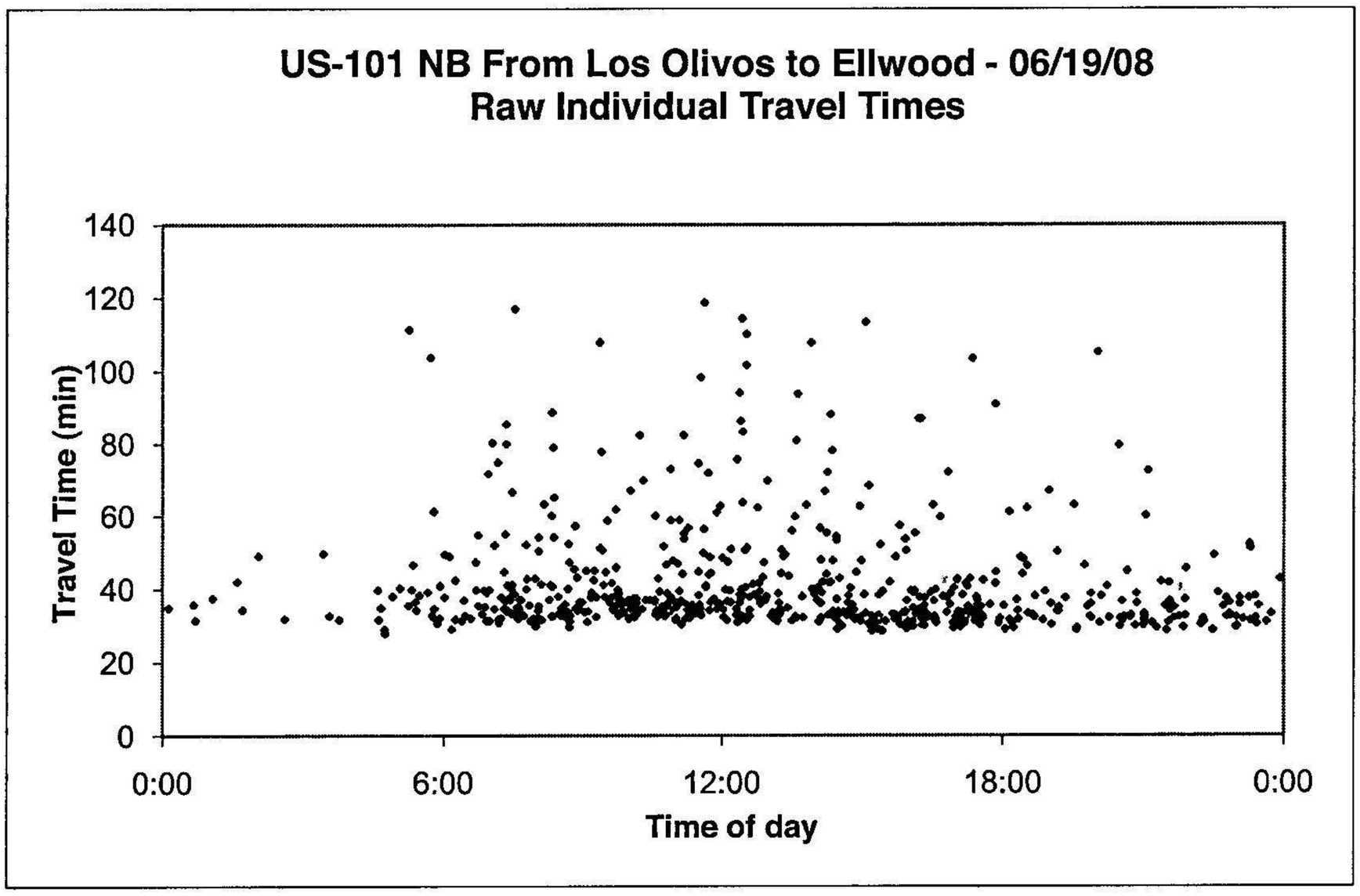

US-101 NB From Los Olivos to Ellwood - 06/16/08
Processed Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

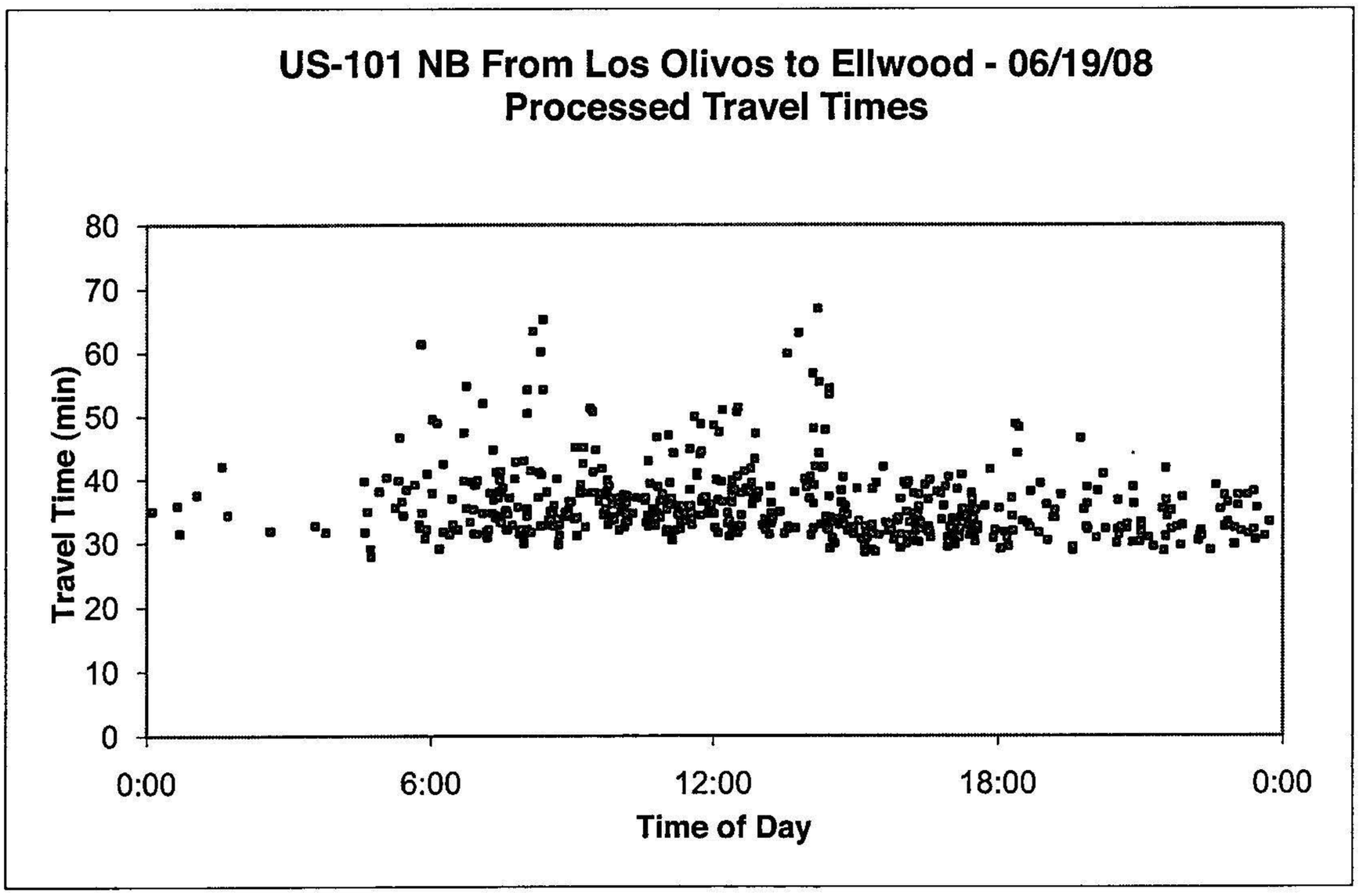

US-101 NB From Los Olivos to Ellwood - 06/17/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

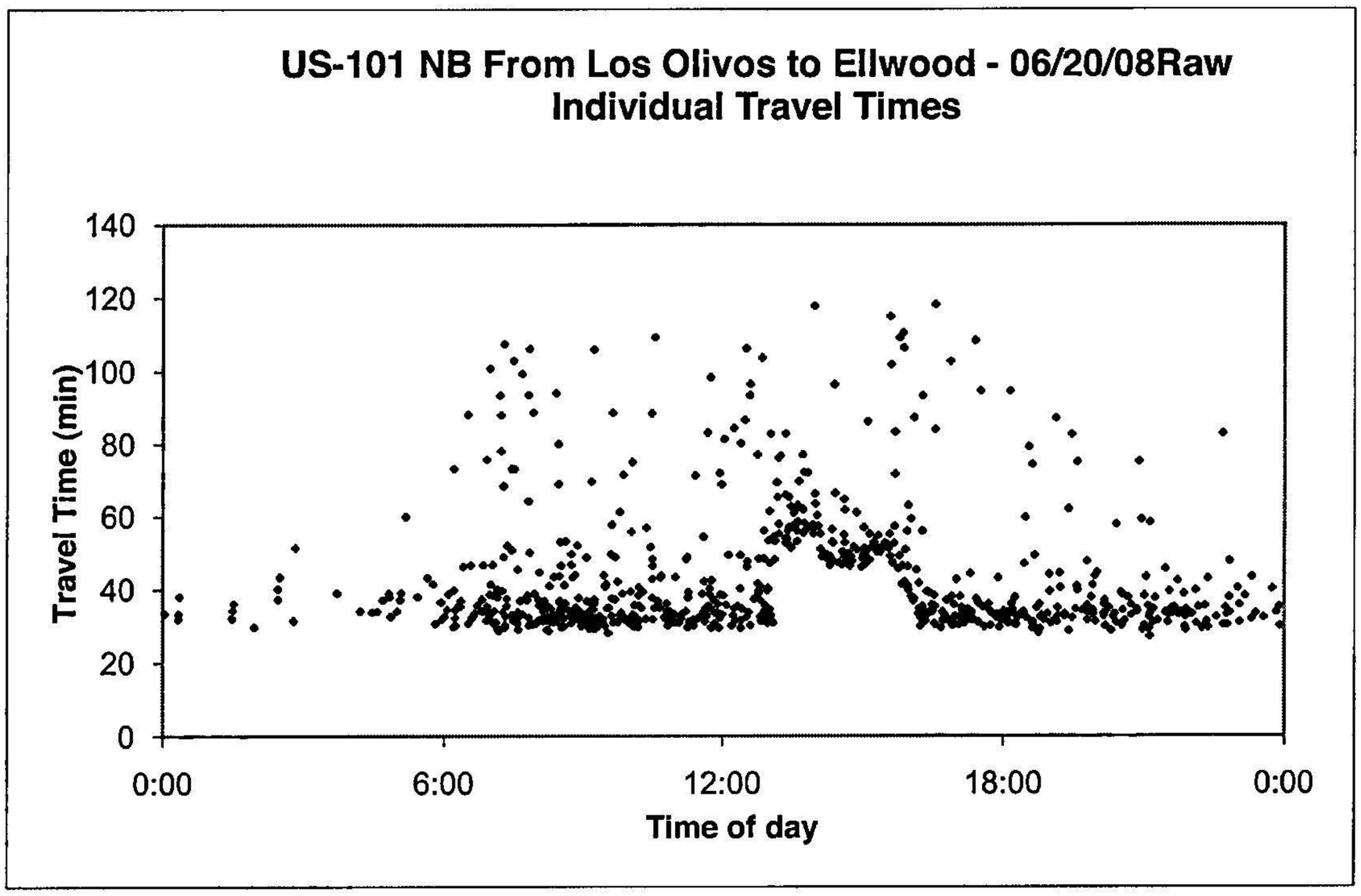

US-101 NB From Los Olivos to Ellwood - 06/17/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

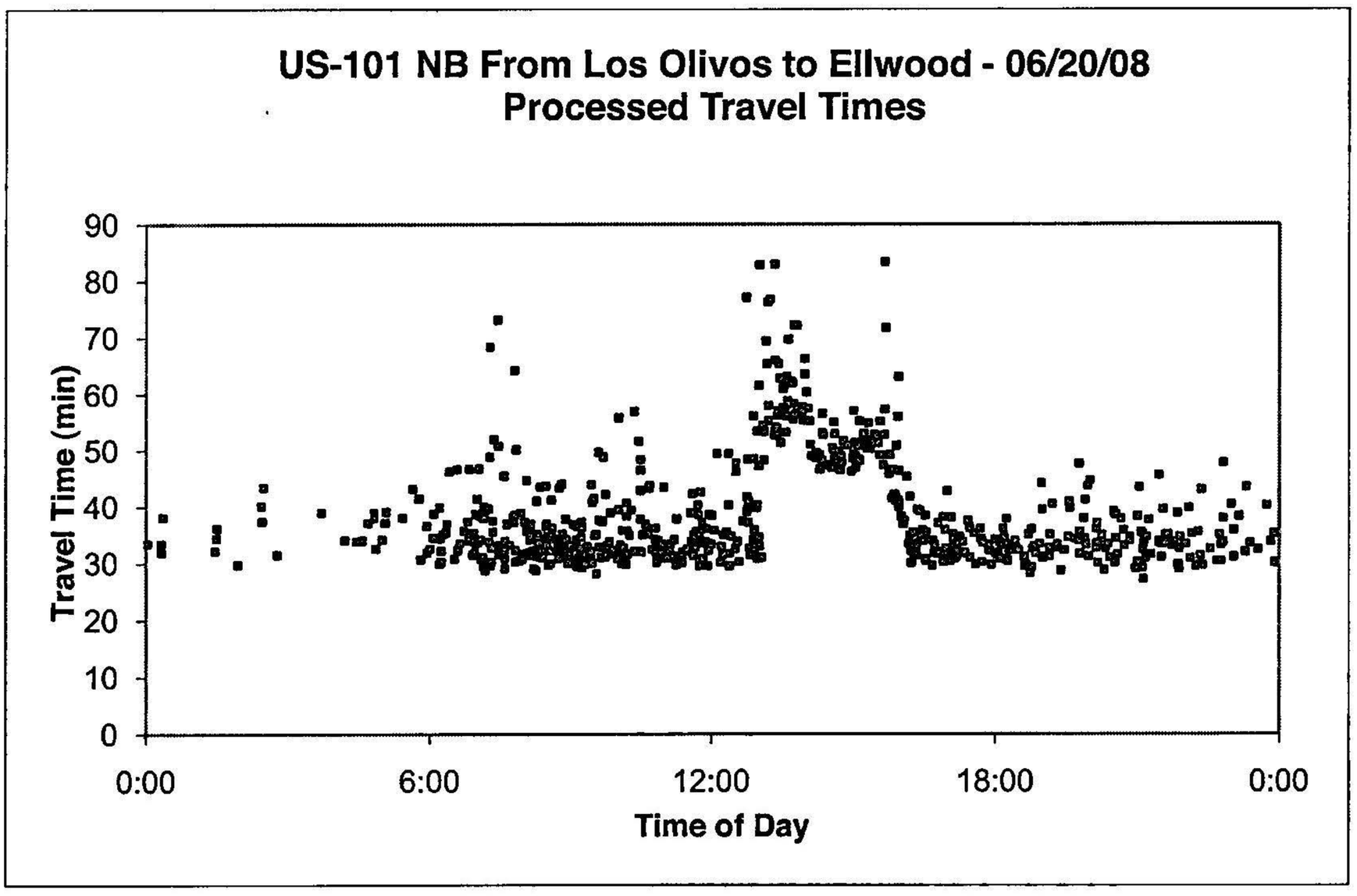

US-101 NB From Los Olivos to Ellwood - 06/18/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

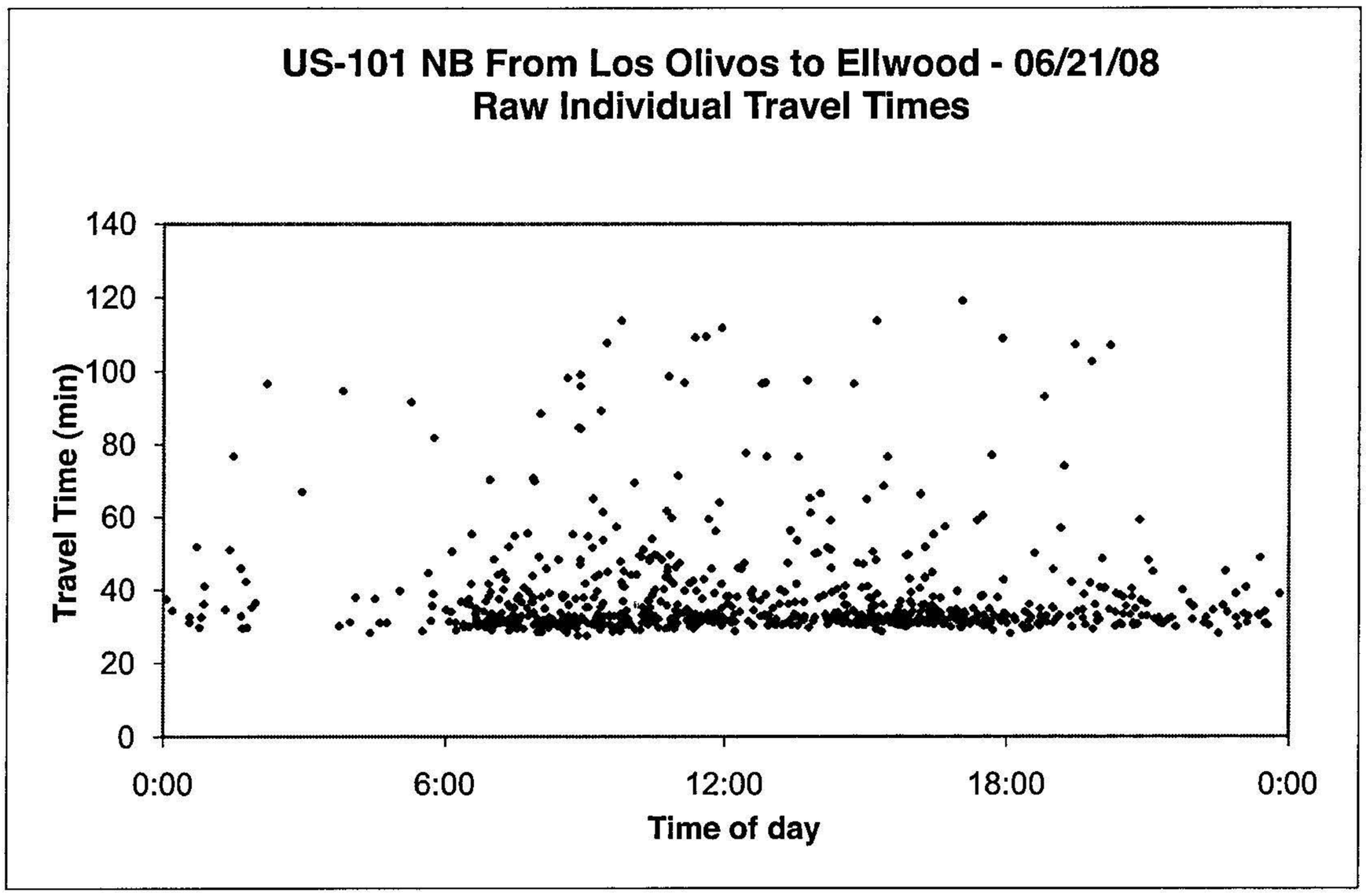

US-101 NB From Los Olivos to Ellwood - 06/18/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

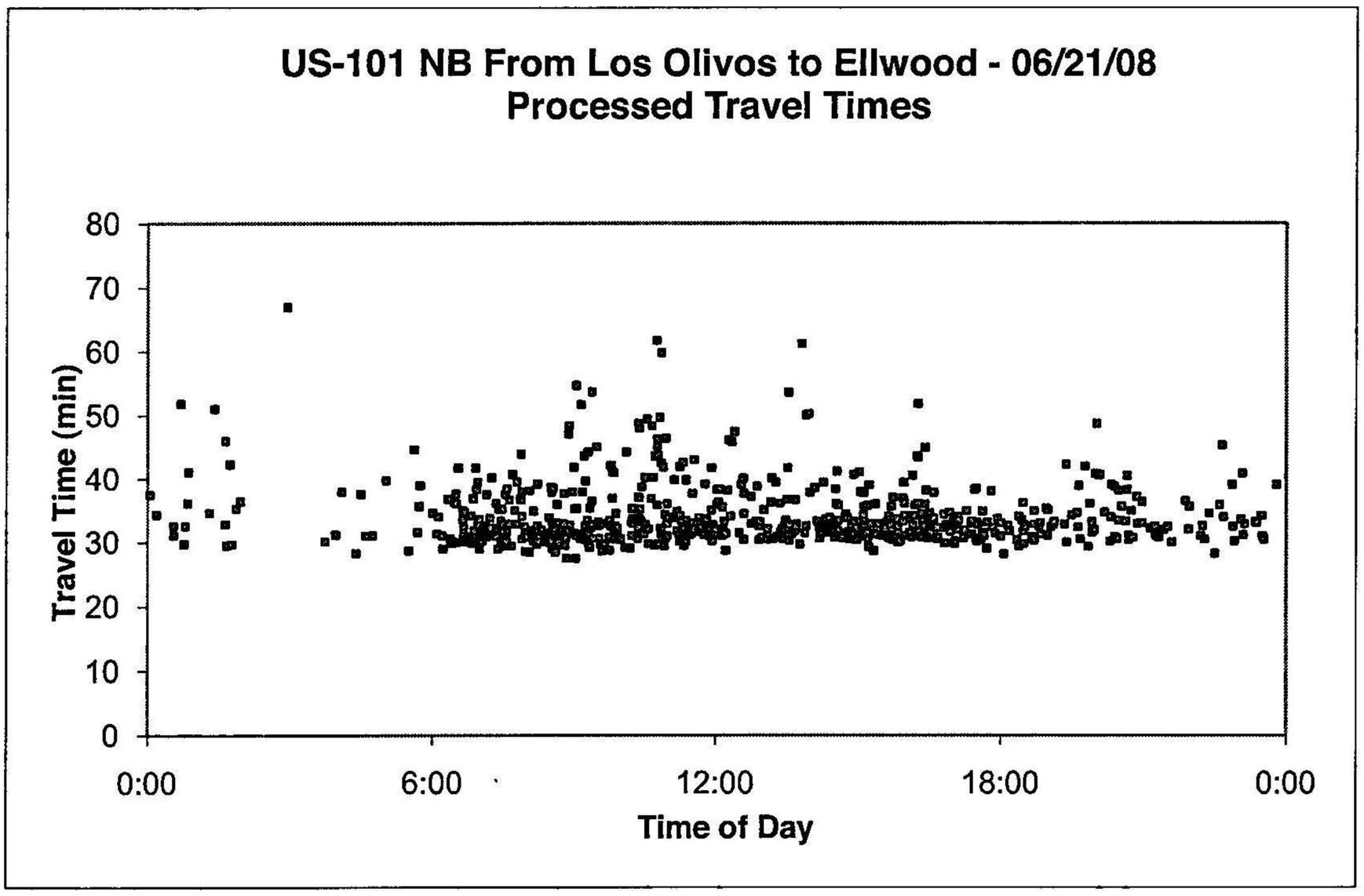

US-101 NB From Los Olivos to Ellwood - 06/19/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

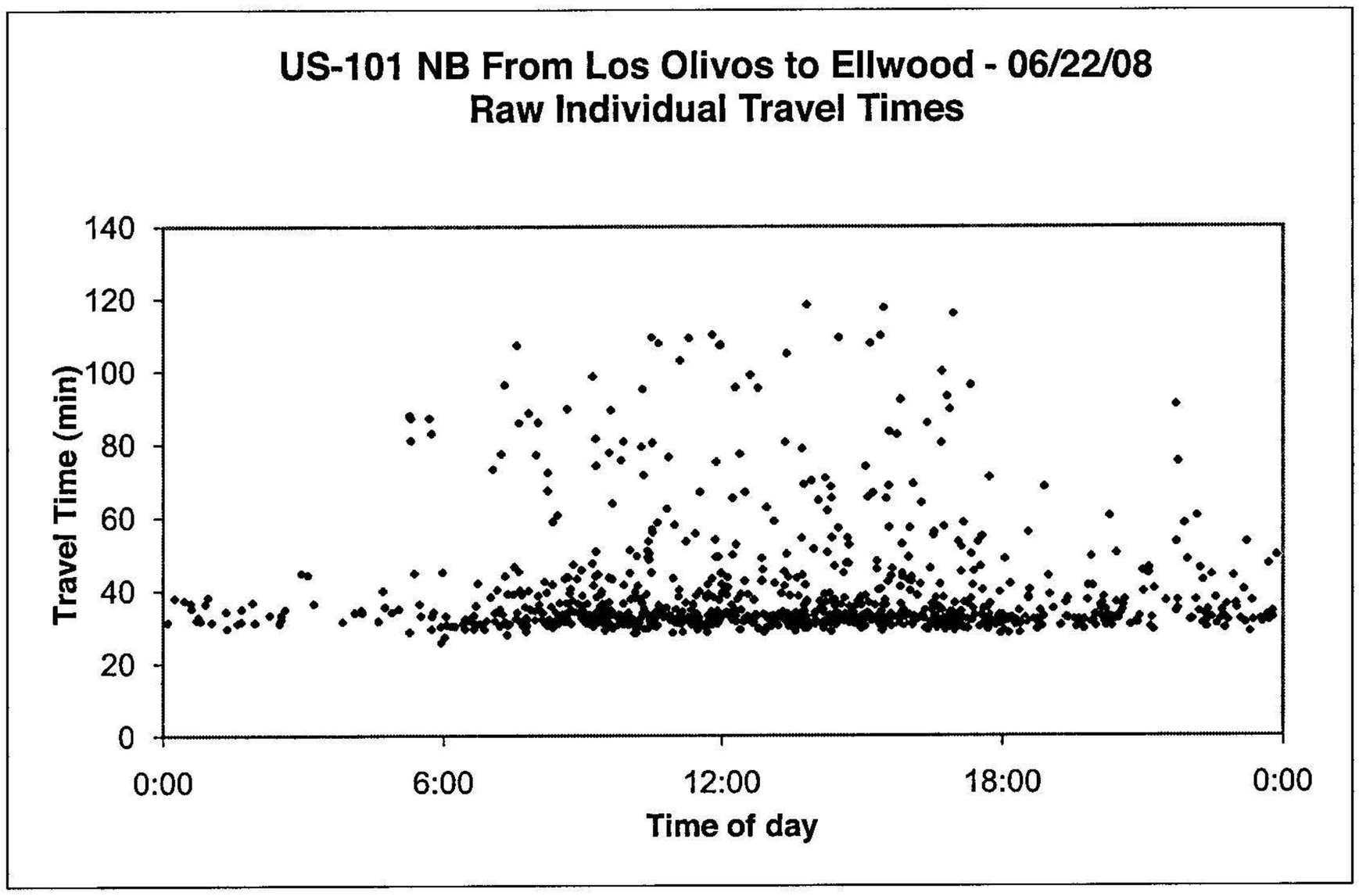

US-101 NB From Los Olivos to Ellwood - 06/19/08
Processed Travel Times
Travel Time (min)
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

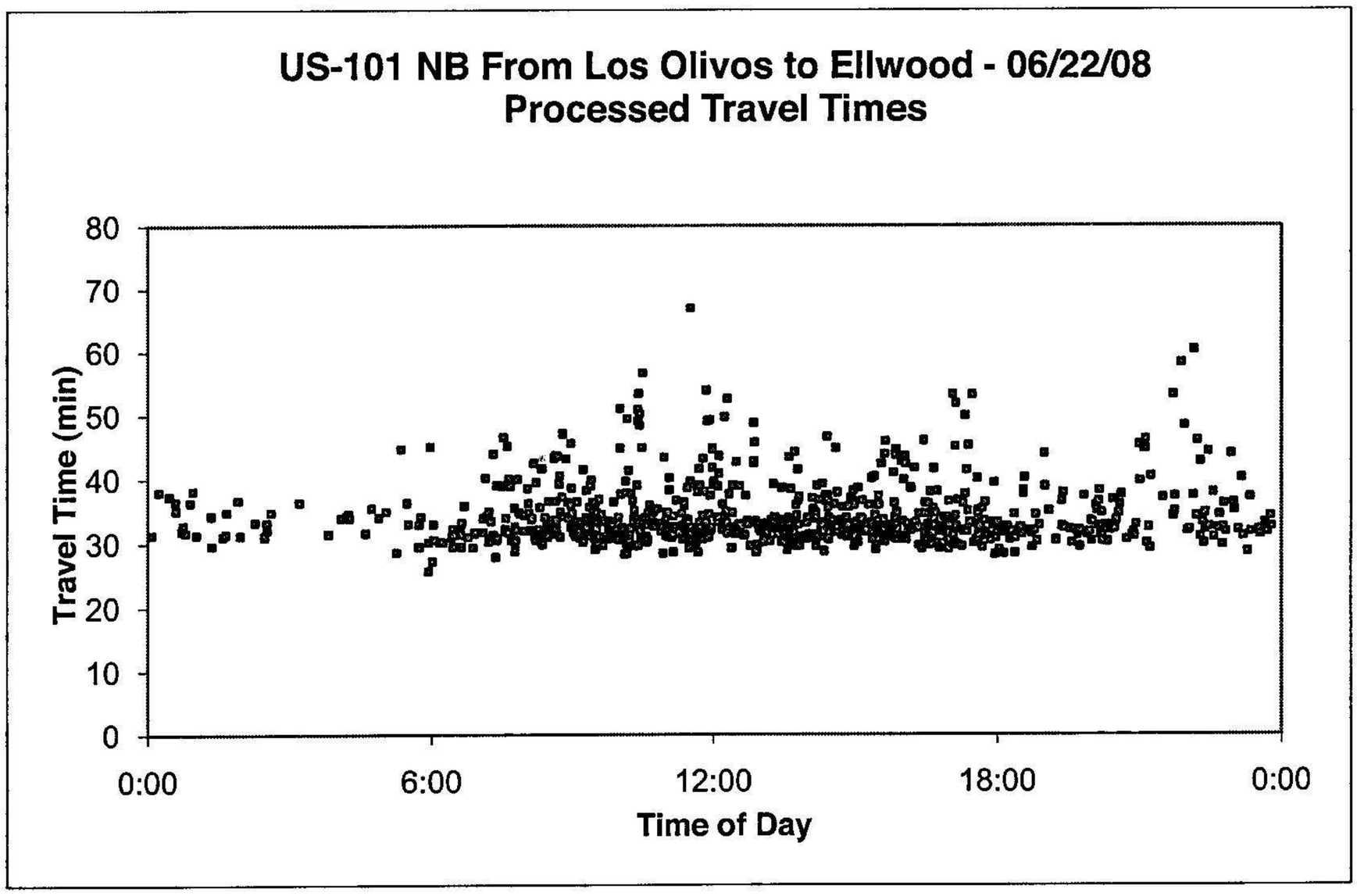

US-101 NB From Los Olivos to Ellwood - 06/20/08Raw
Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 NB From Los Olivos to Ellwood - 06/20/08
Processed Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

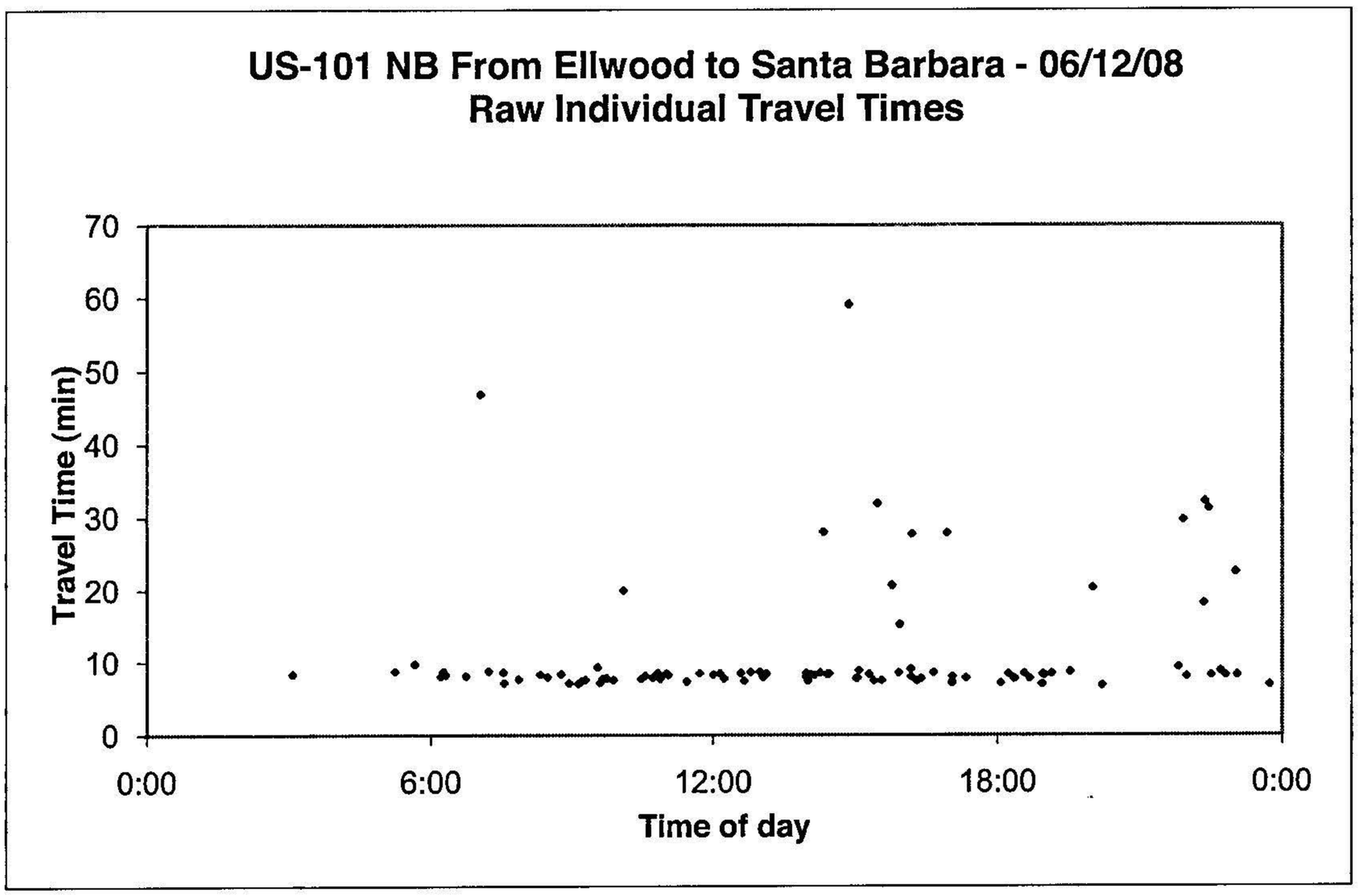

US-101 NB From Los Olivos to Ellwood - 06/21/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

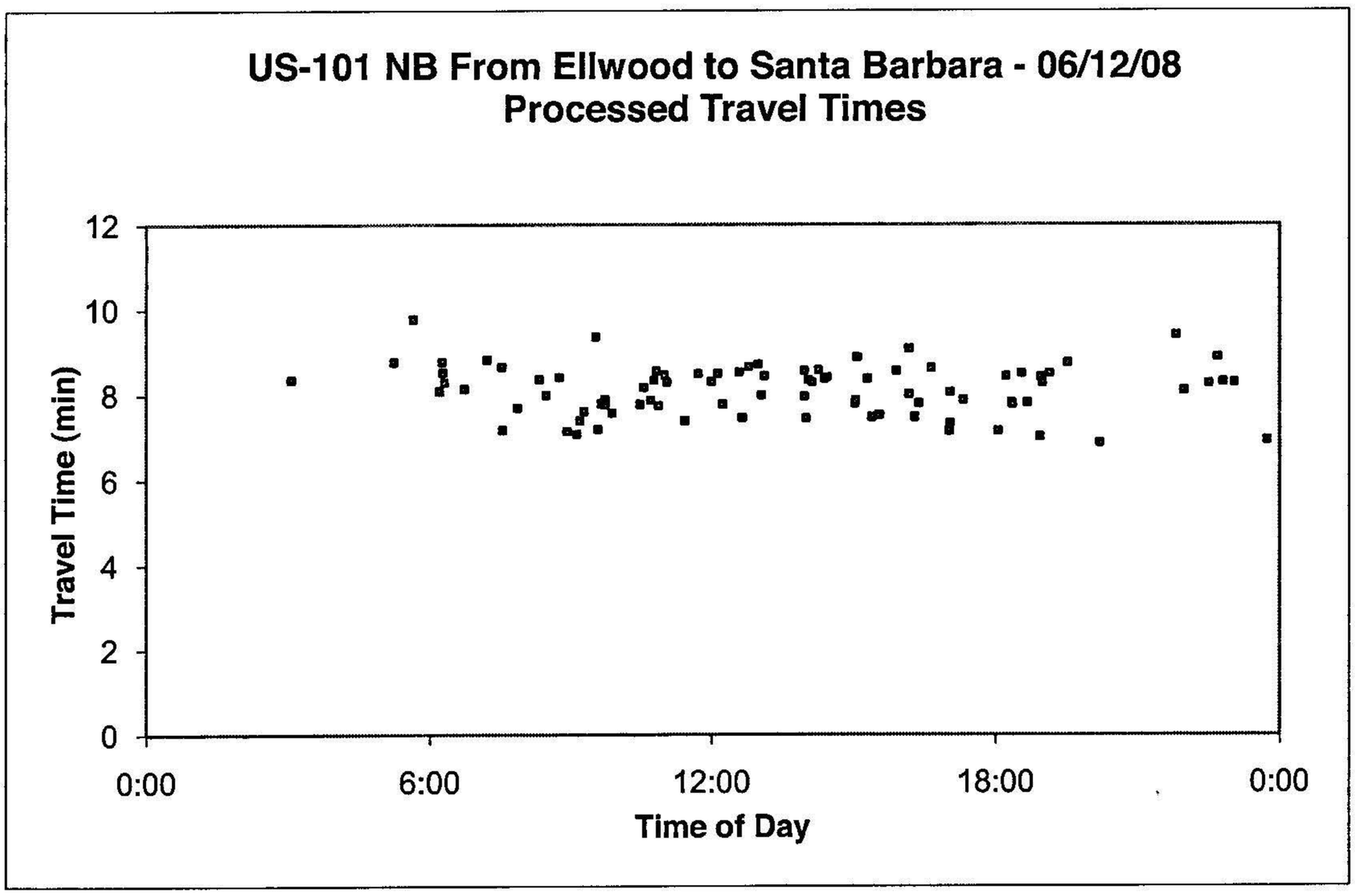

US-101 NB From Los Olivos to Ellwood - 06/21/08
Processed Travel Times
Travel Time (min)
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

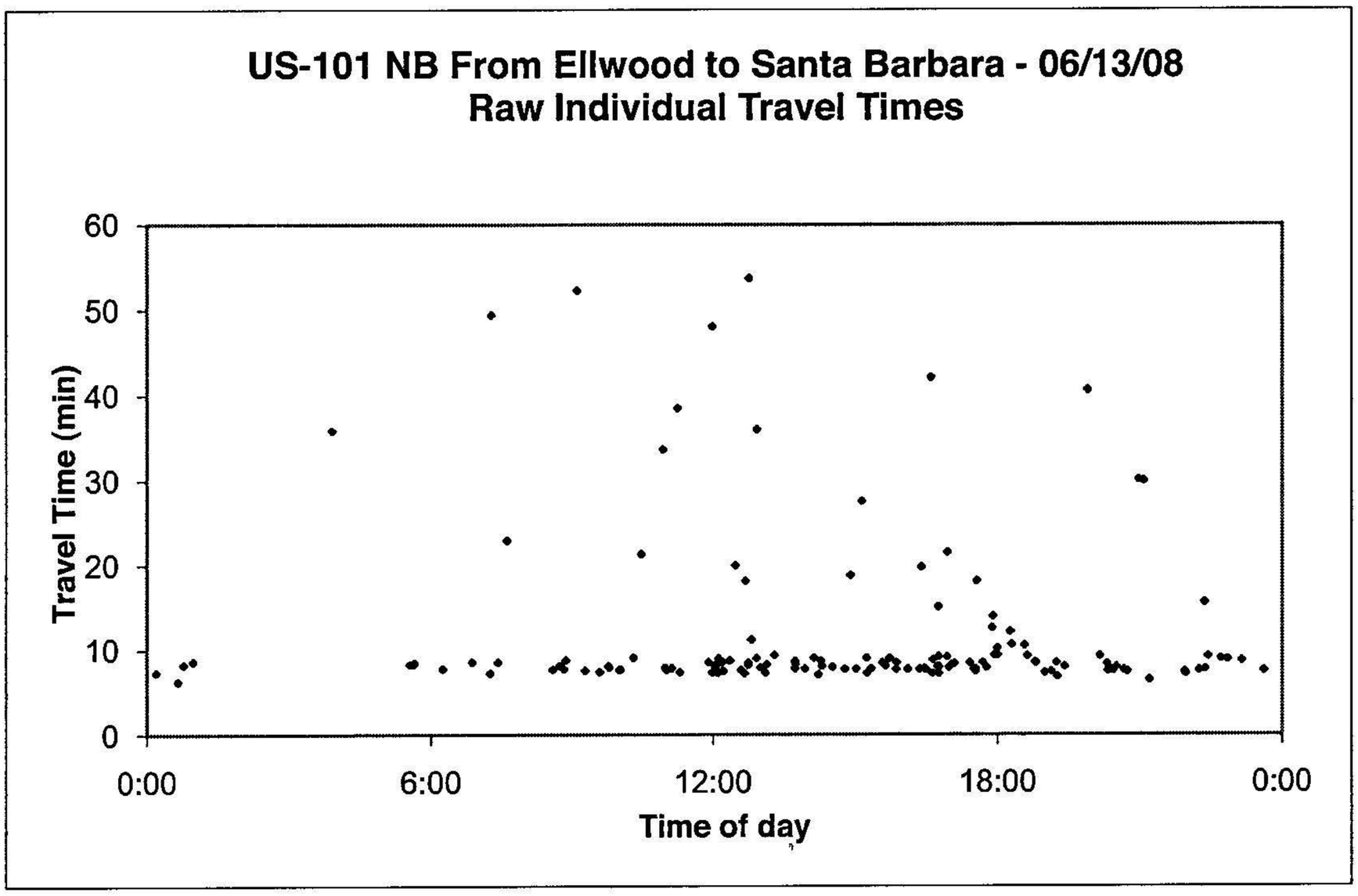

US-101 NB From Los Olivos to Ellwood - 06/22/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

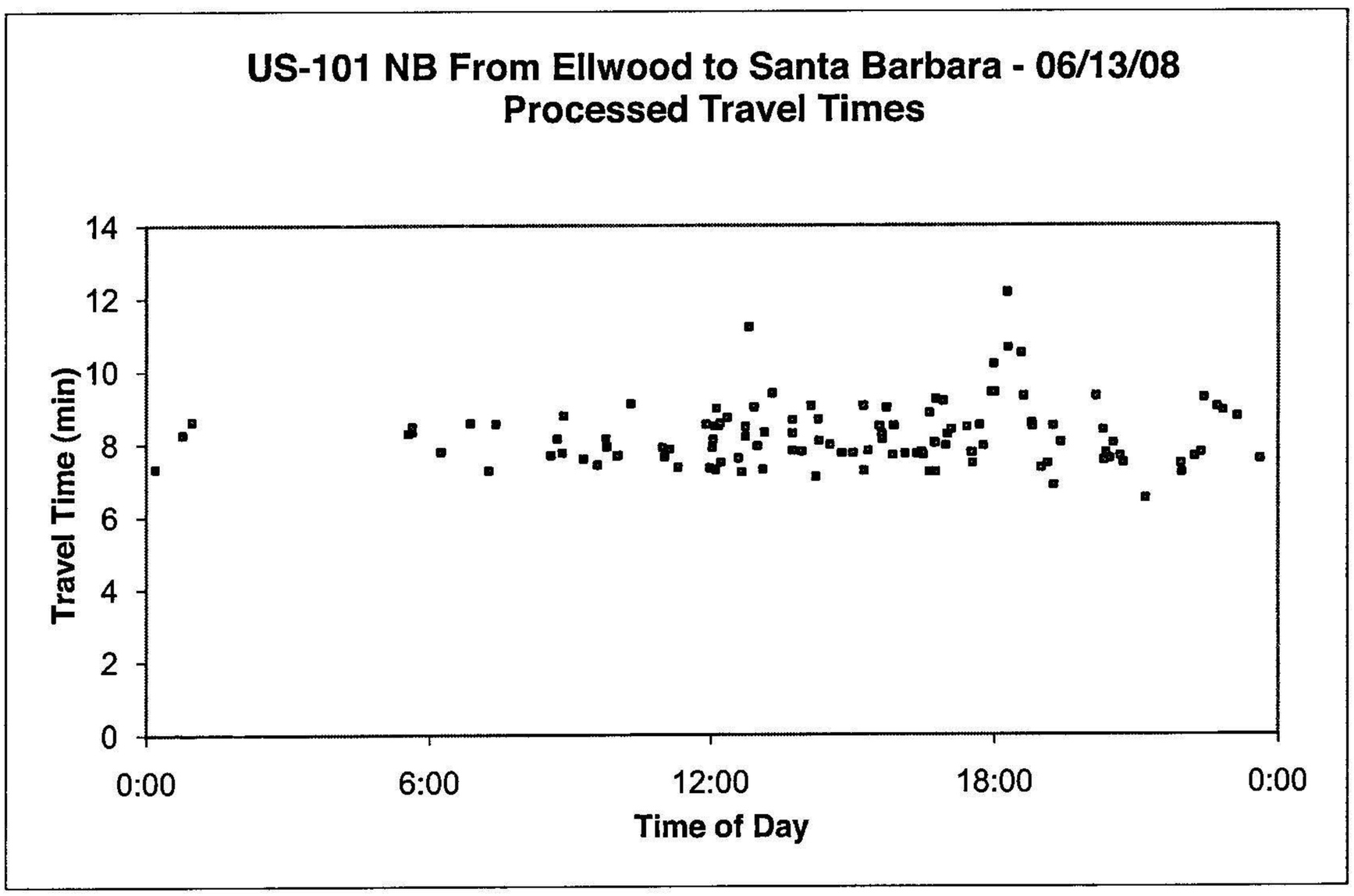

US-101 NB From Los Olivos to Ellwood - 06/22/08
Processed Travel Times
Travel Time (min)
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

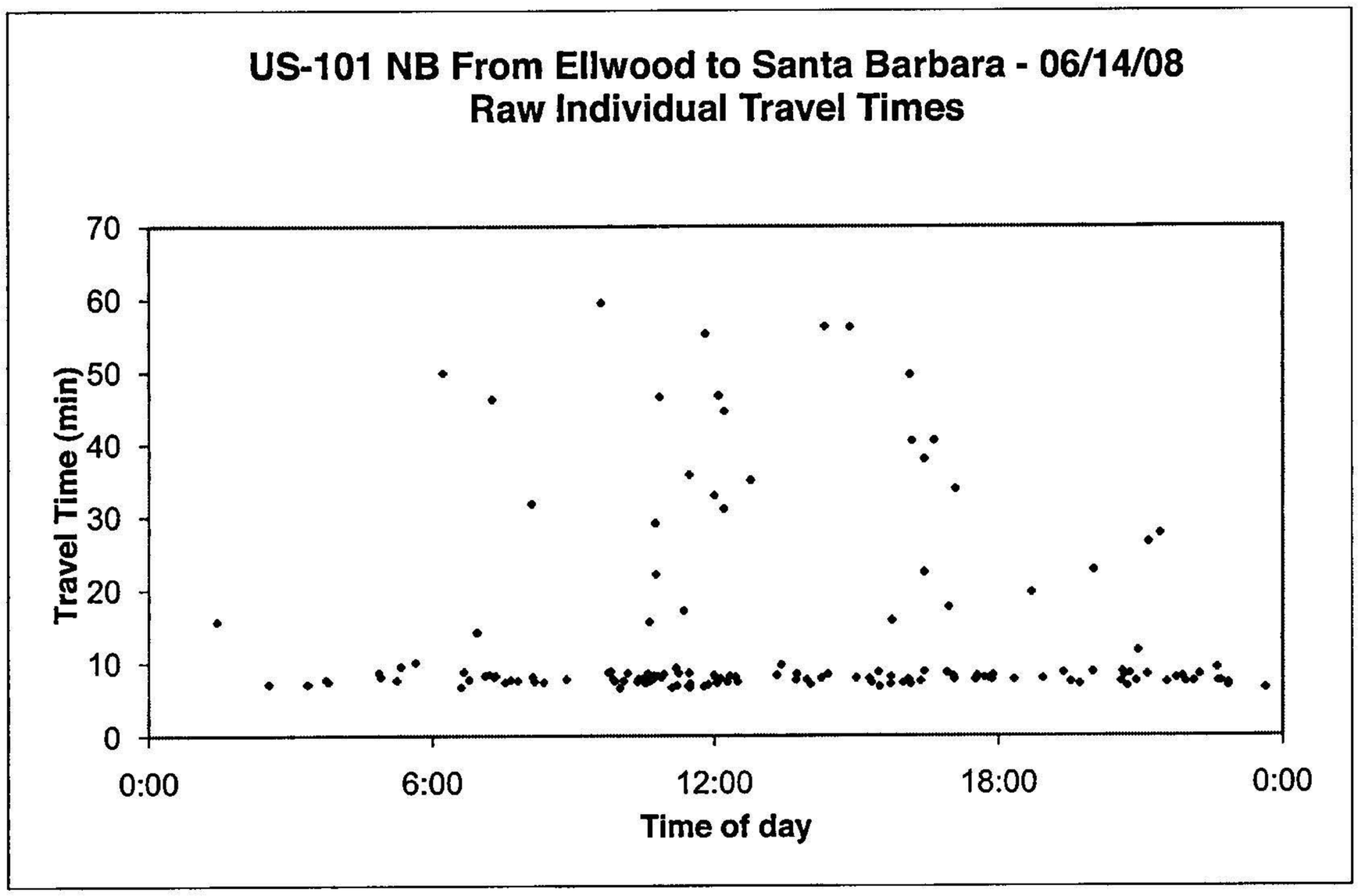
C.6 US-101 From Ellwood to Santa Barbara Travel Time Distribution

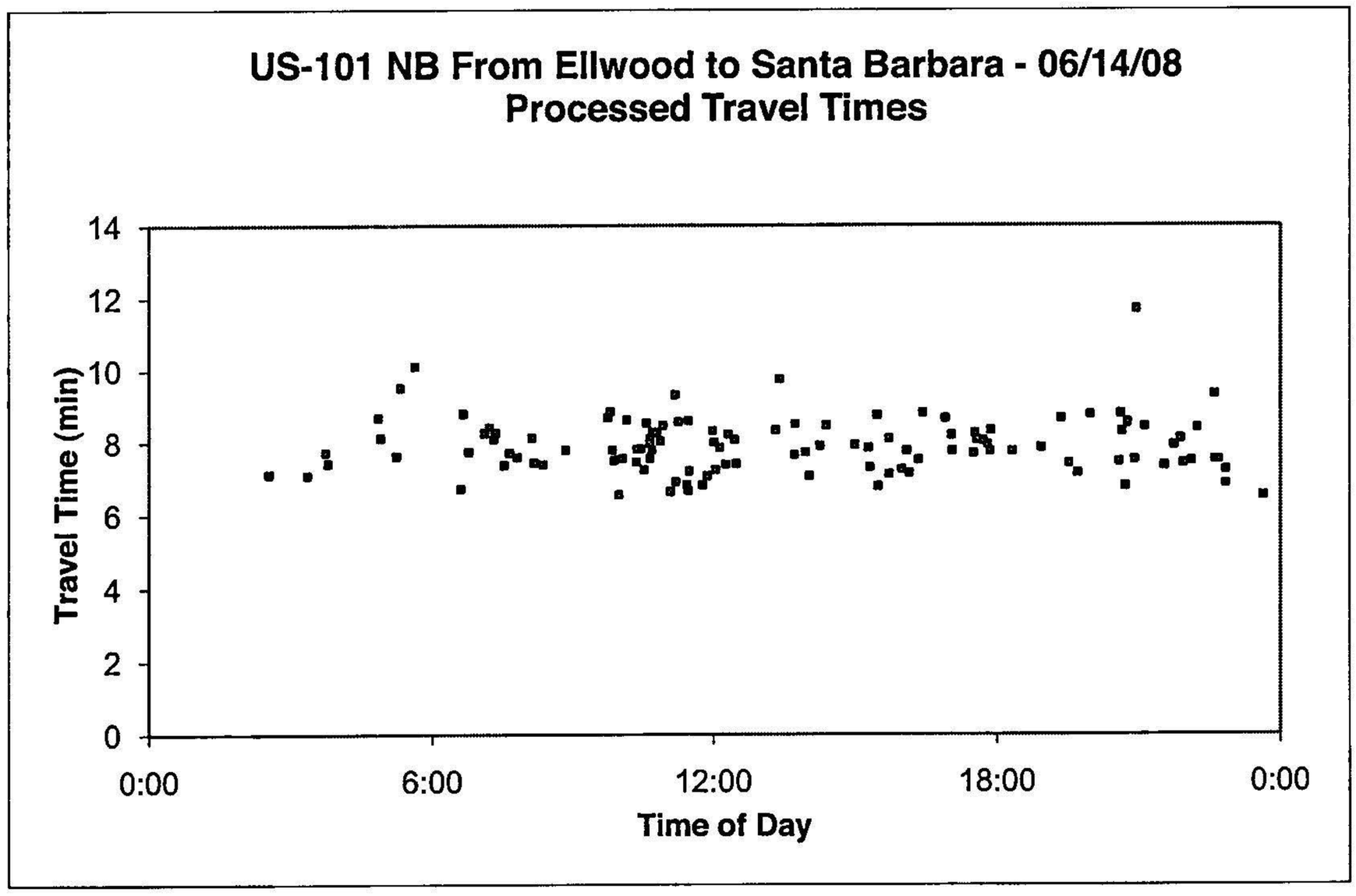


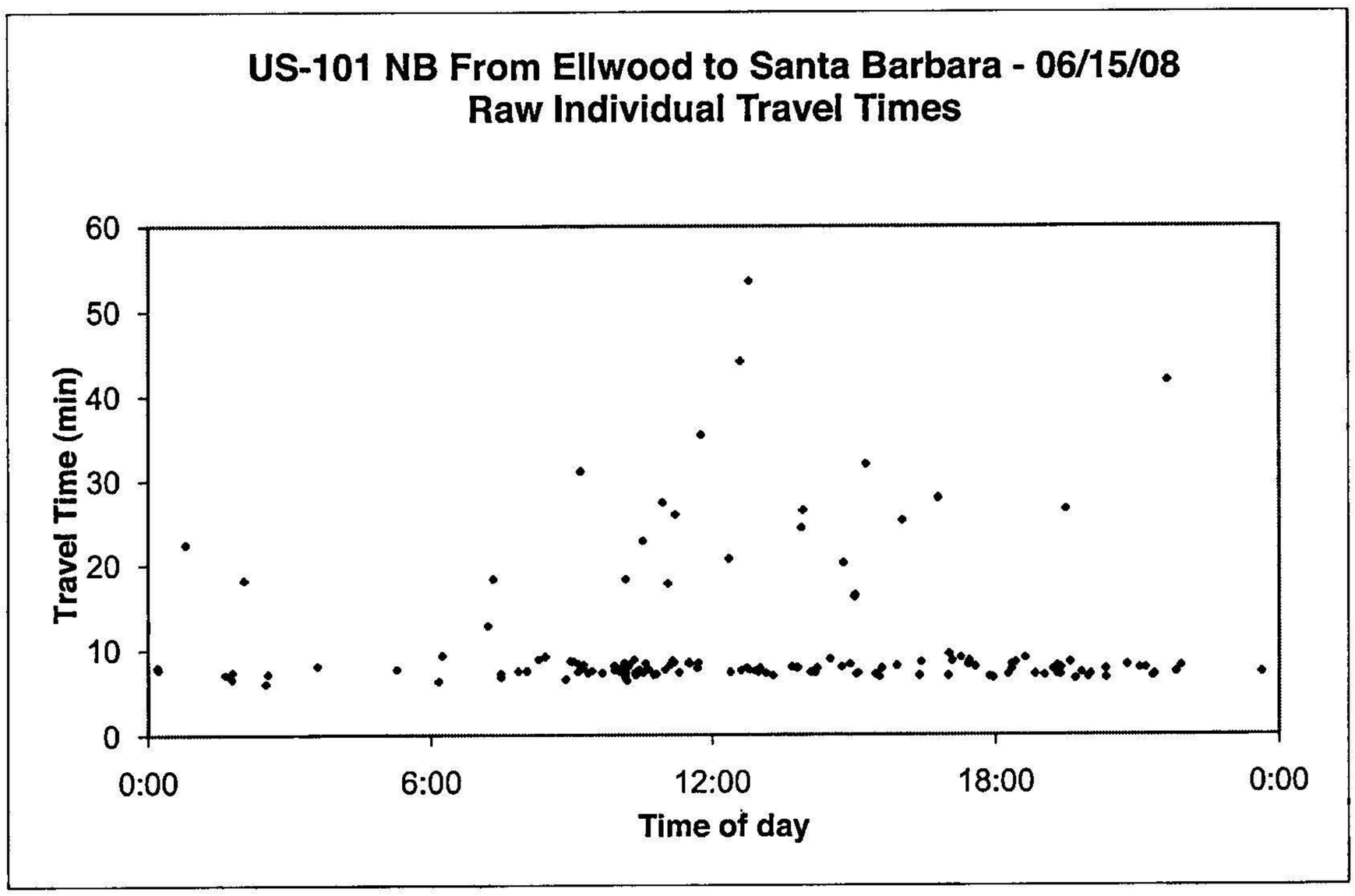


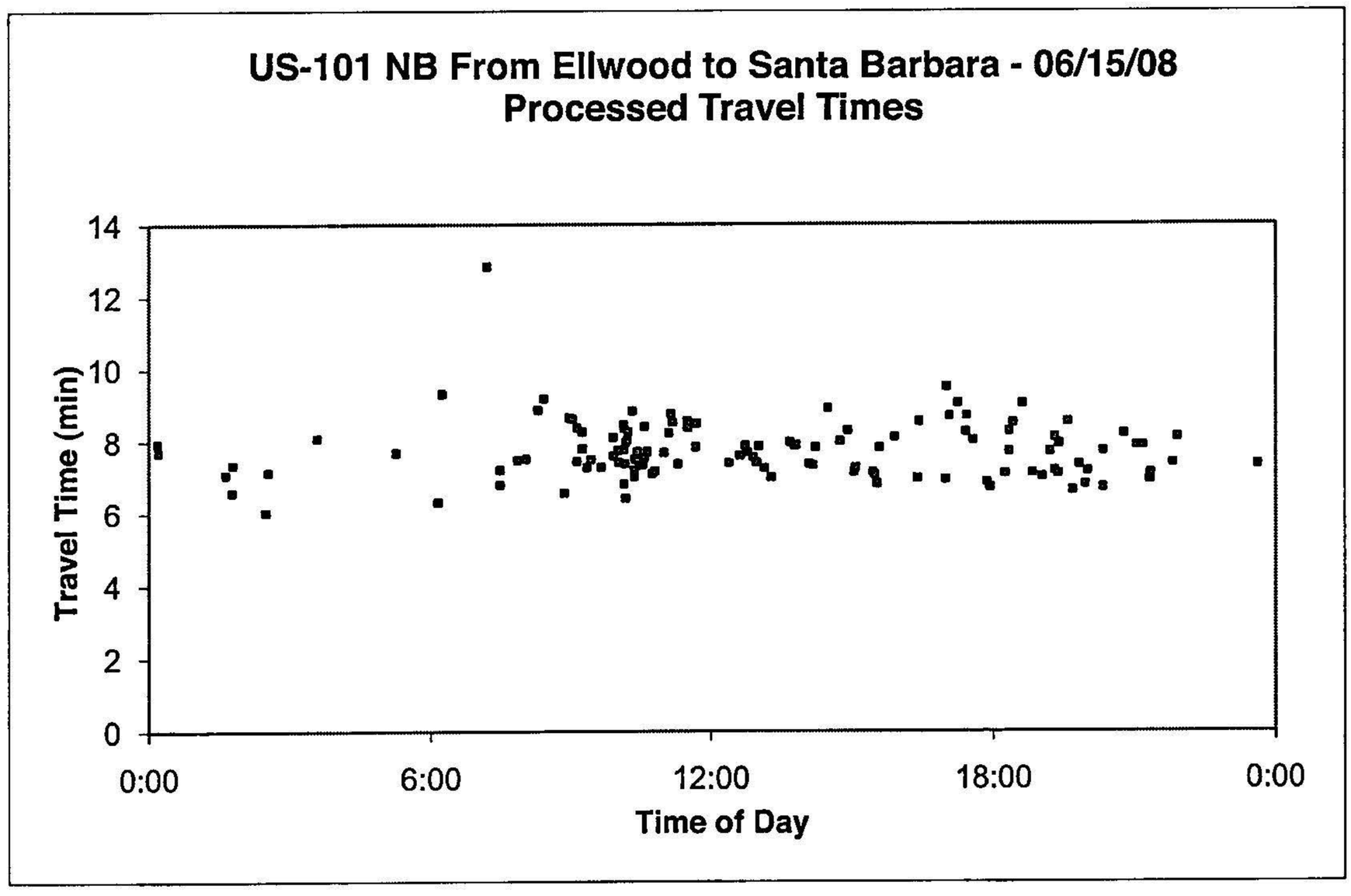

US-101 NB From Ellwood to Santa Barbara - 06/13/08
Raw Individual Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

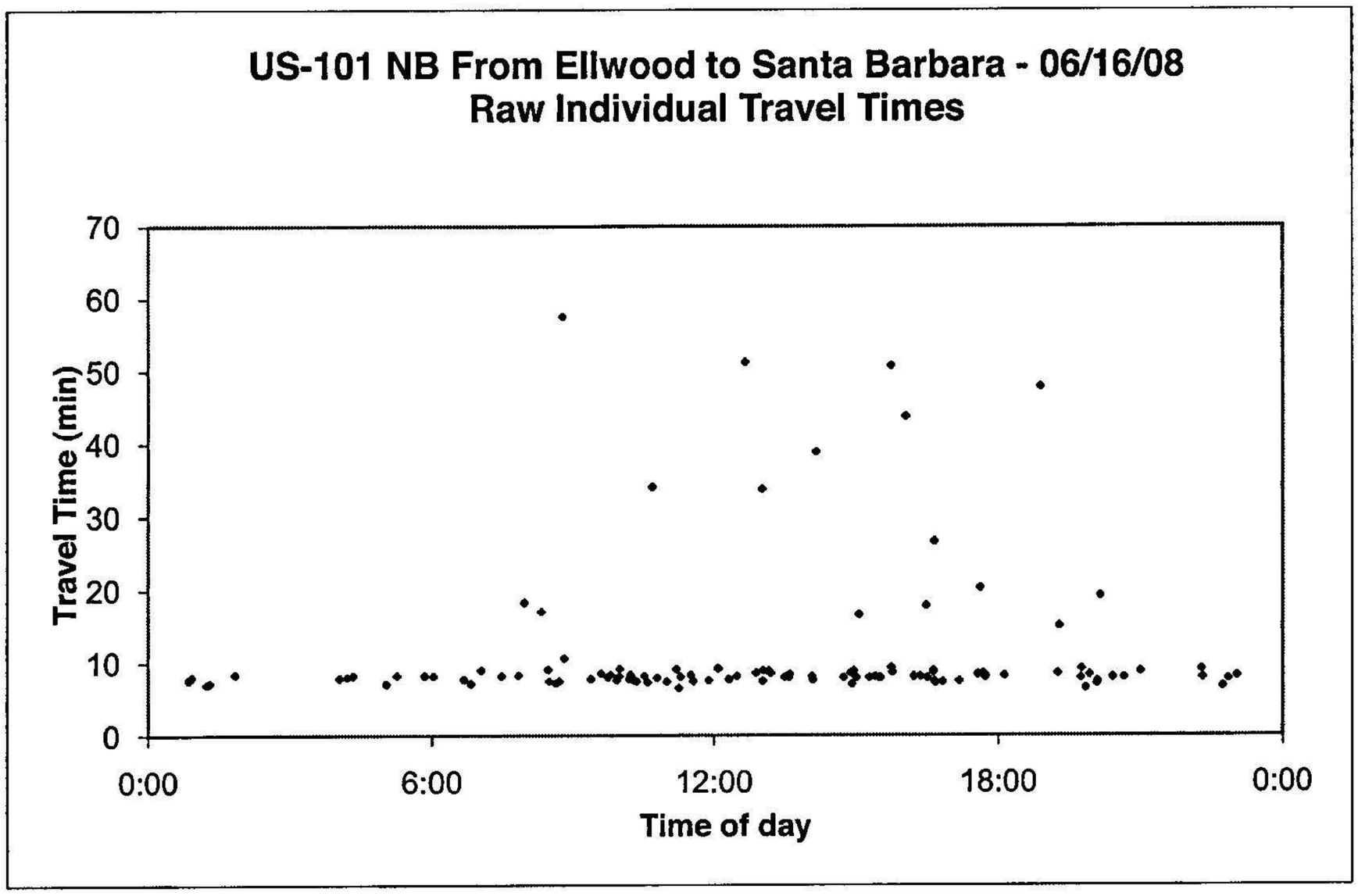

US-101 NB From Ellwood to Santa Barbara - 06/13/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

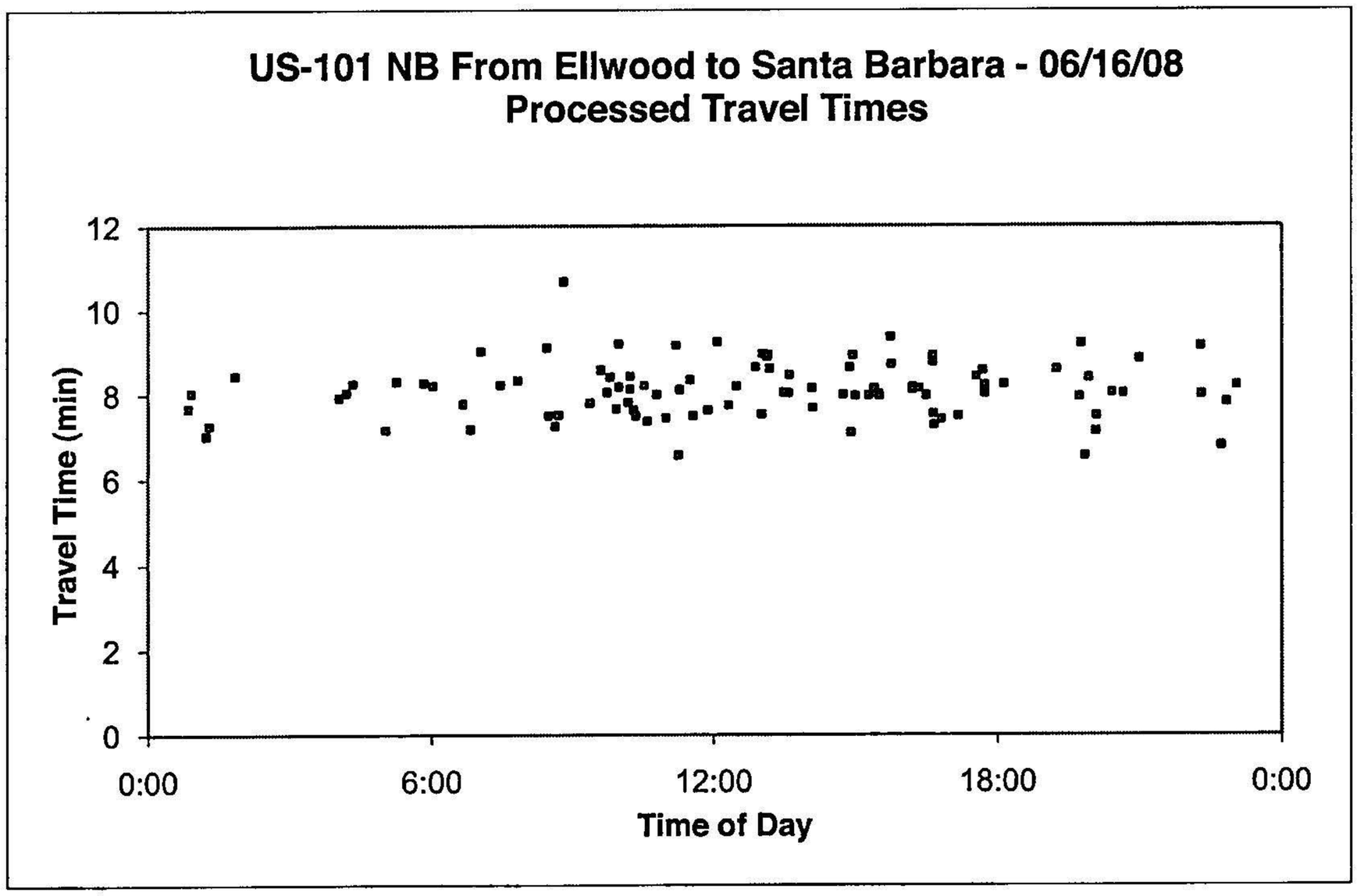

US-101 NB From Ellwood to Santa Barbara - 06/14/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

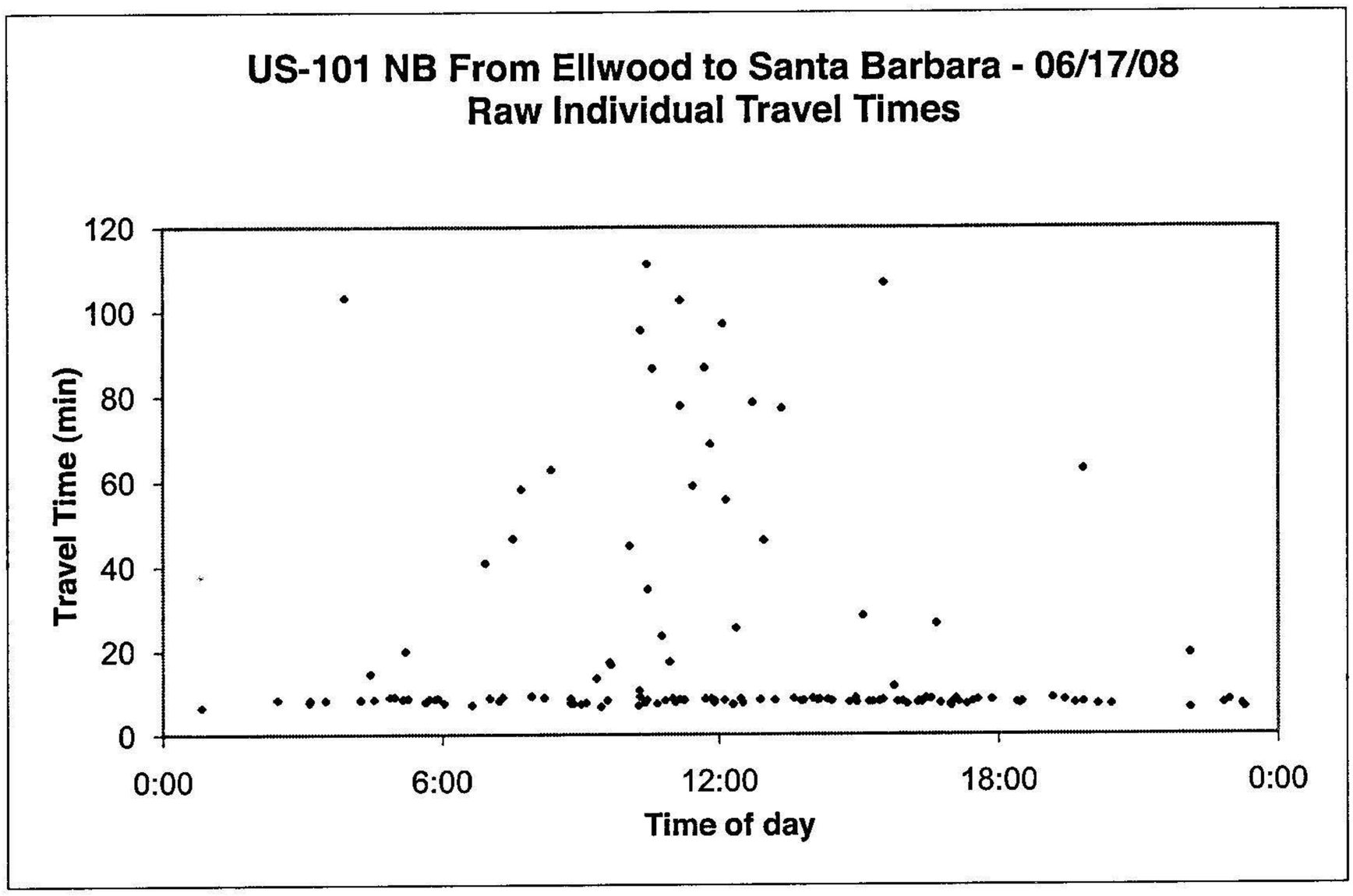

US-101 NB From Ellwood to Santa Barbara - 06/14/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

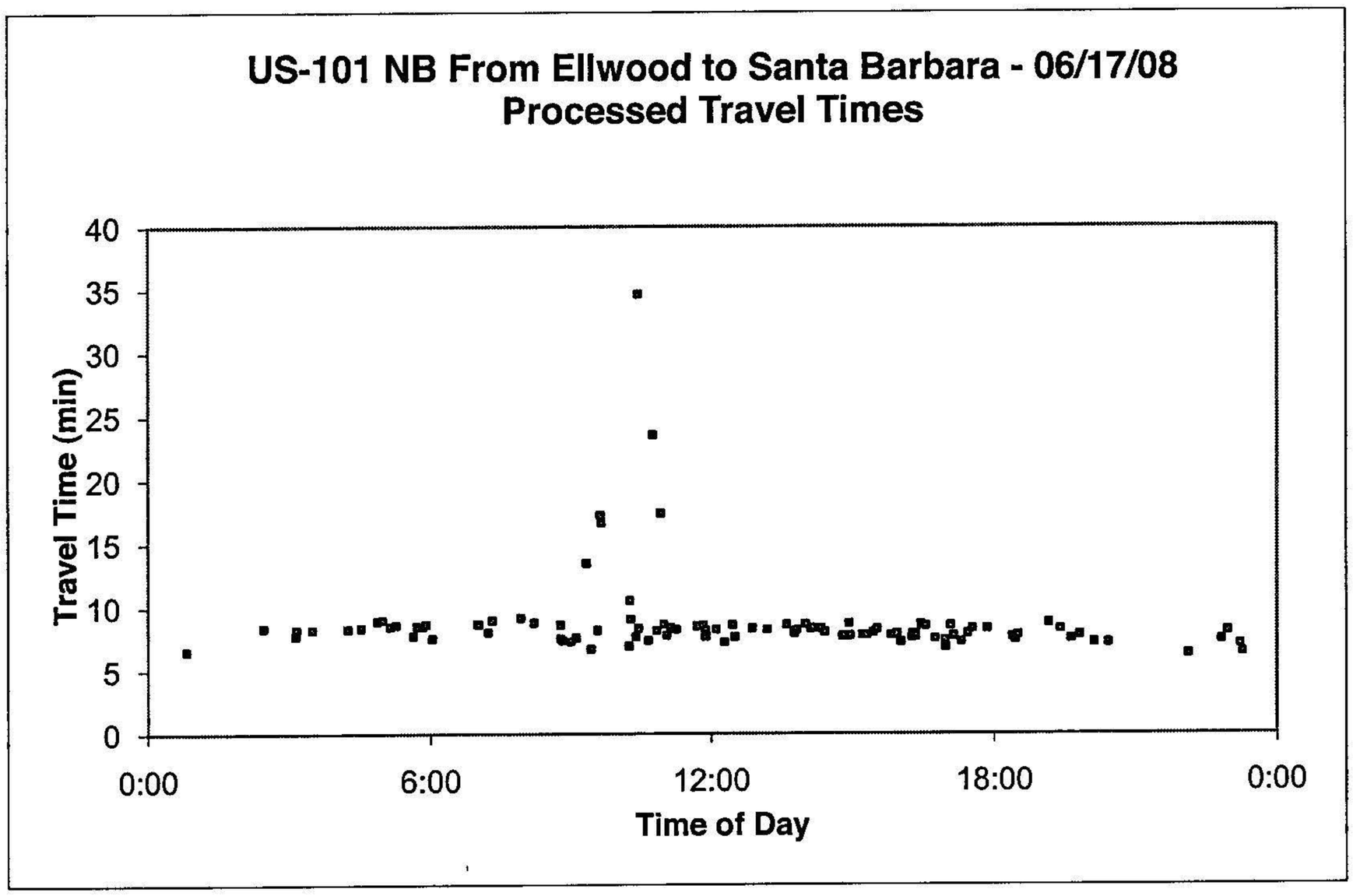

US-101 NB From Ellwood to Santa Barbara - 06/15/08
Raw Individual Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

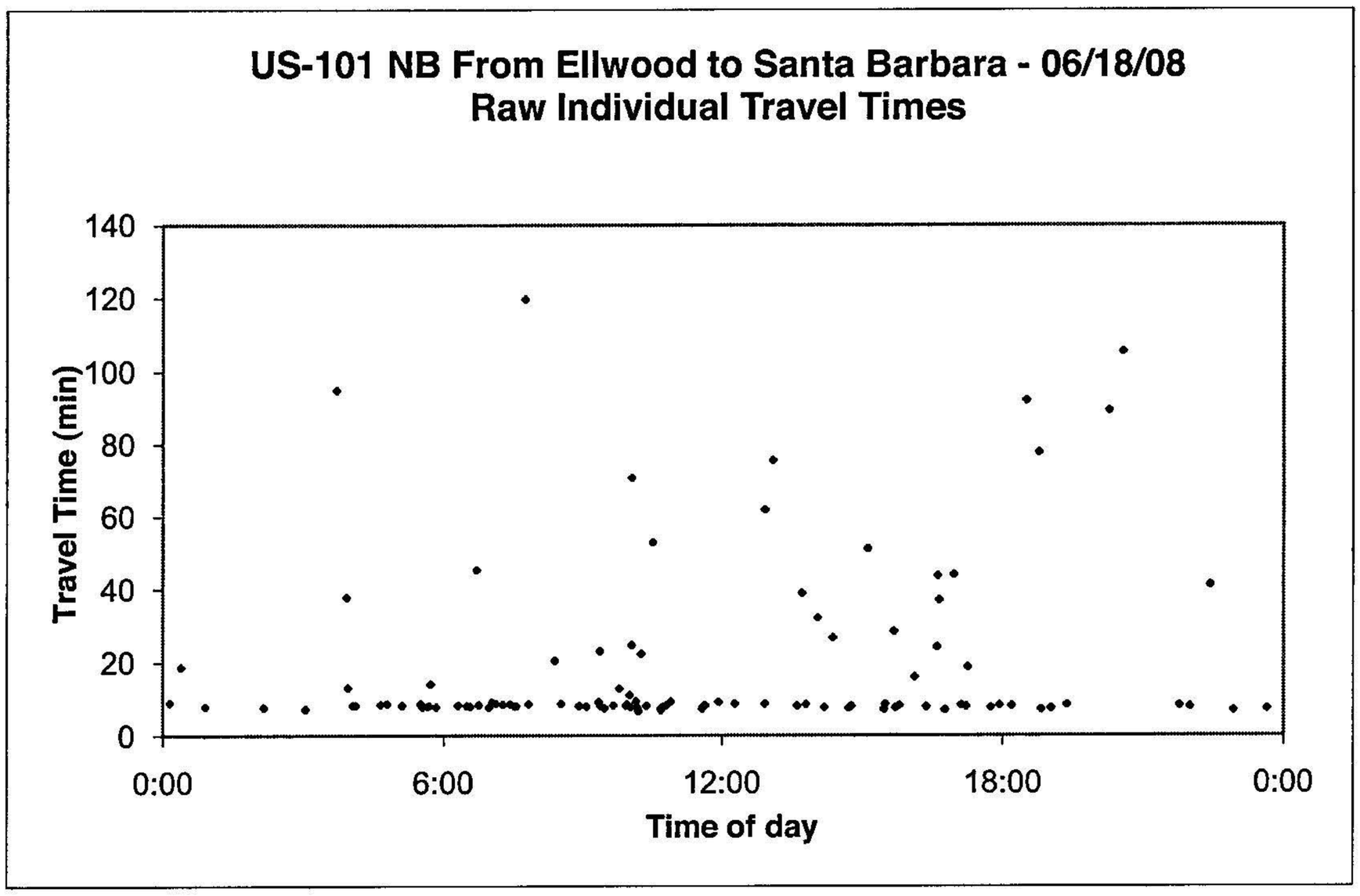

US-101 NB From Ellwood to Santa Barbara - 06/15/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

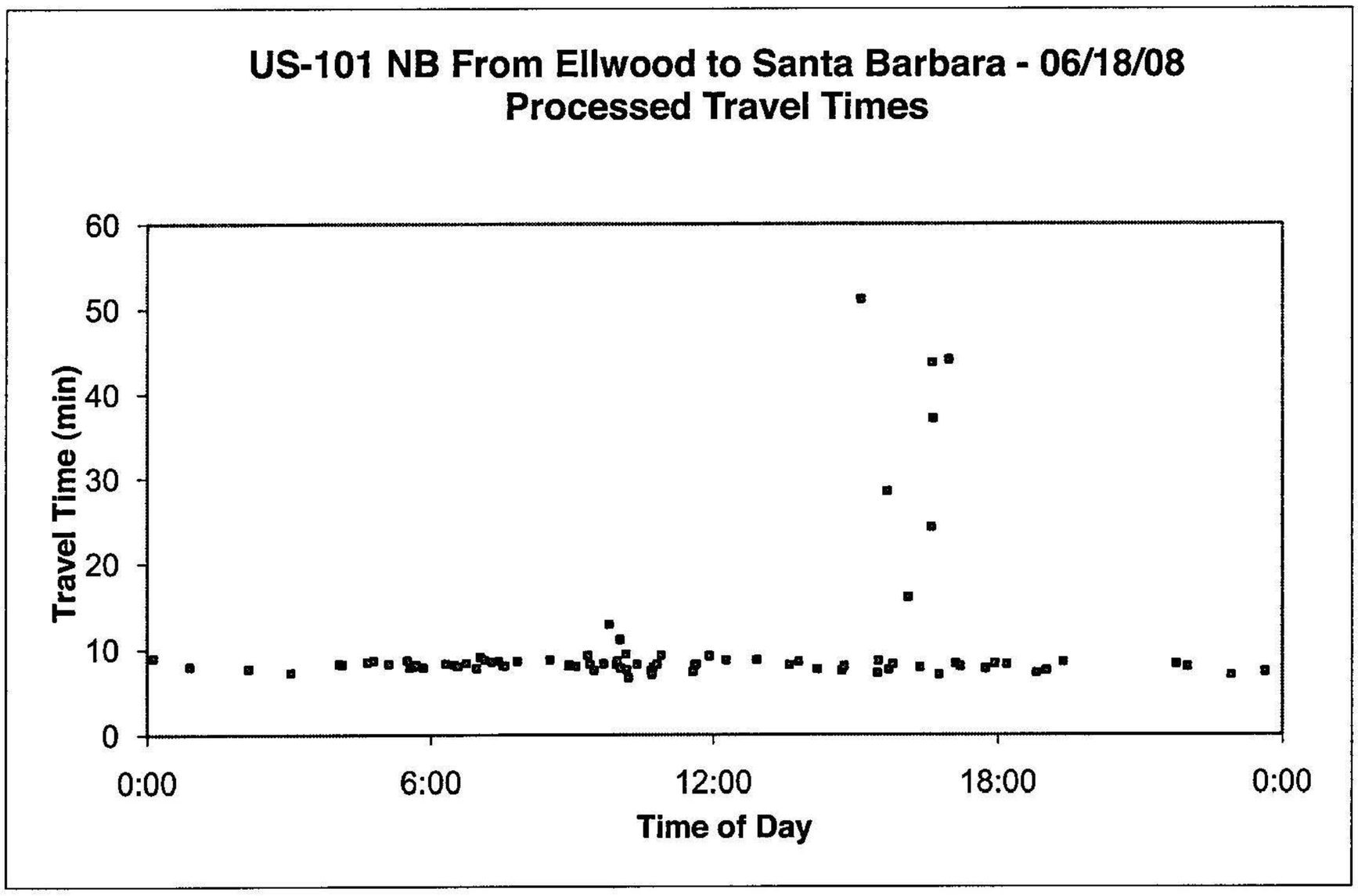

US-101 NB From Ellwood to Santa Barbara - 06/16/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

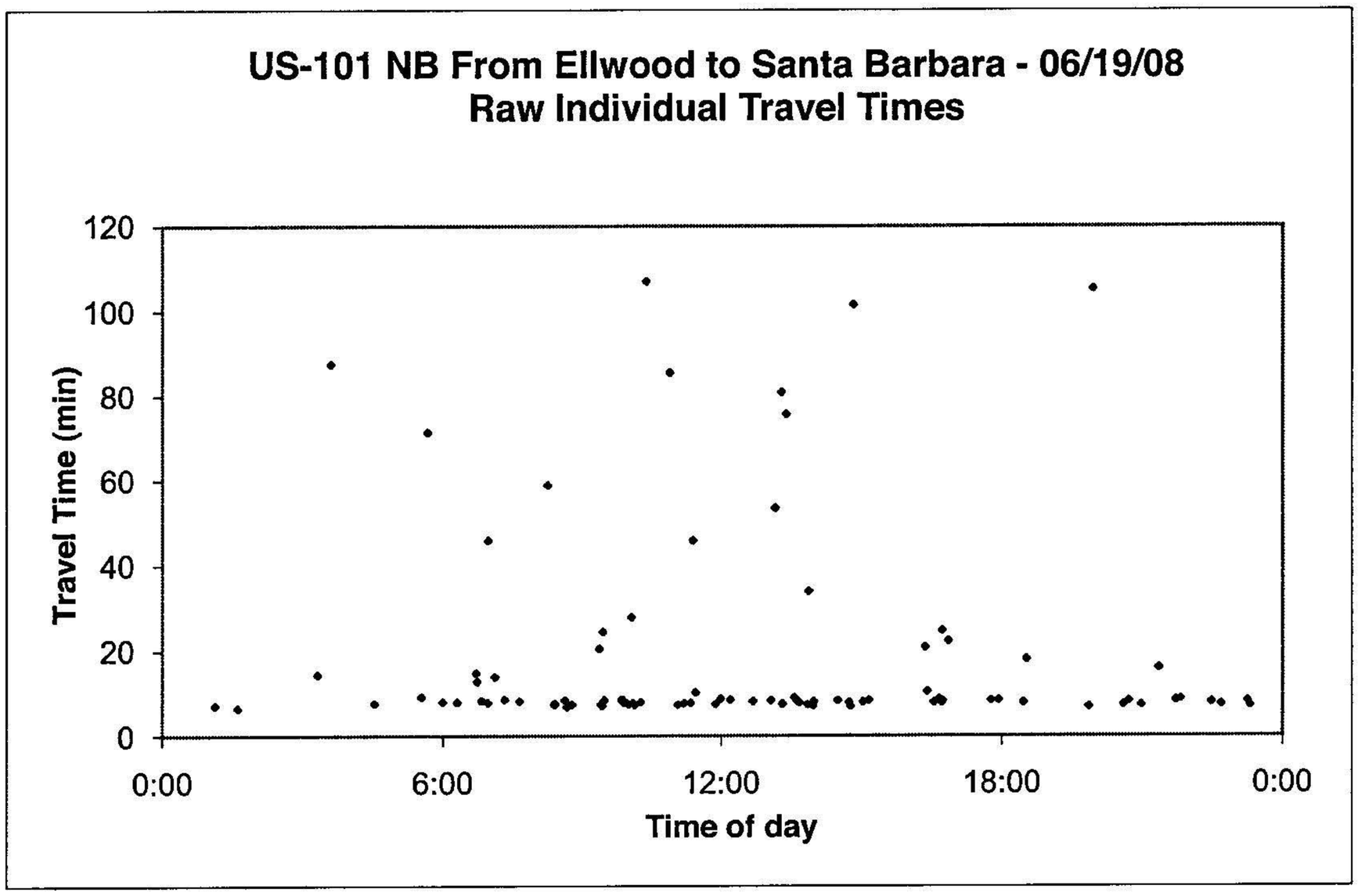

US-101 NB From Ellwood to Santa Barbara - 06/16/08
Processed Travel Times
Travel Time (min)
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

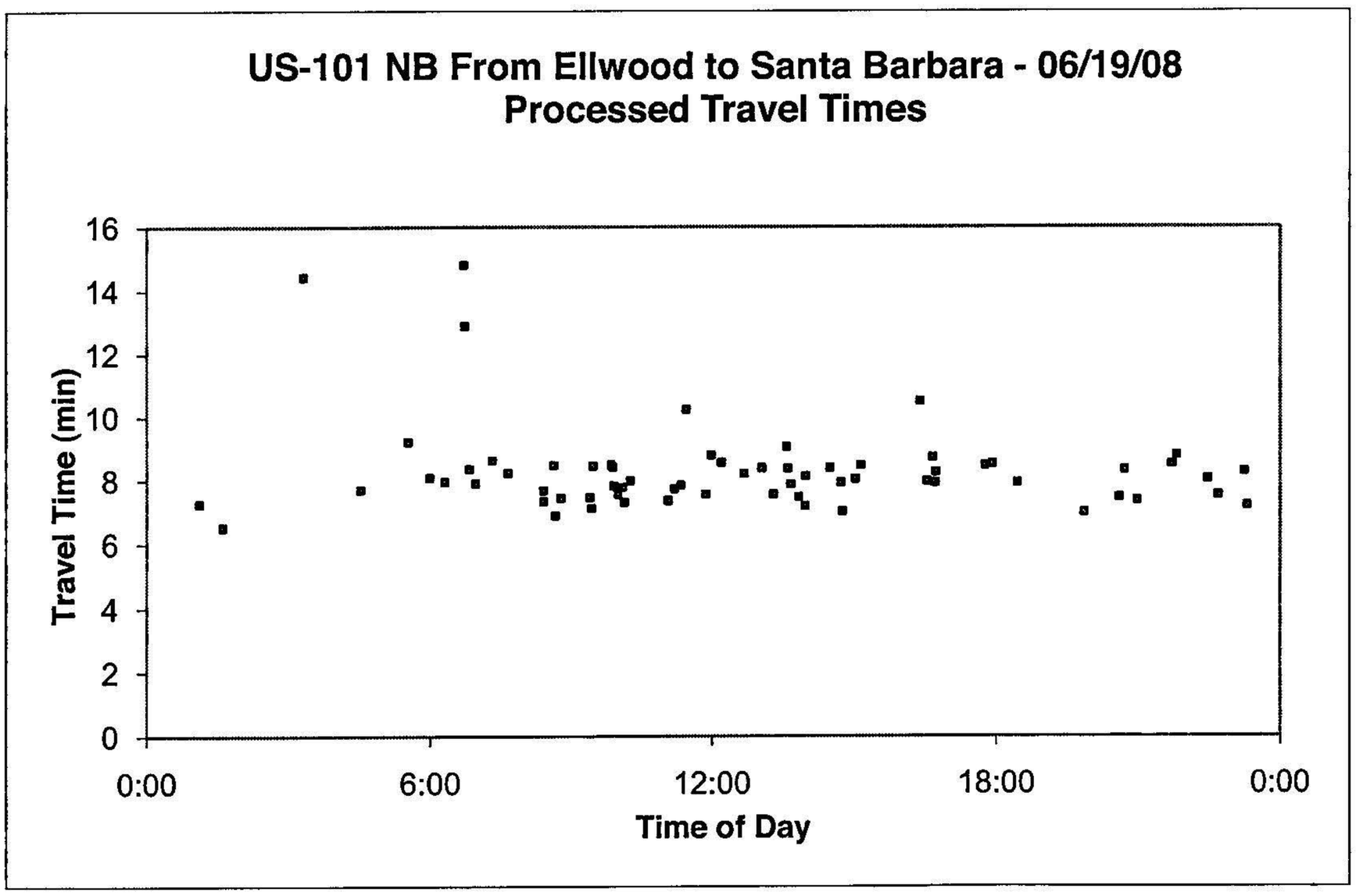

US-101 NB From Ellwood to Santa Barbara - 06/17/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

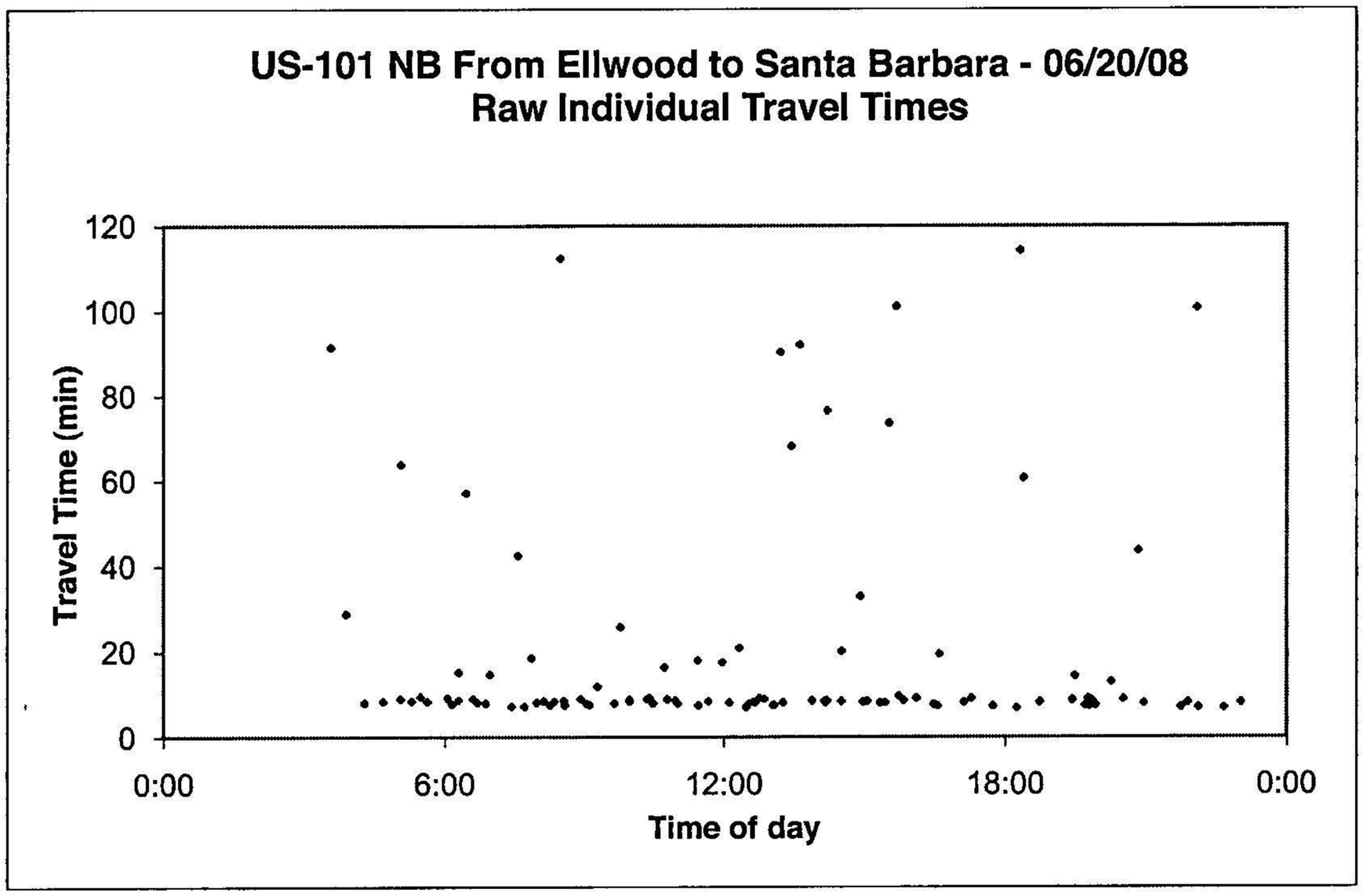

US-101 NB From Ellwood to Santa Barbara - 06/17/08
Processed Travel Times
Travel Time (min)
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

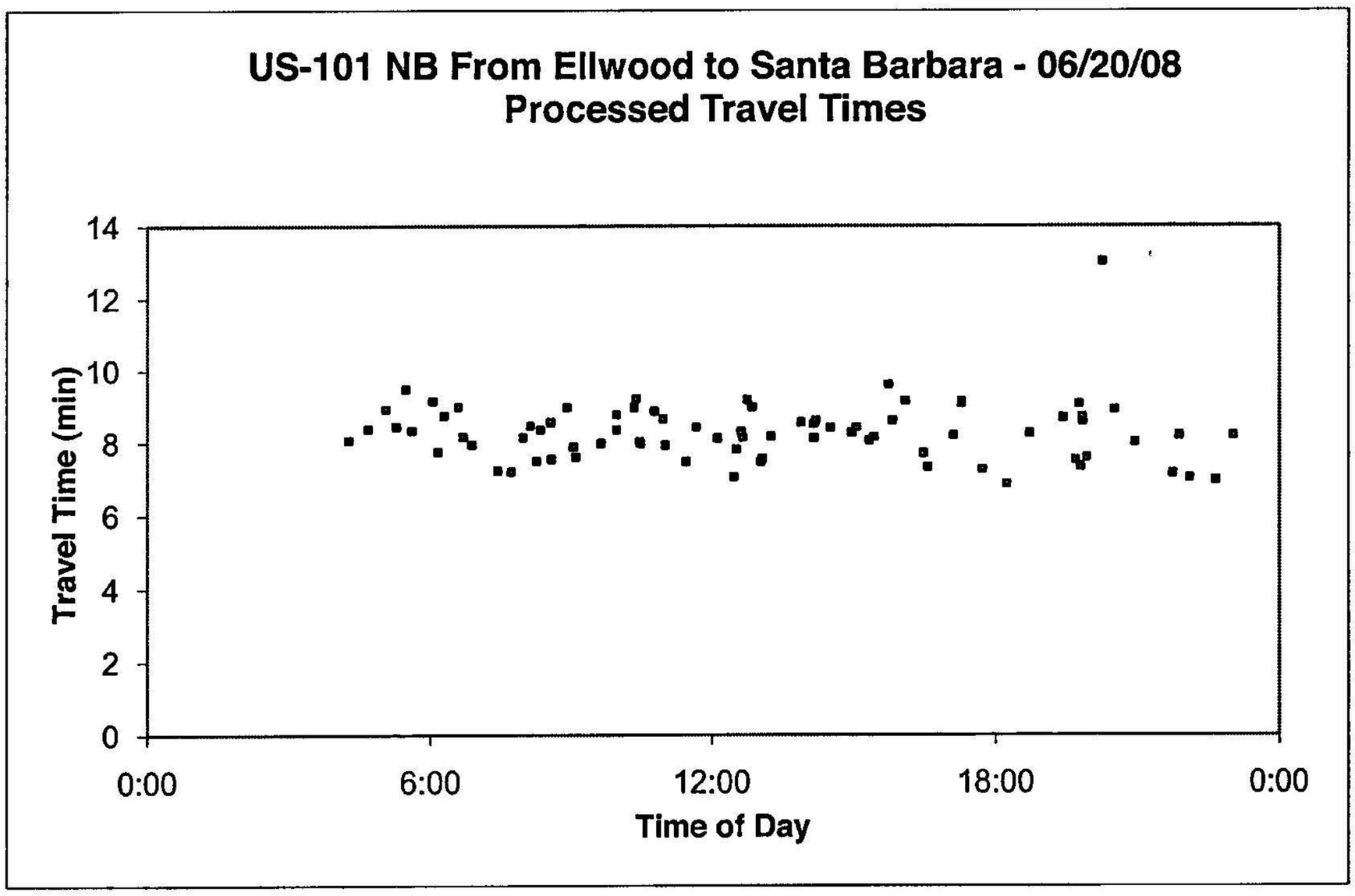

US-101 NB From Ellwood to Santa Barbara - 06/18/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

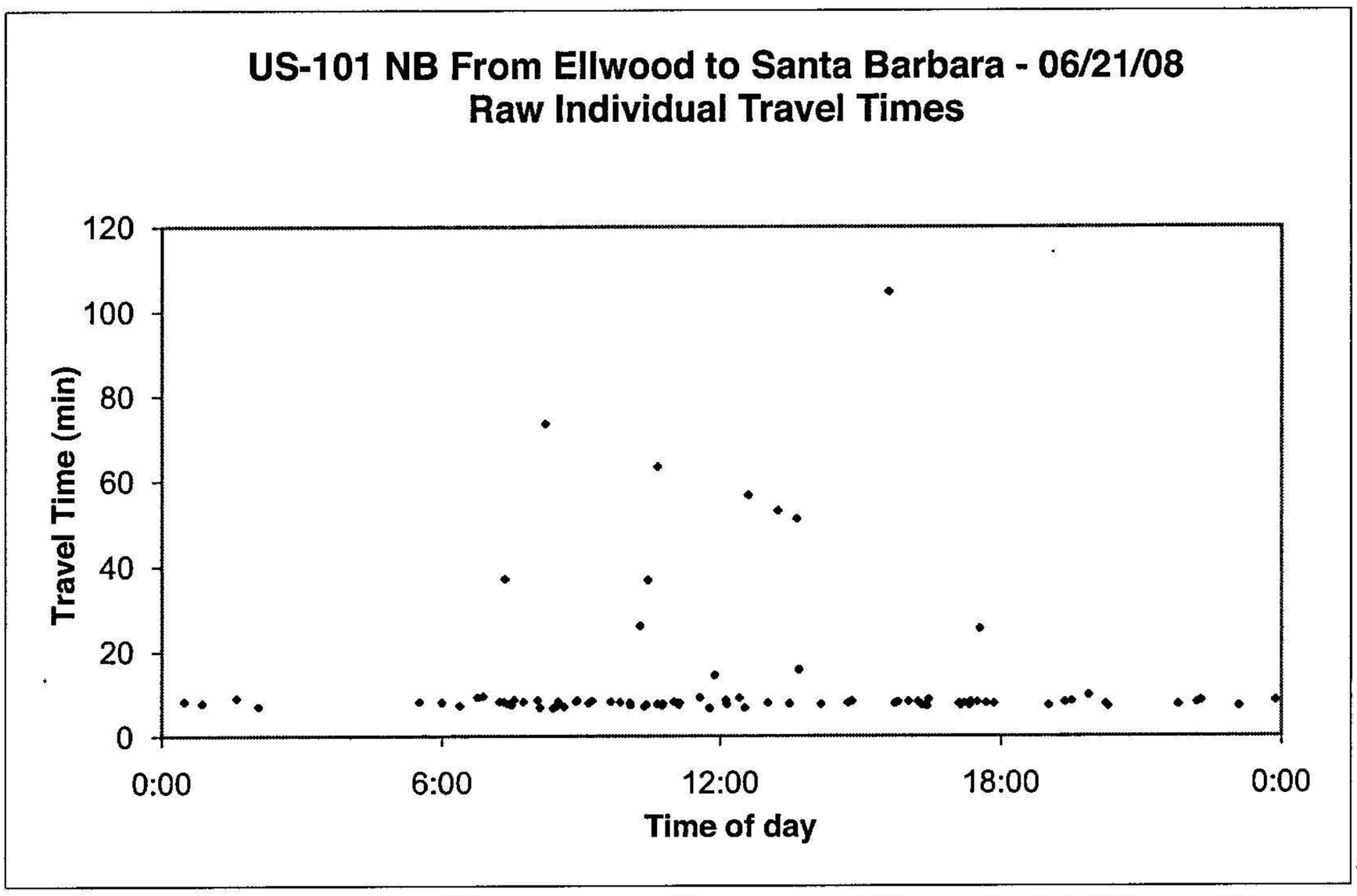

US-101 NB From Ellwood to Santa Barbara - 06/18/08
Processed Travel Times
Travel Time (min)
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

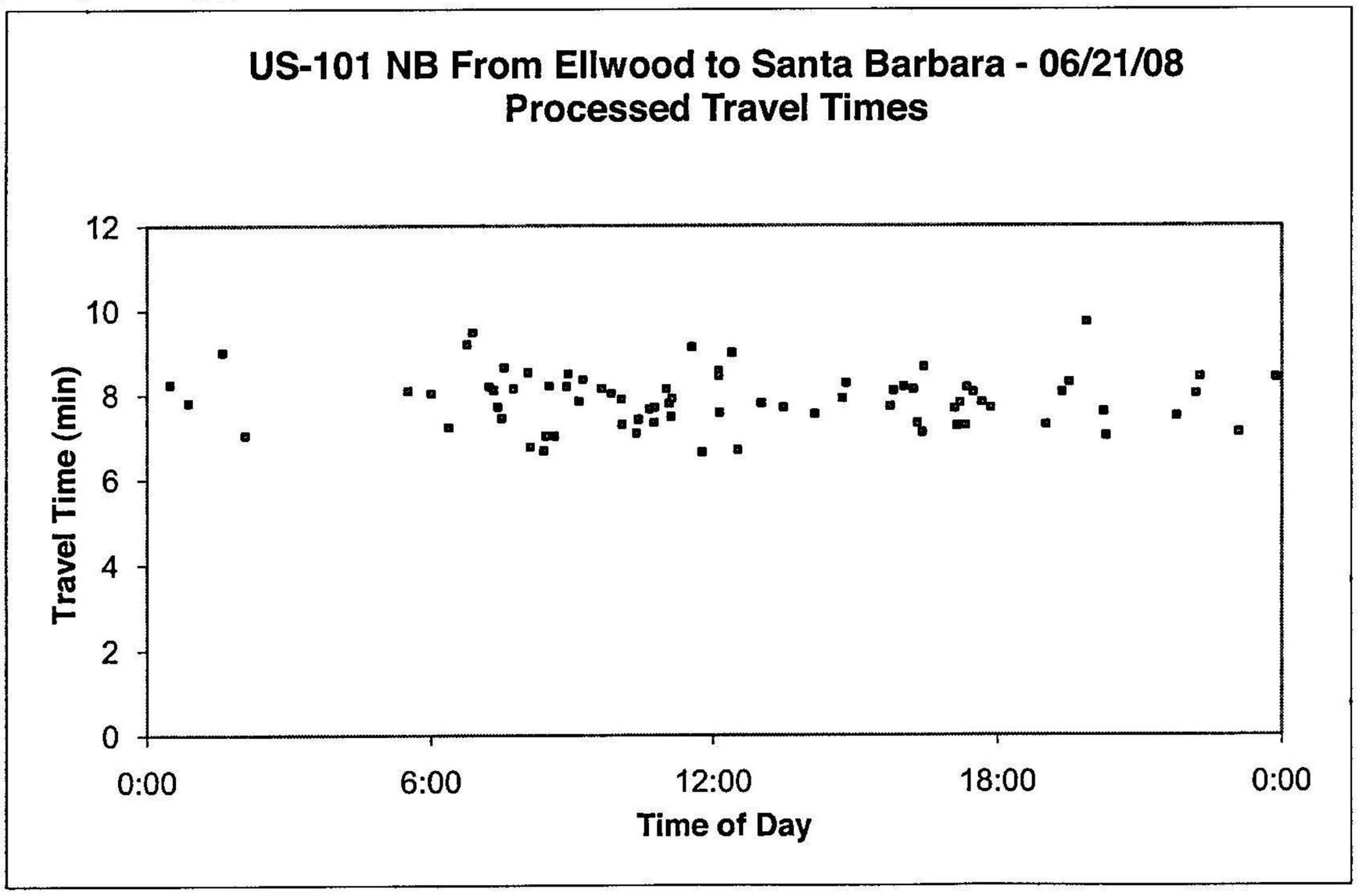

US-101 NB From Ellwood to Santa Barbara - 06/19/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

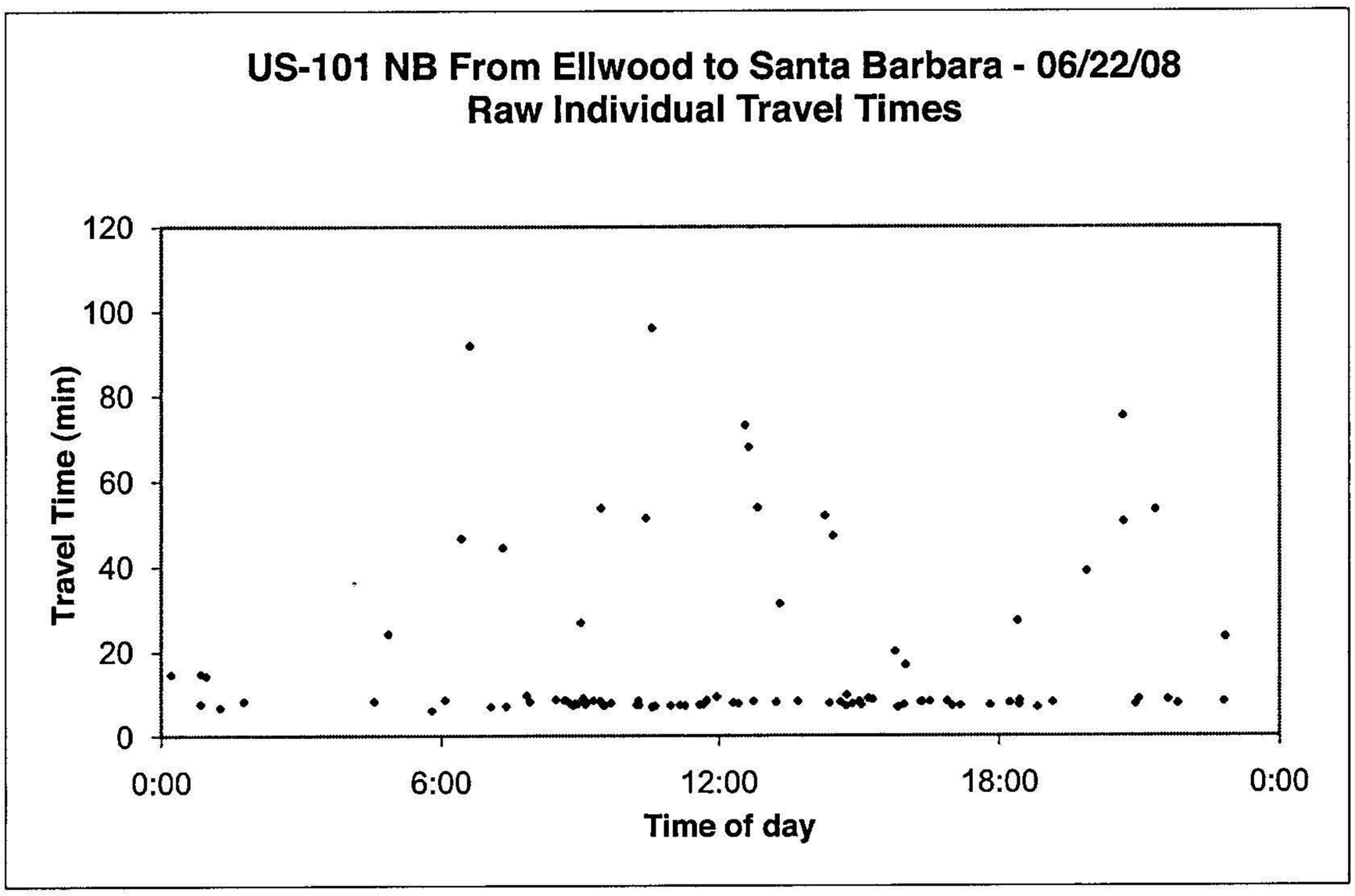

US-101 NB From Ellwood to Santa Barbara - 06/19/08
Processed Travel Times
Travel Time (min)
16
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

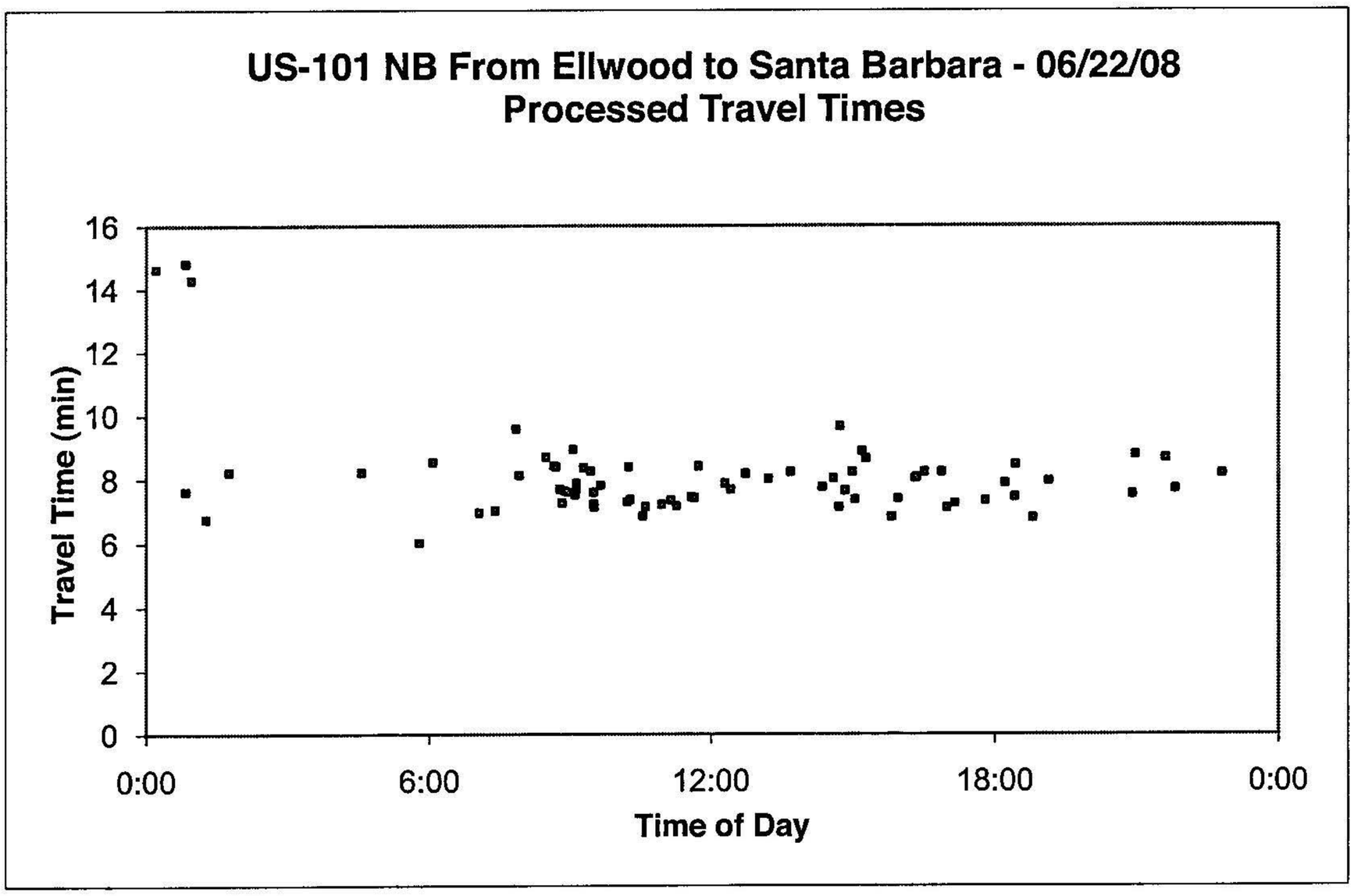

US-101 NB From Ellwood to Santa Barbara - 06/20/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

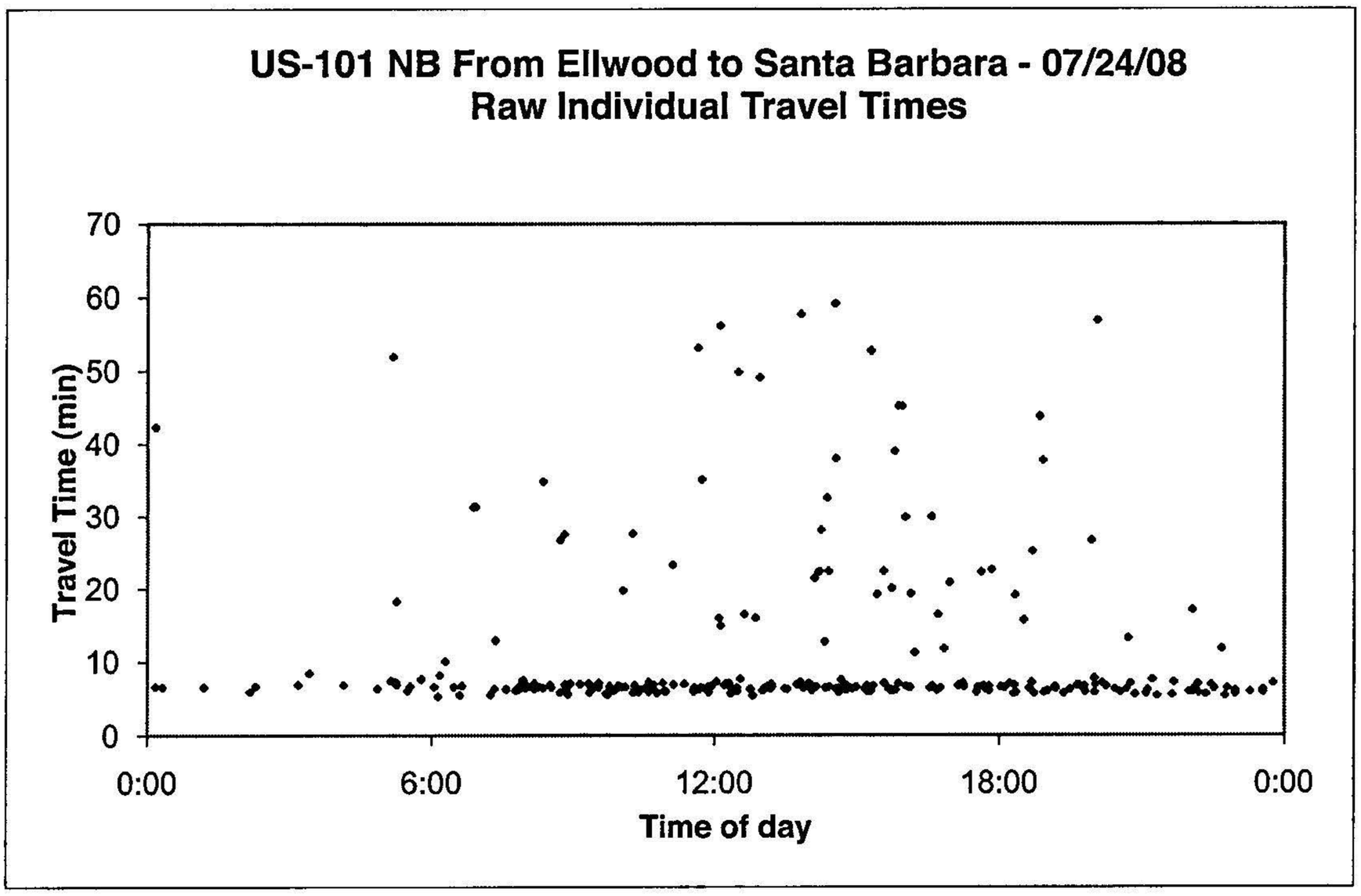

US-101 NB From Ellwood to Santa Barbara - 06/20/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

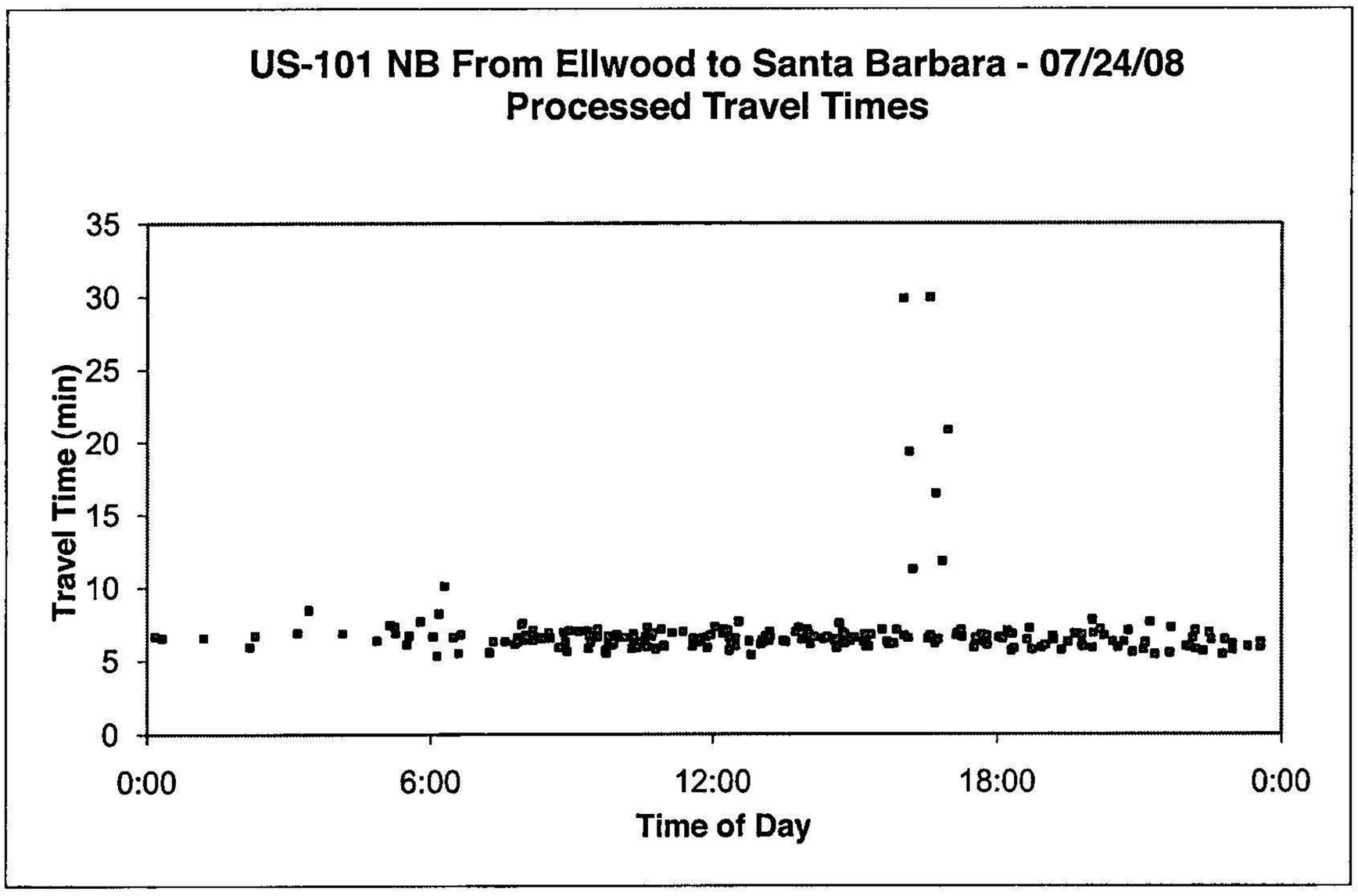

US-101 NB From Ellwood to Santa Barbara - 06/21/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

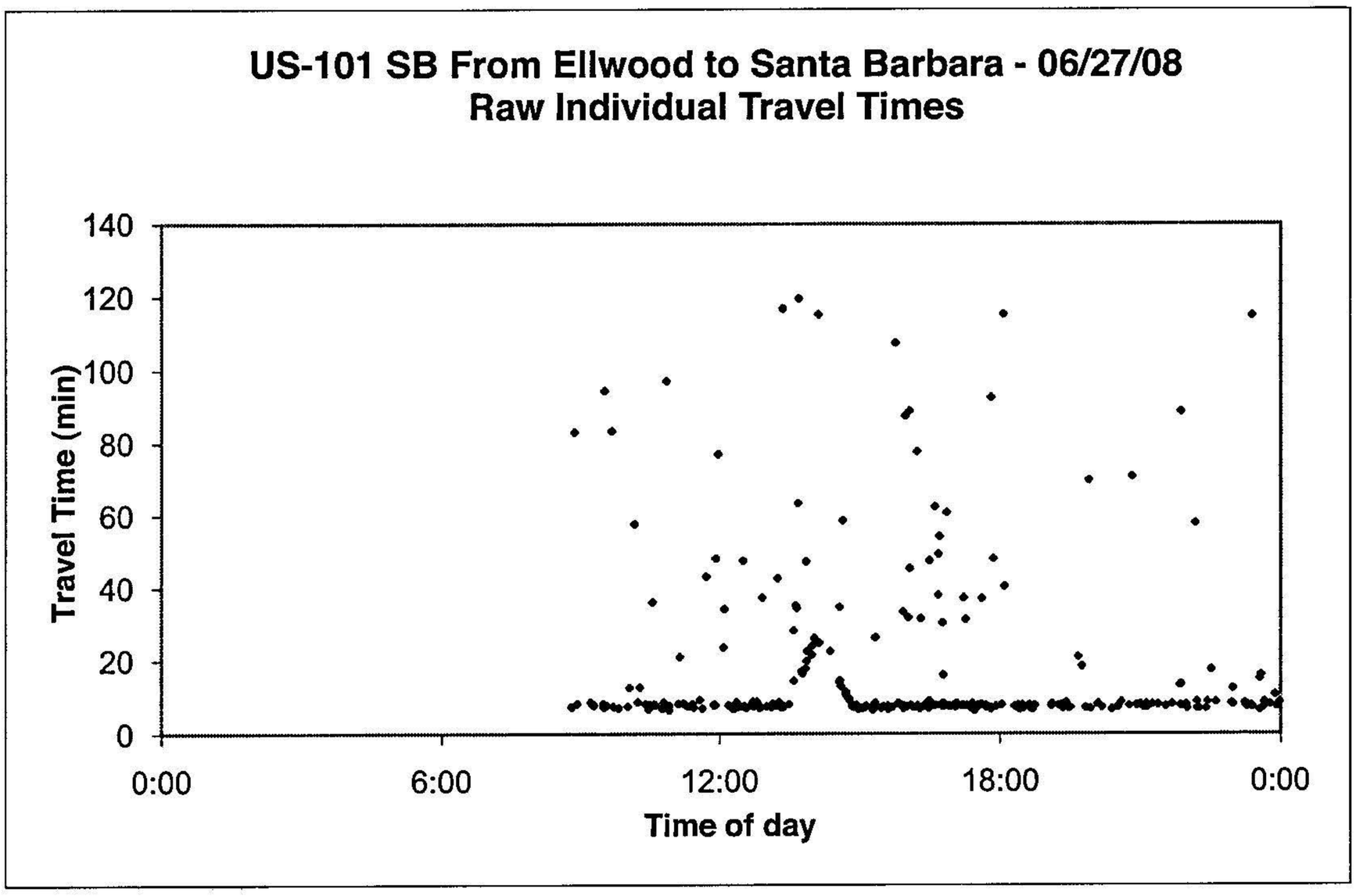

US-101 NB From Ellwood to Santa Barbara - 06/21/08
Processed Travel Times
Travel Time (min)
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

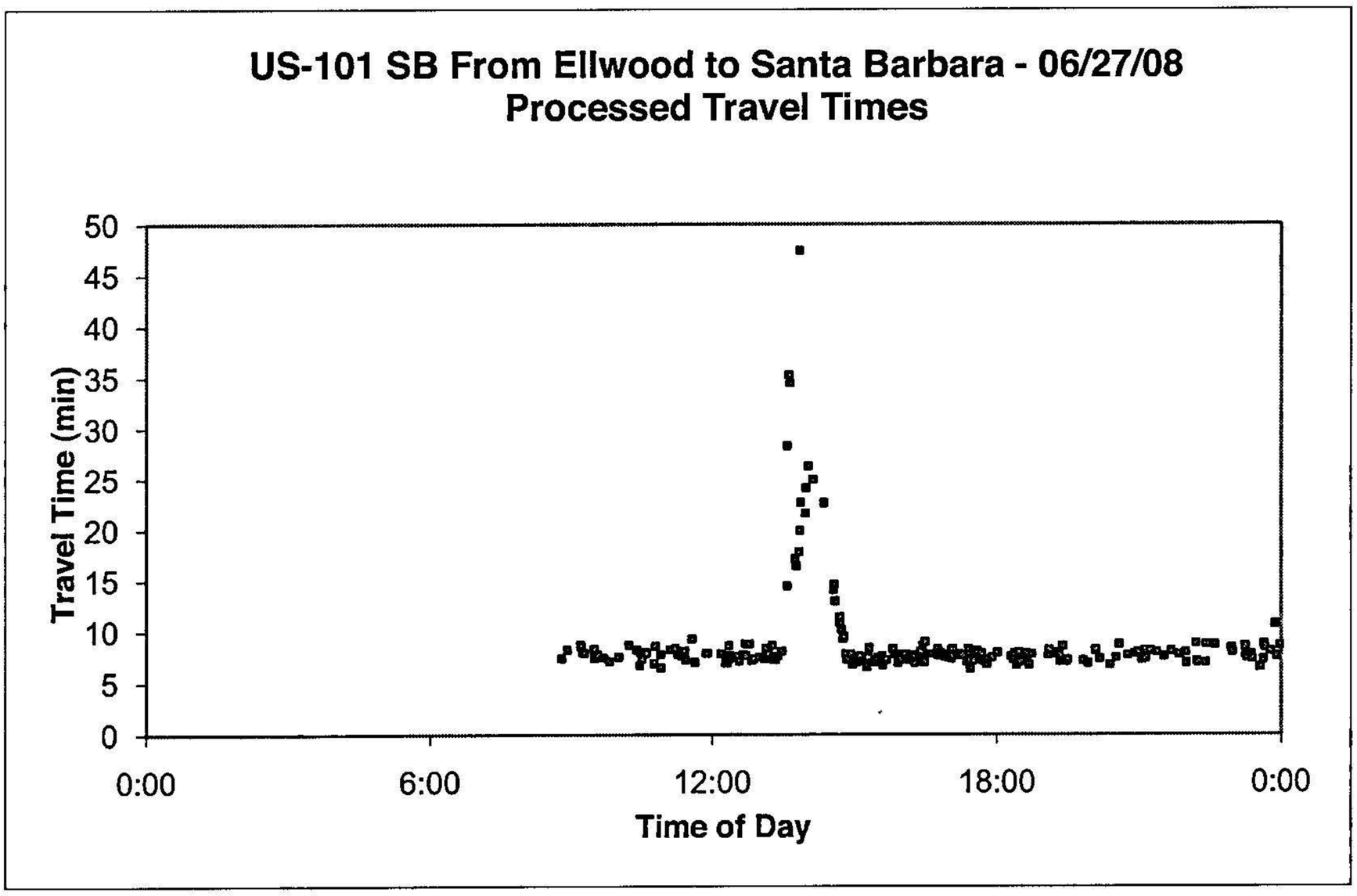

US-101 NB From Ellwood to Santa Barbara - 06/22/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

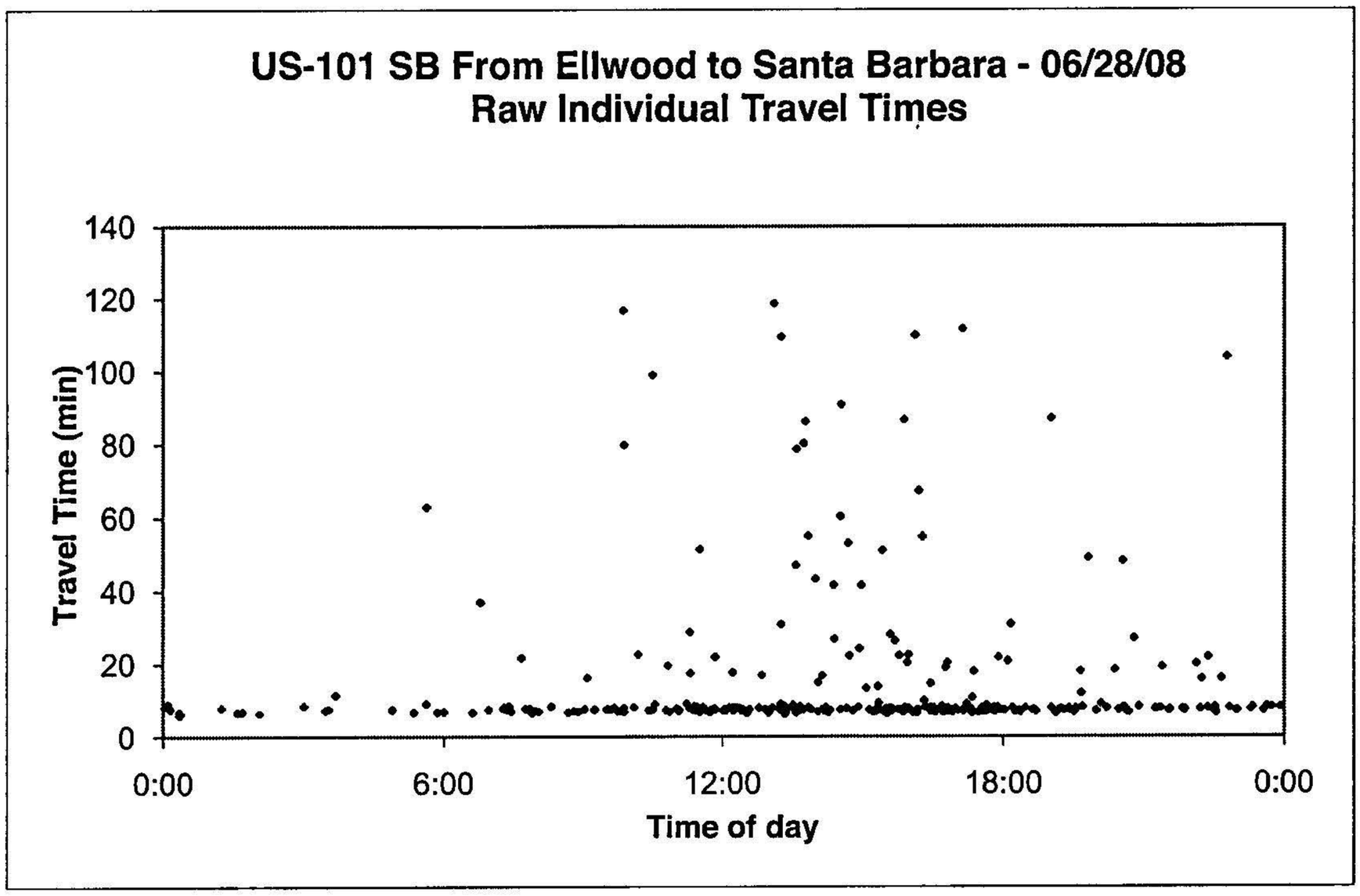

US-101 NB From Ellwood to Santa Barbara - 06/22/08
Processed Travel Times
Travel Time (min)
16
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

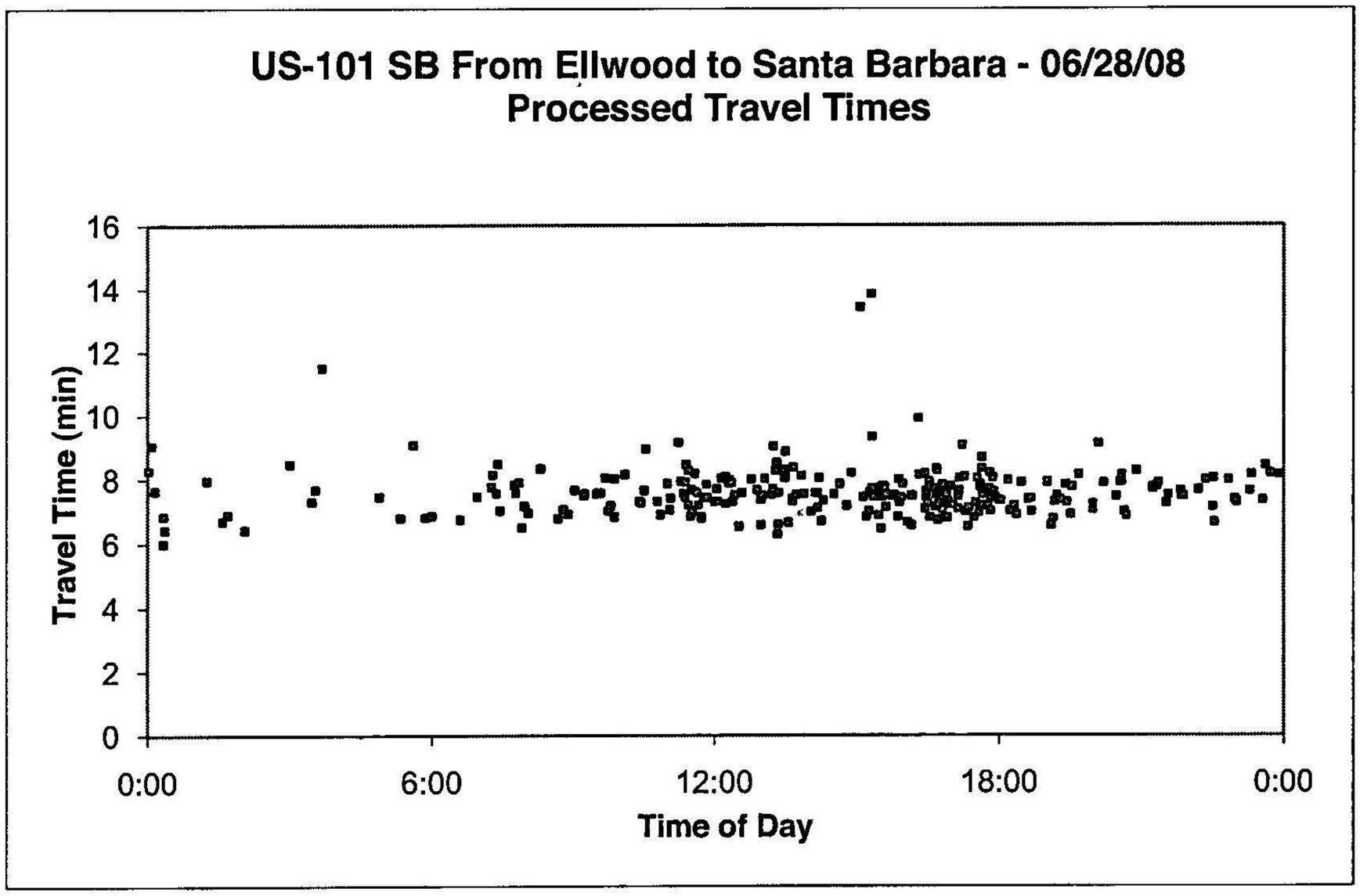

US-101 NB From Ellwood to Santa Barbara - 07/24/08
Raw Individual Travel Times
Travel Time (min)
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

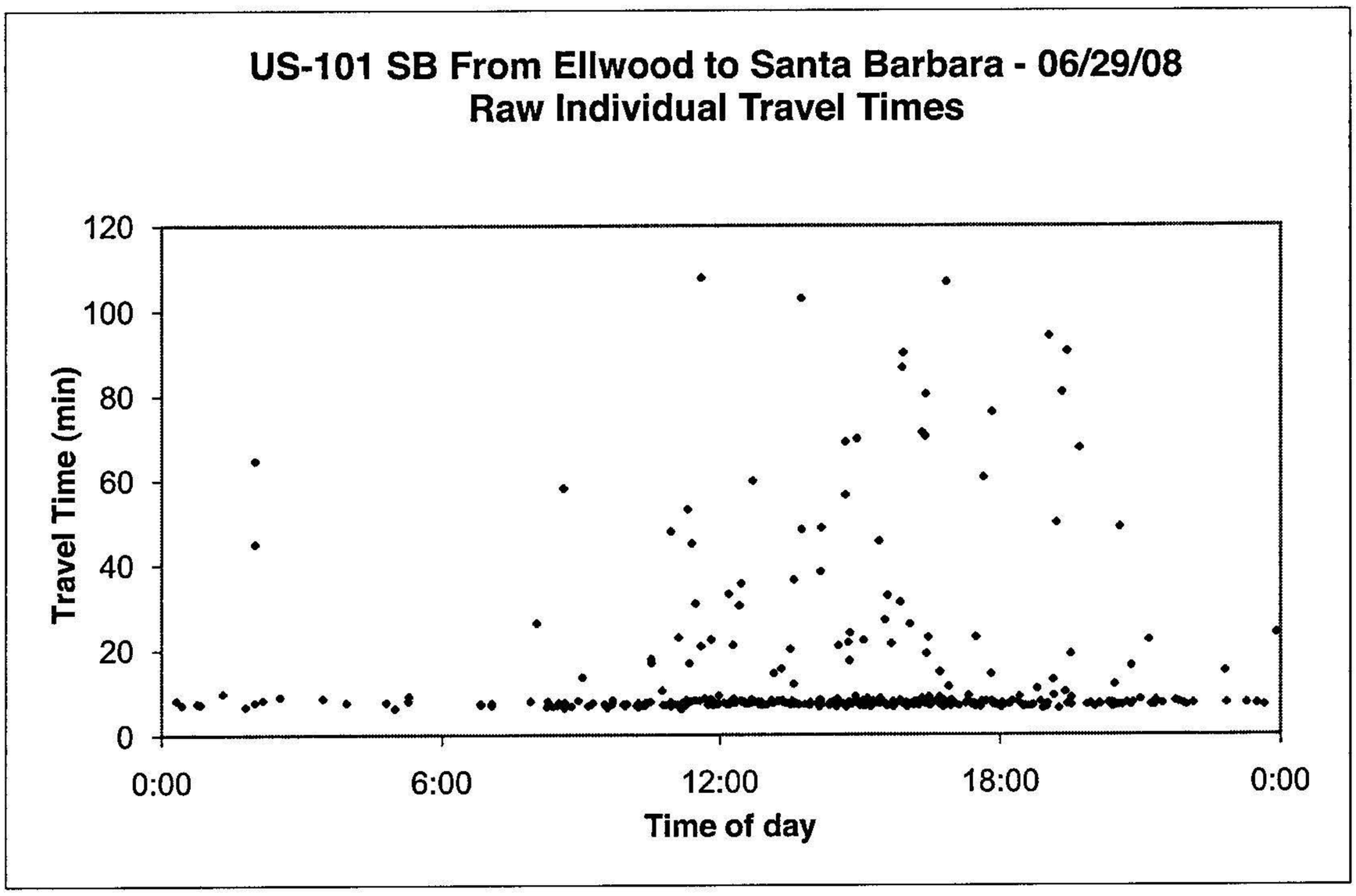

US-101 NB From Ellwood to Santa Barbara - 07/24/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

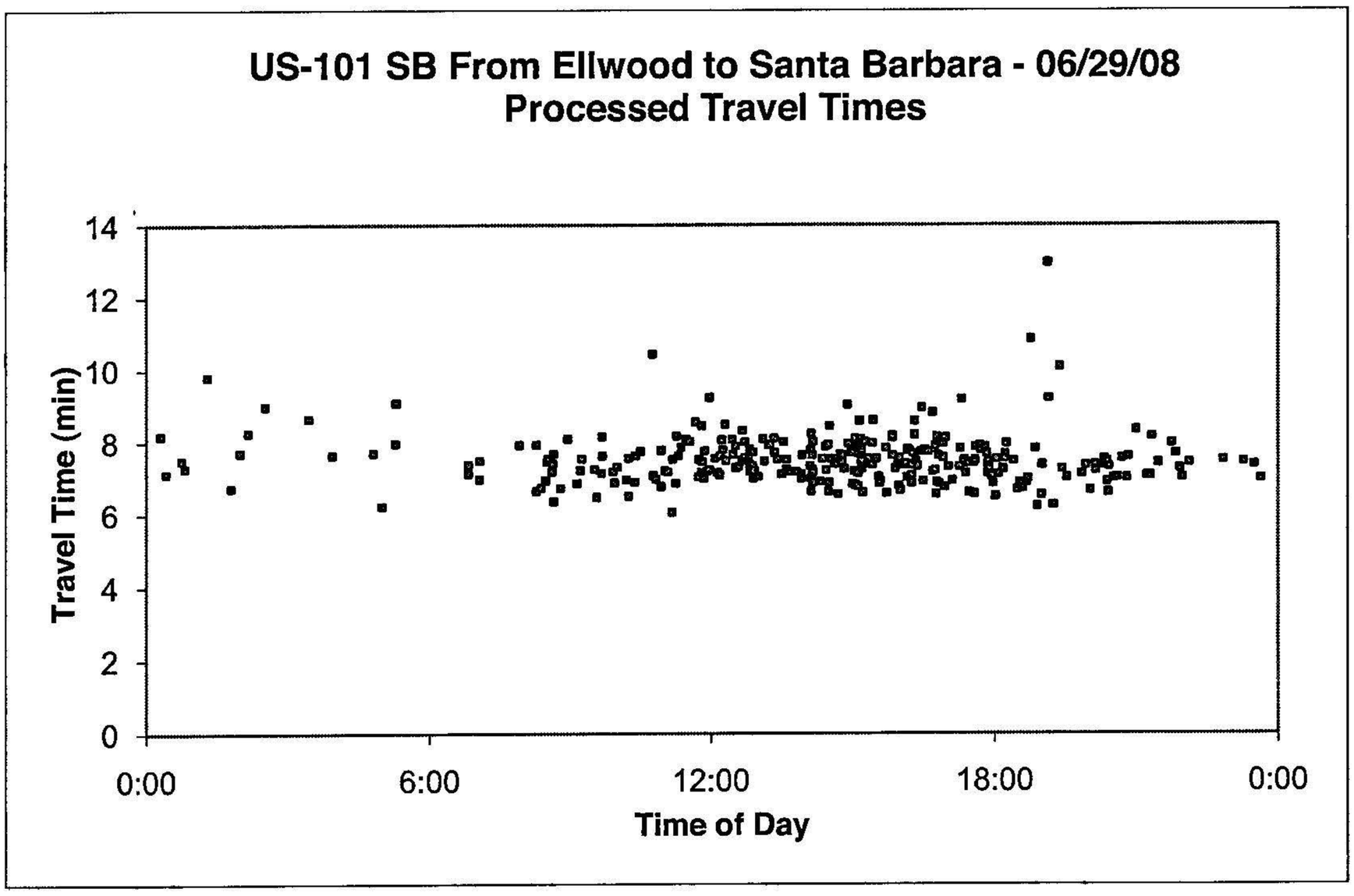

US-101 SB From Ellwood to Santa Barbara - 06/27/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

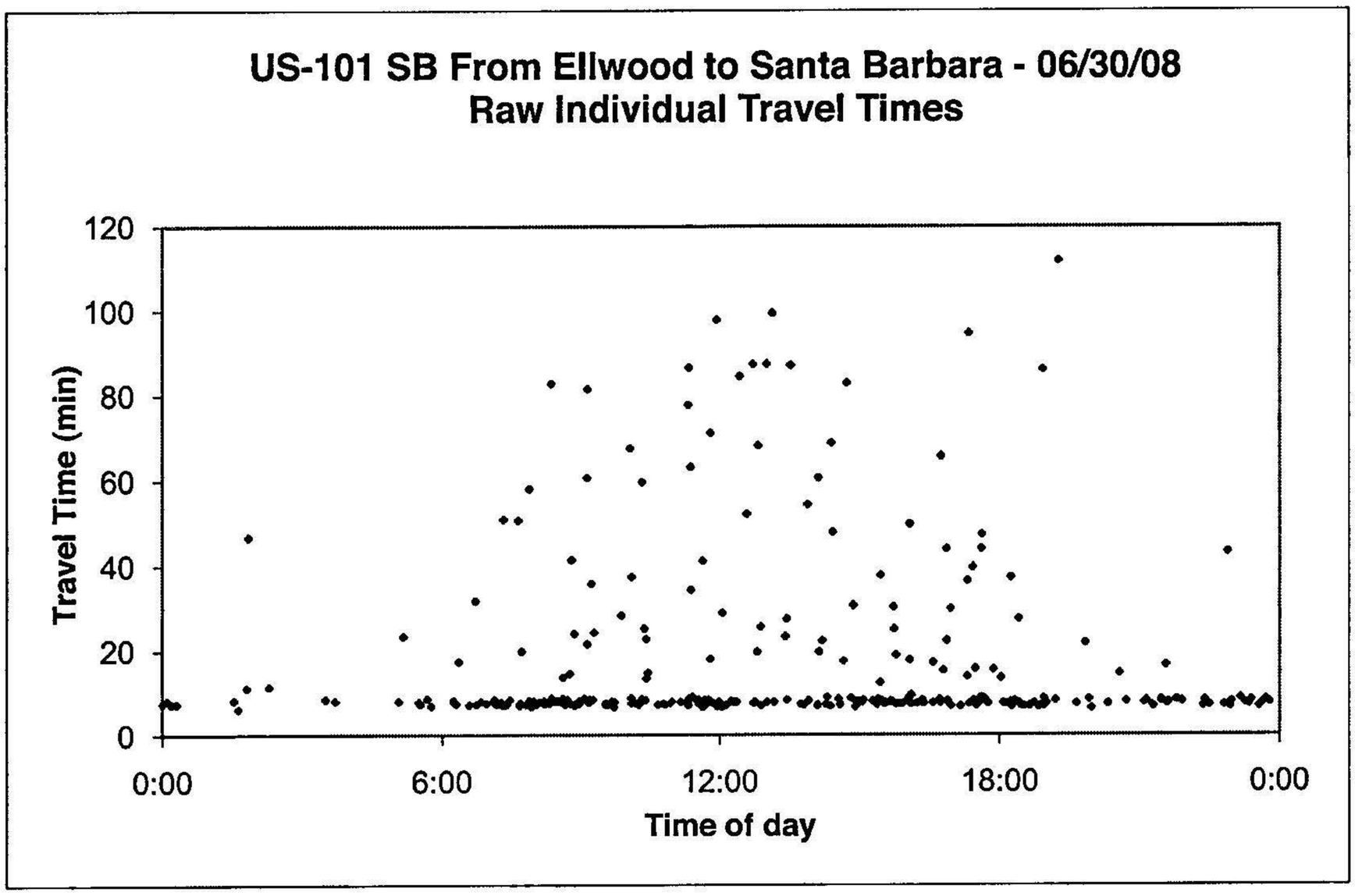

US-101 SB From Ellwood to Santa Barbara - 06/27/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

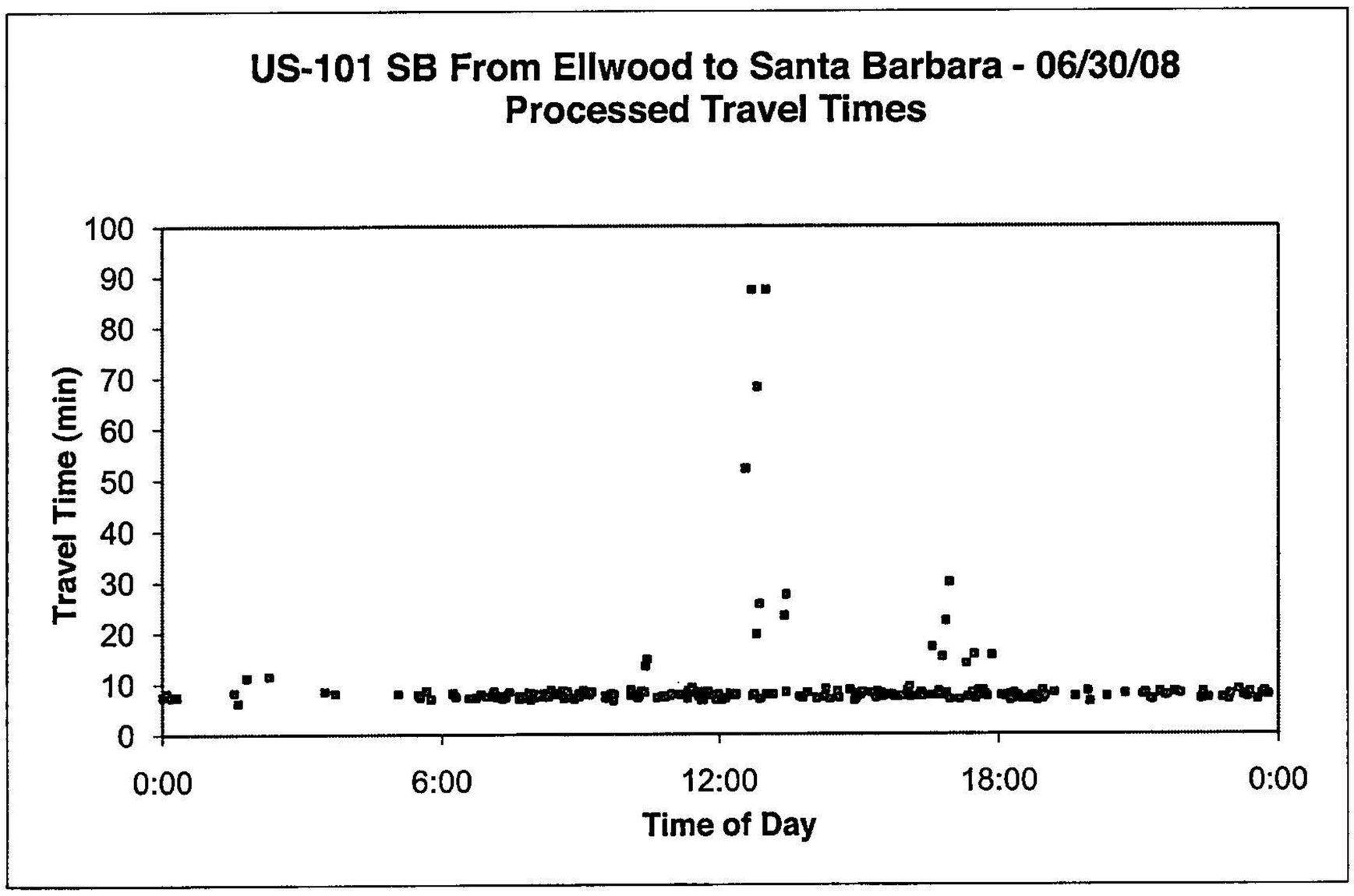

US-101 SB From Ellwood to Santa Barbara - 06/28/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

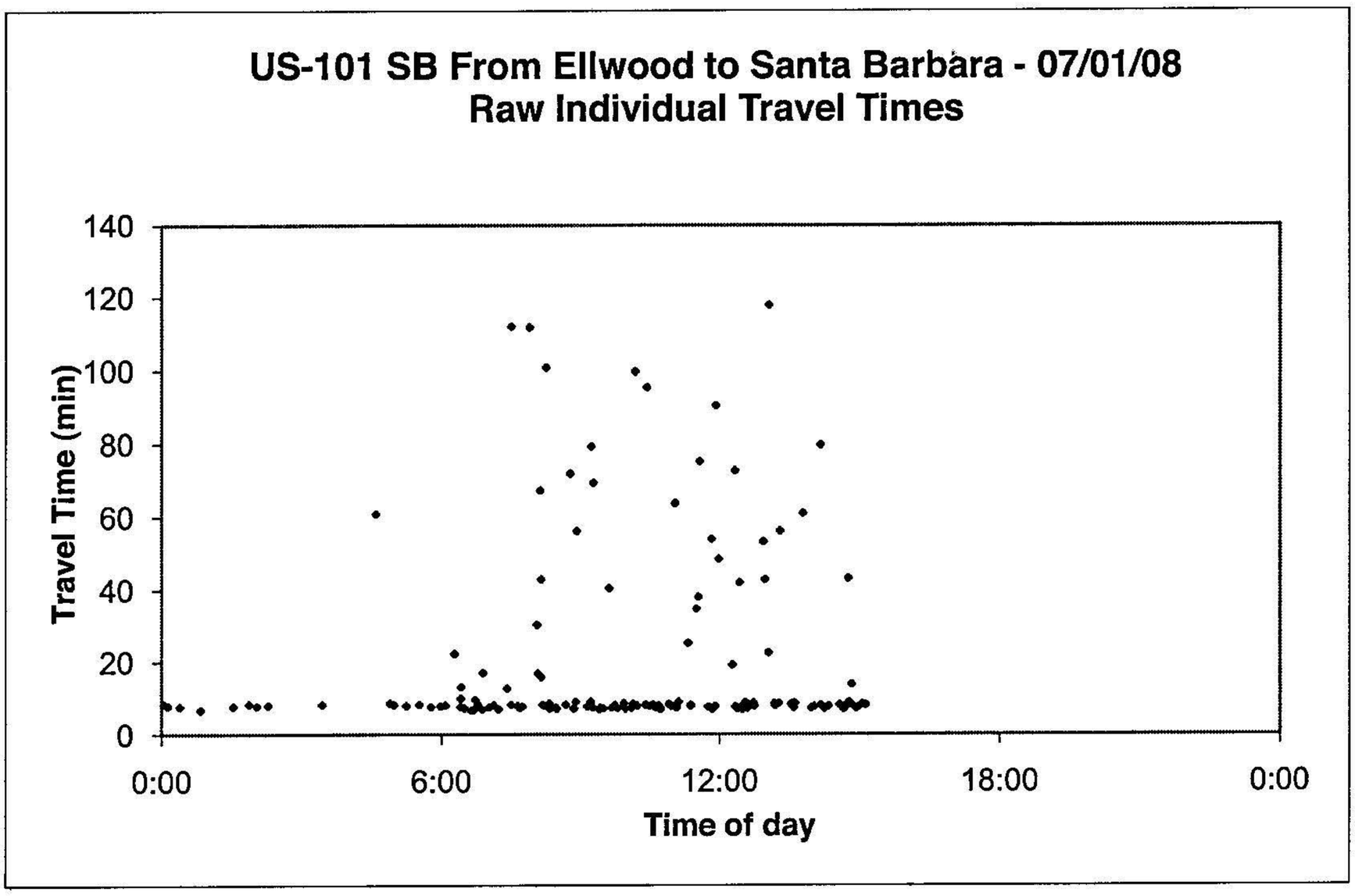

US-101 SB From Ellwood to Santa Barbara - 06/28/08
Processed Travel Times
Travel Time (min)
16
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

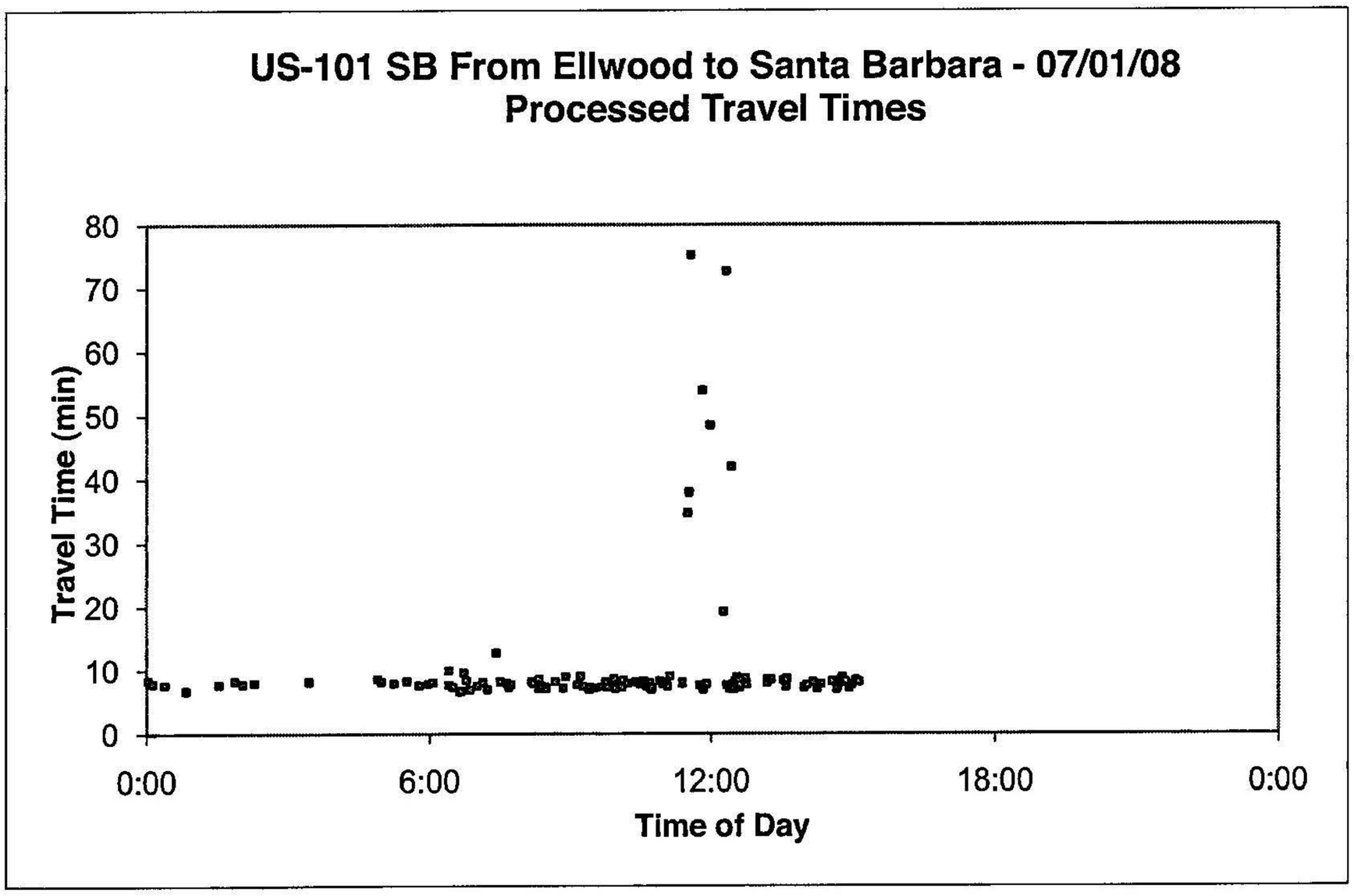

US-101 SB From Ellwood to Santa Barbara - 06/29/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

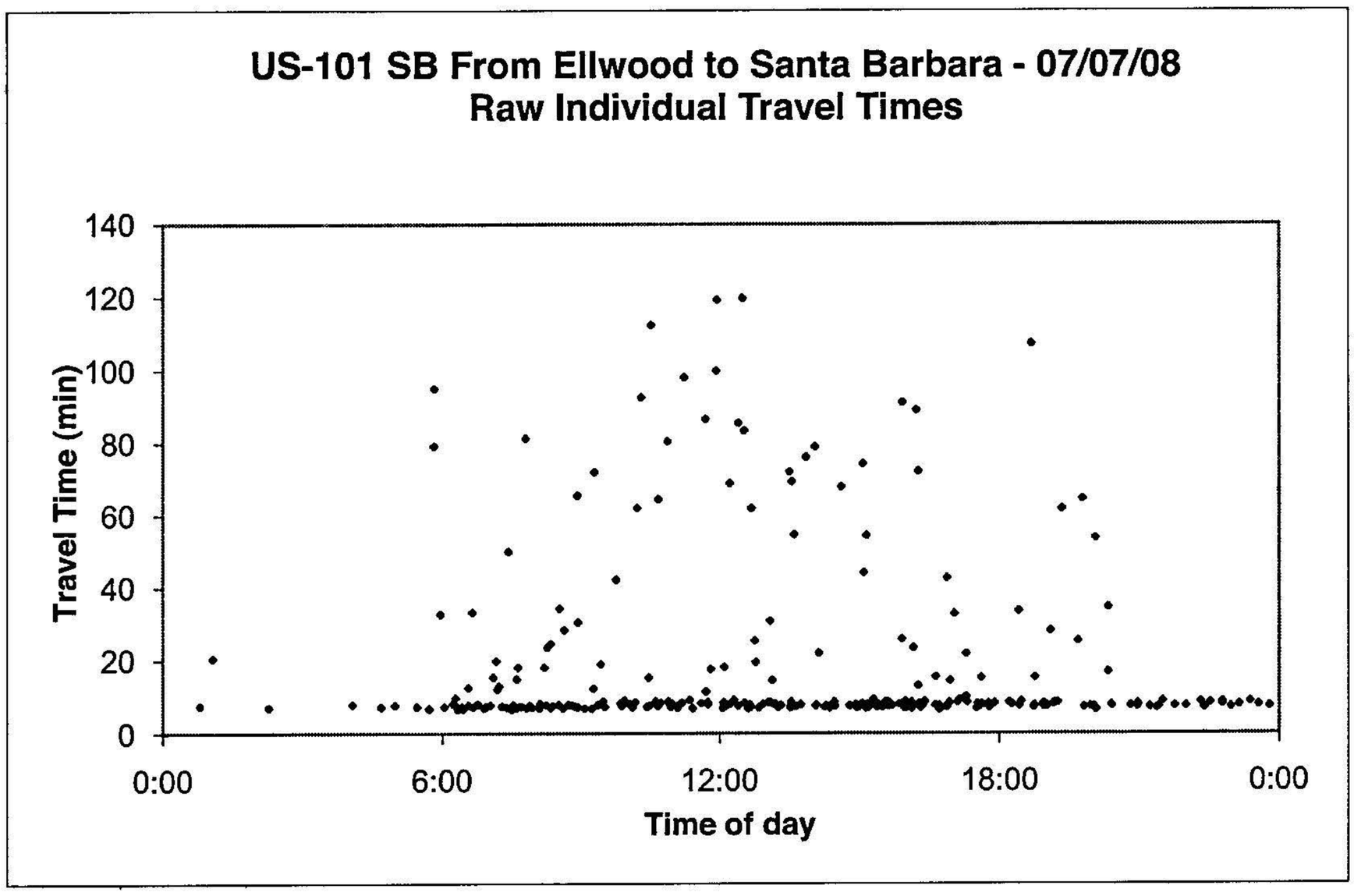

US-101 SB From Ellwood to Santa Barbara - 06/29/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

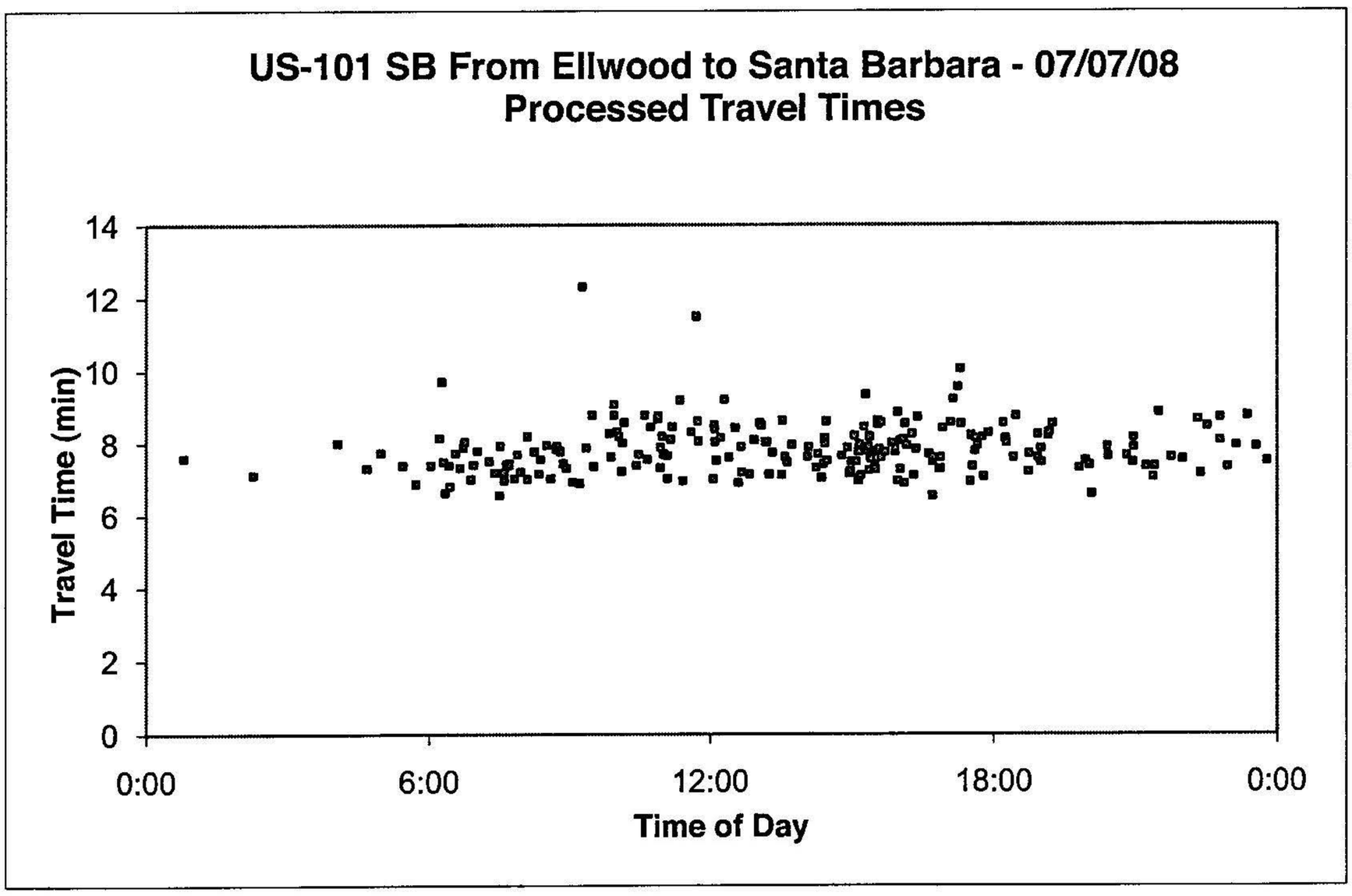

US-101 SB From Ellwood to Santa Barbara - 06/30/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

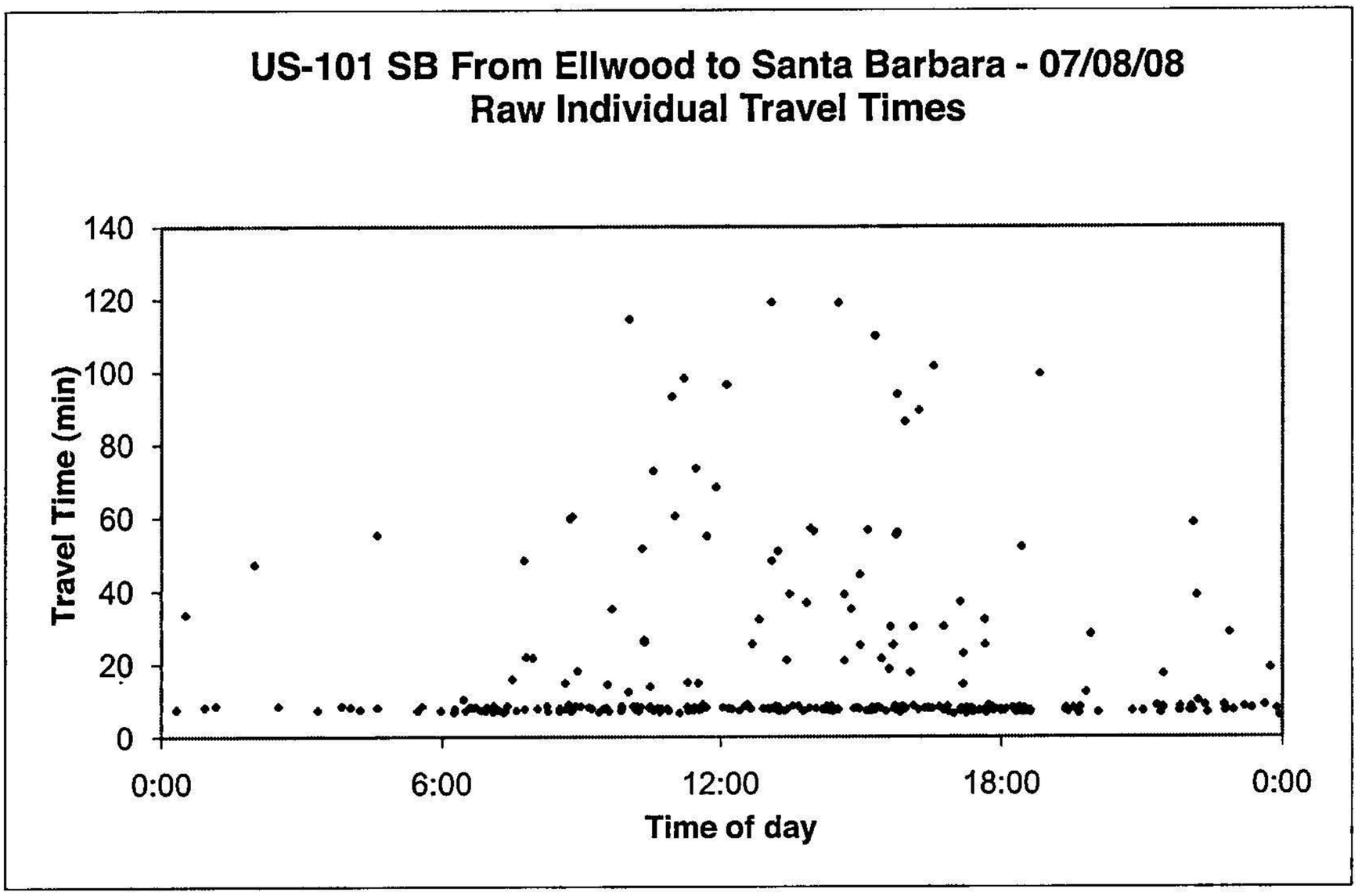

US-101 SB From Ellwood to Santa Barbara - 06/30/08
Processed Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

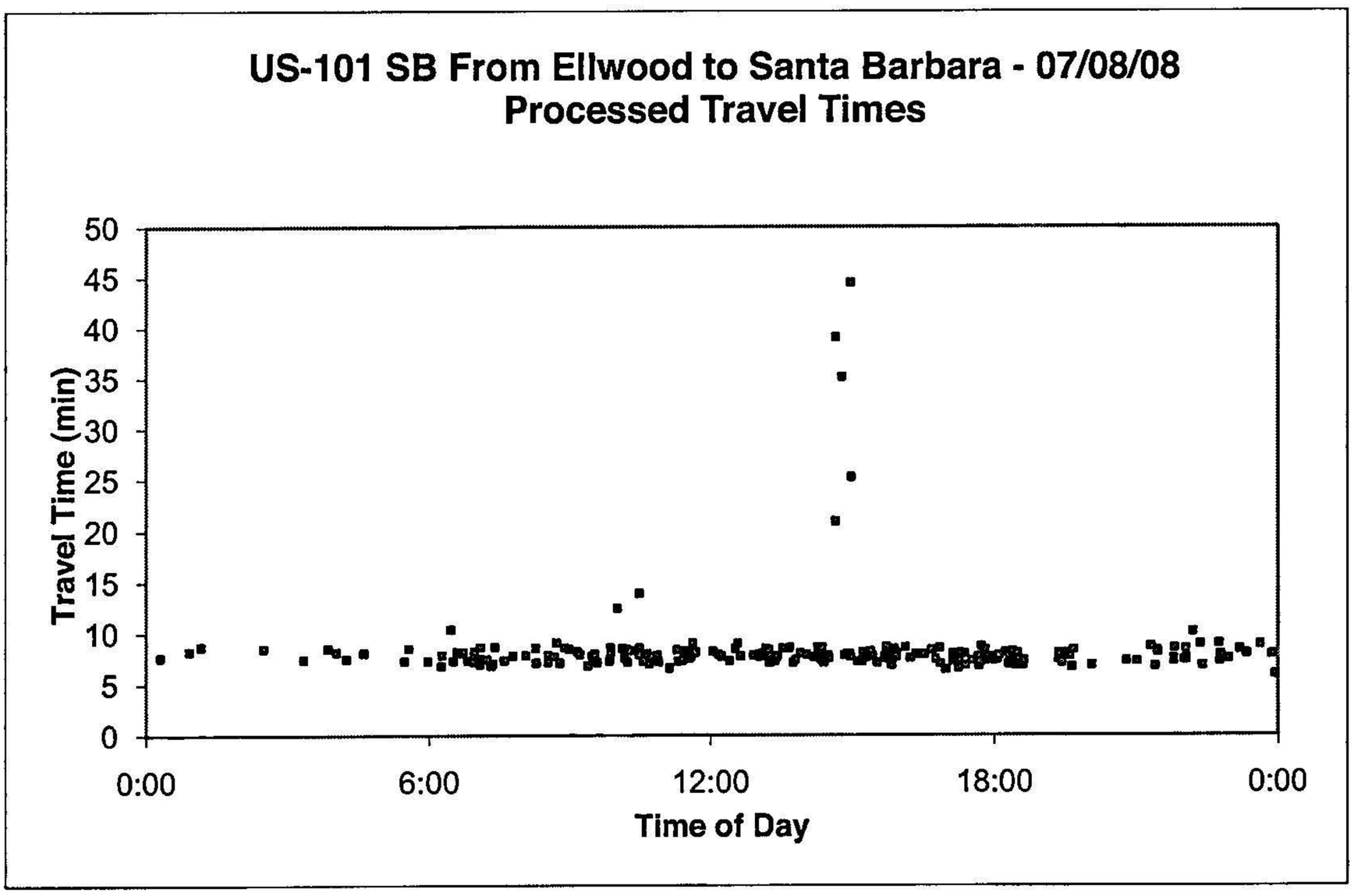

US-101 SB From Ellwood to Santa Barbara - 07/01/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

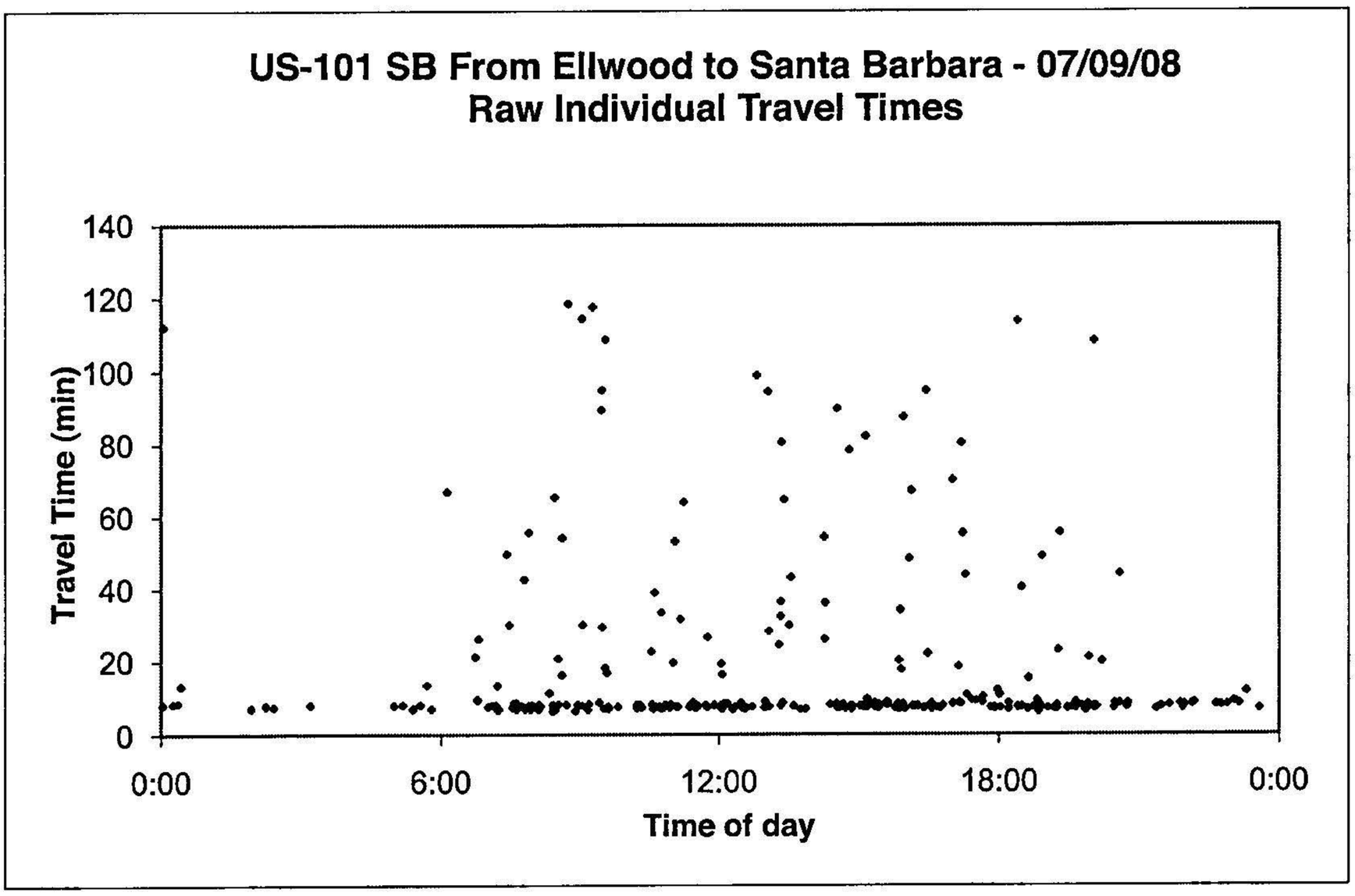

US-101 SB From Ellwood to Santa Barbara - 07/01/08
Processed Travel Times
Travel Time (min)
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of Day

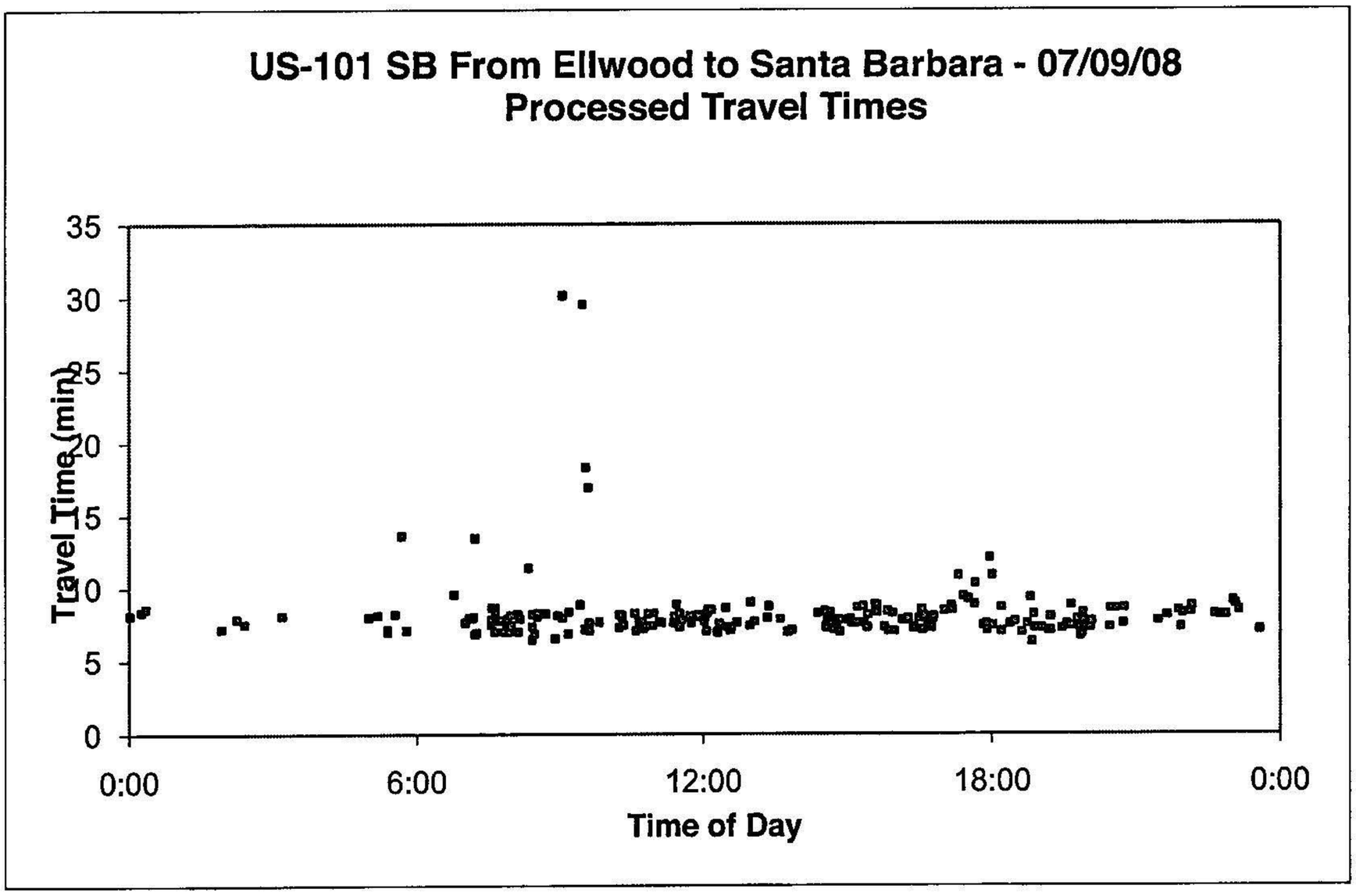

US-101 SB From Ellwood to Santa Barbara - 07/07/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

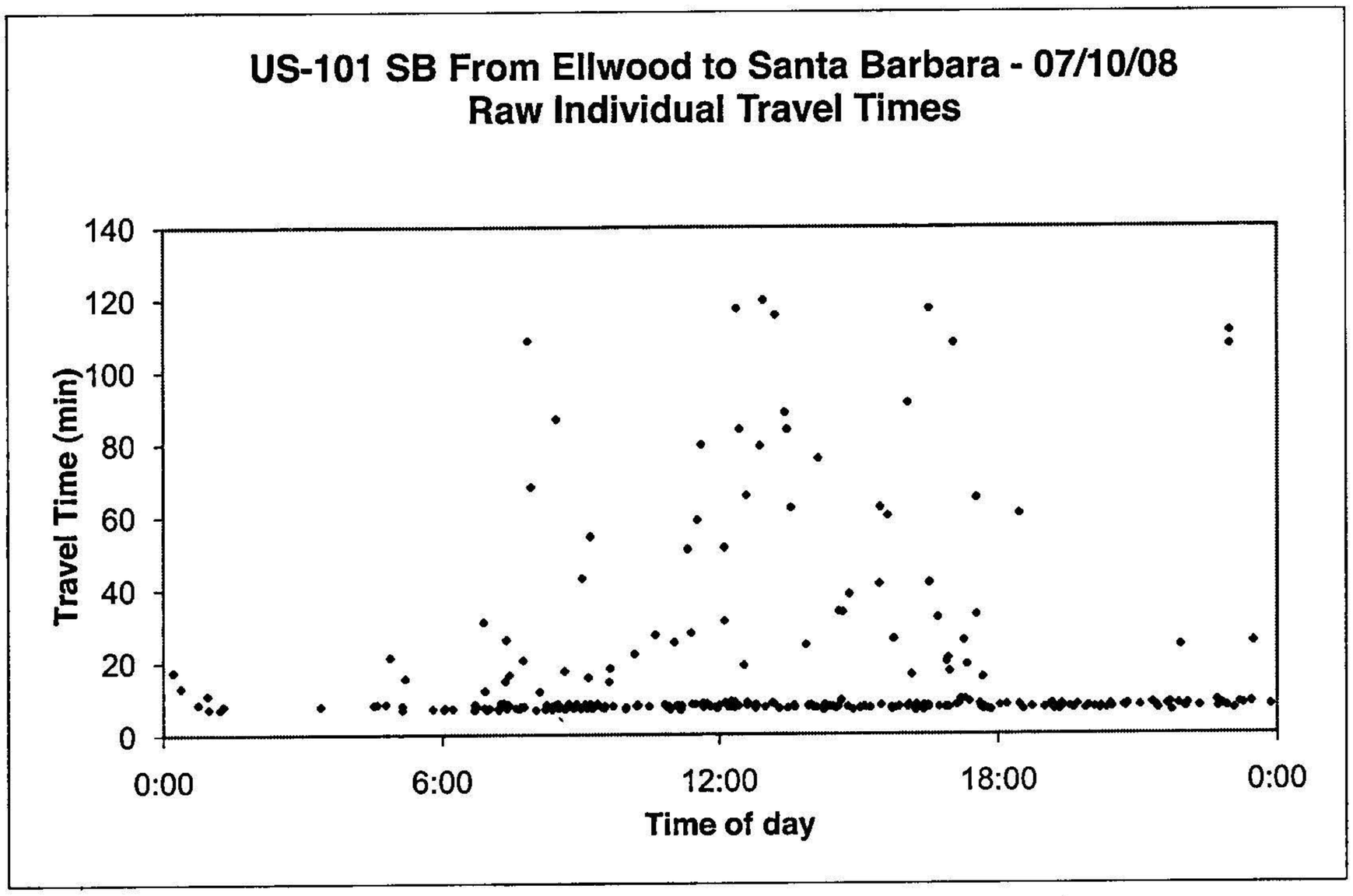

US-101 SB From Ellwood to Santa Barbara - 07/07/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

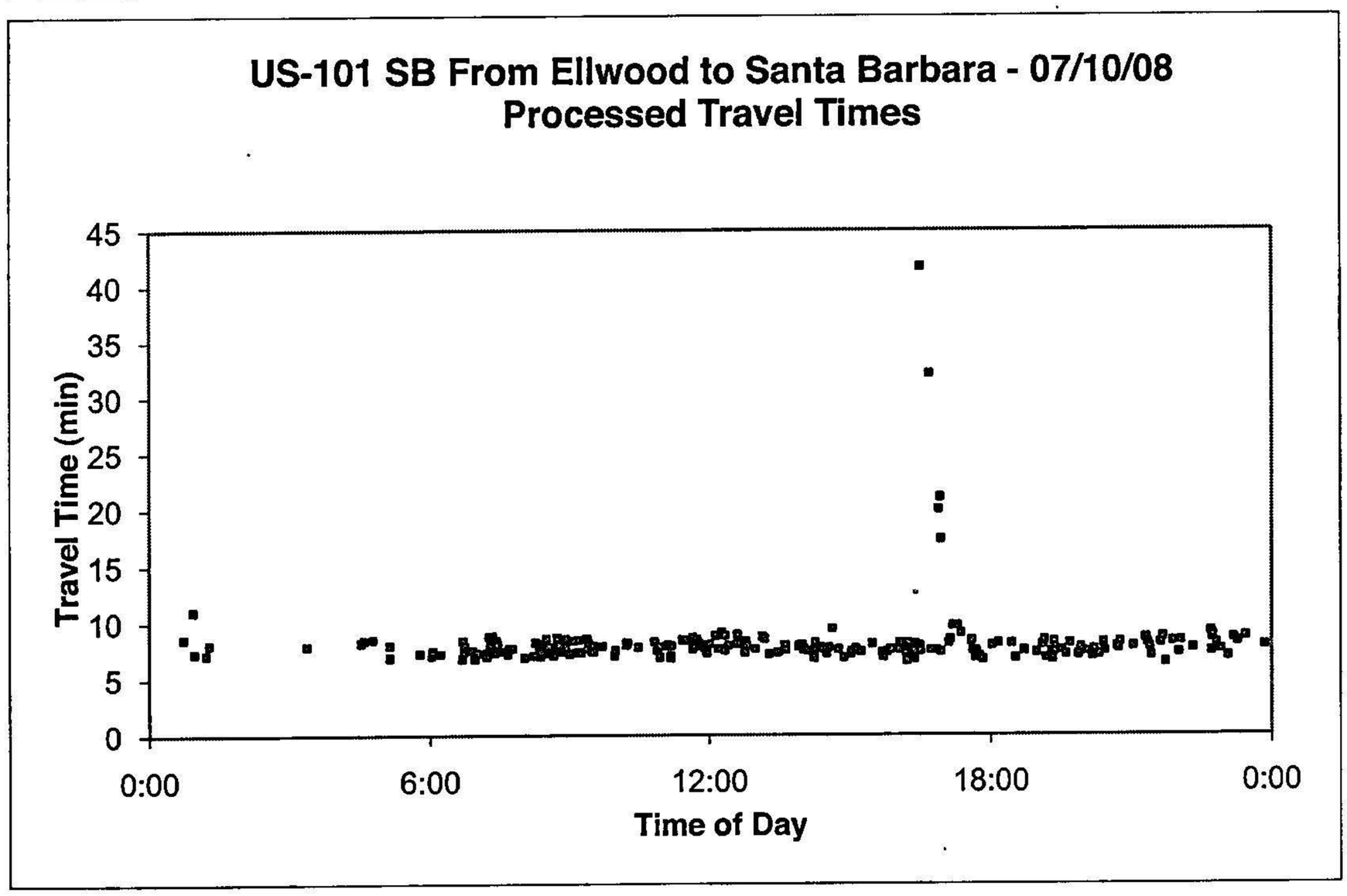

US-101 SB From Ellwood to Santa Barbara - 07/08/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

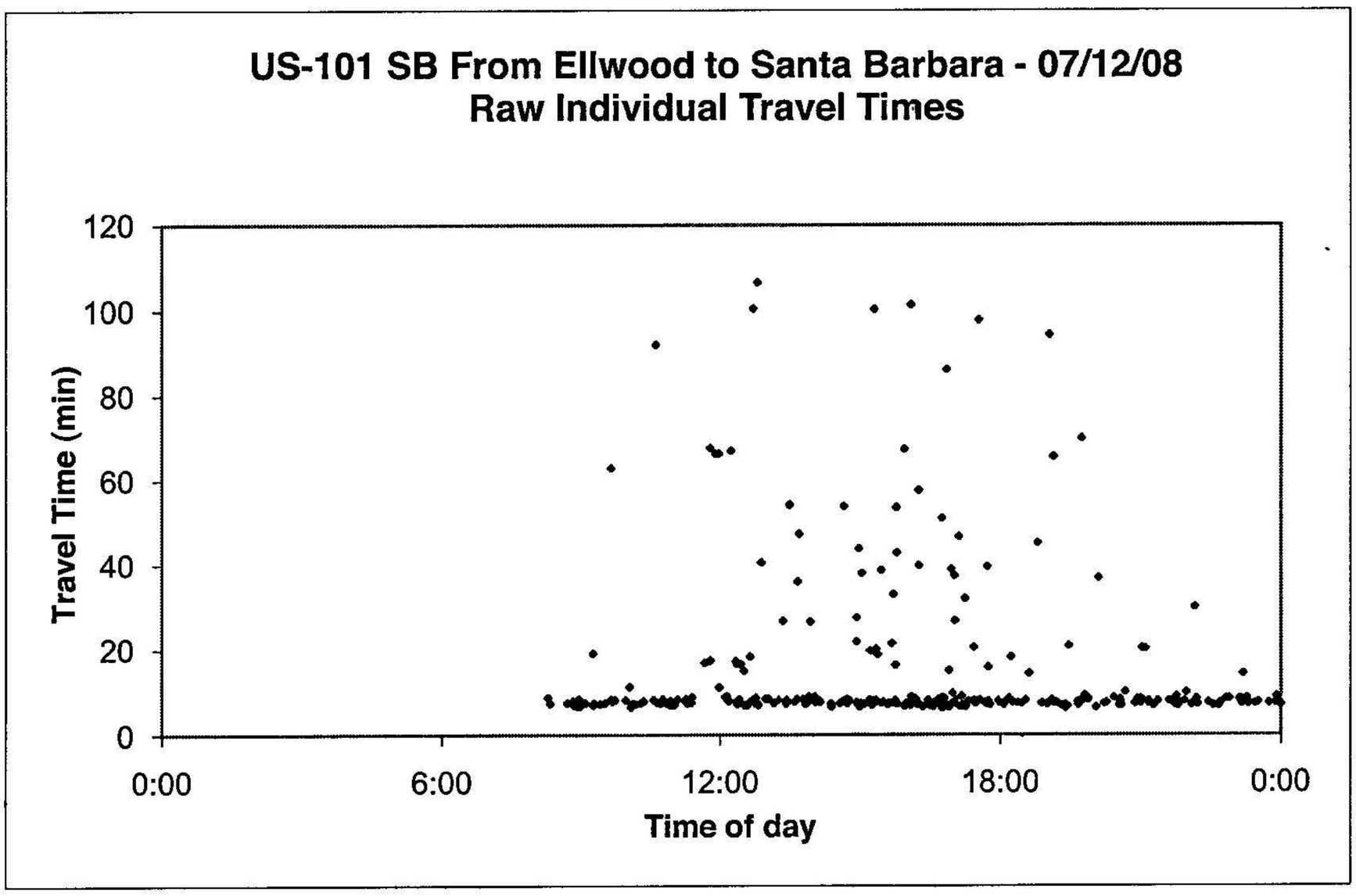

US-101 SB From Ellwood to Santa Barbara - 07/08/08
Processed Travel Times
Travel Time (min)
50
45
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

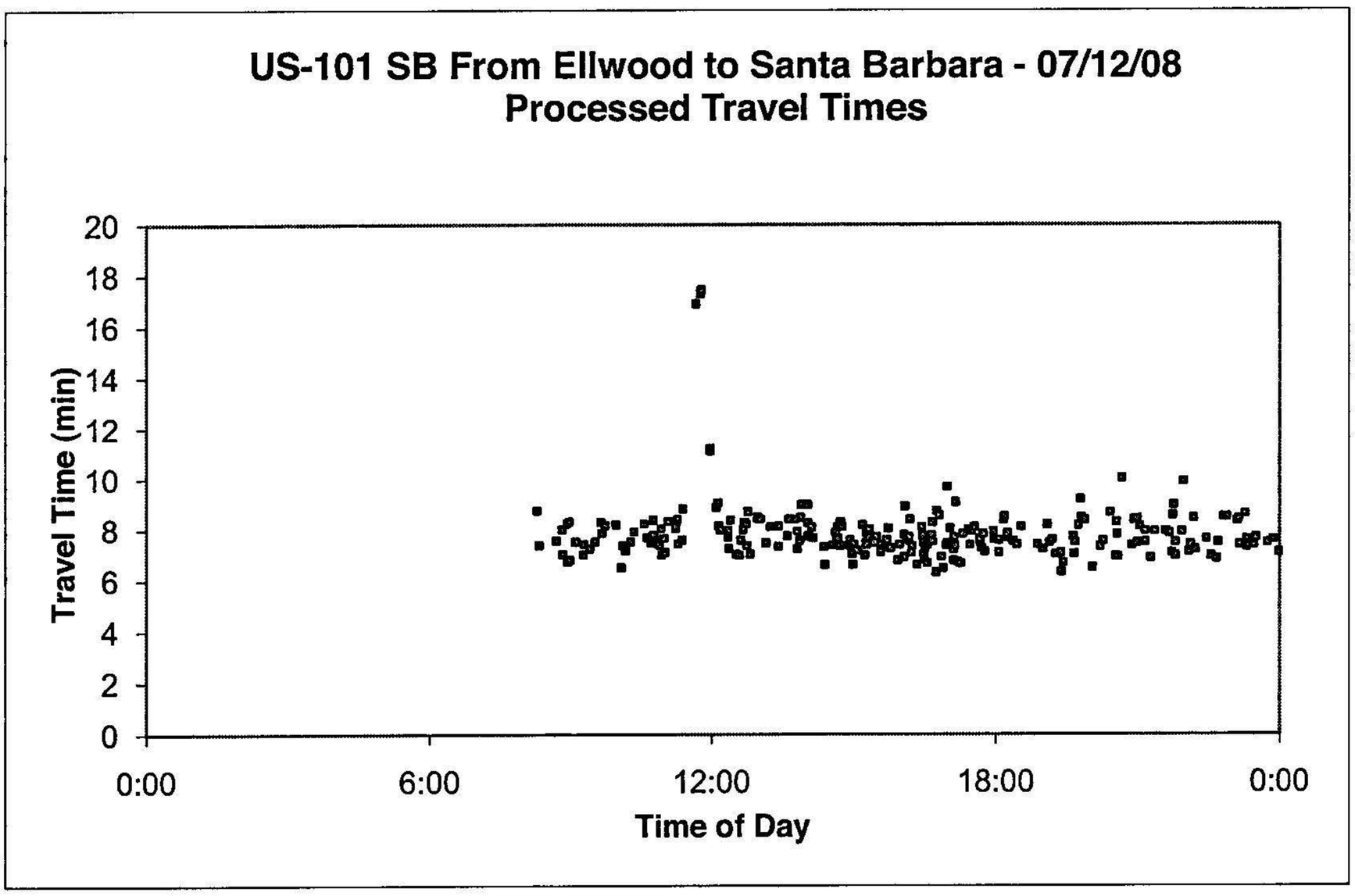

US-101 SB From Ellwood to Santa Barbara - 07/09/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

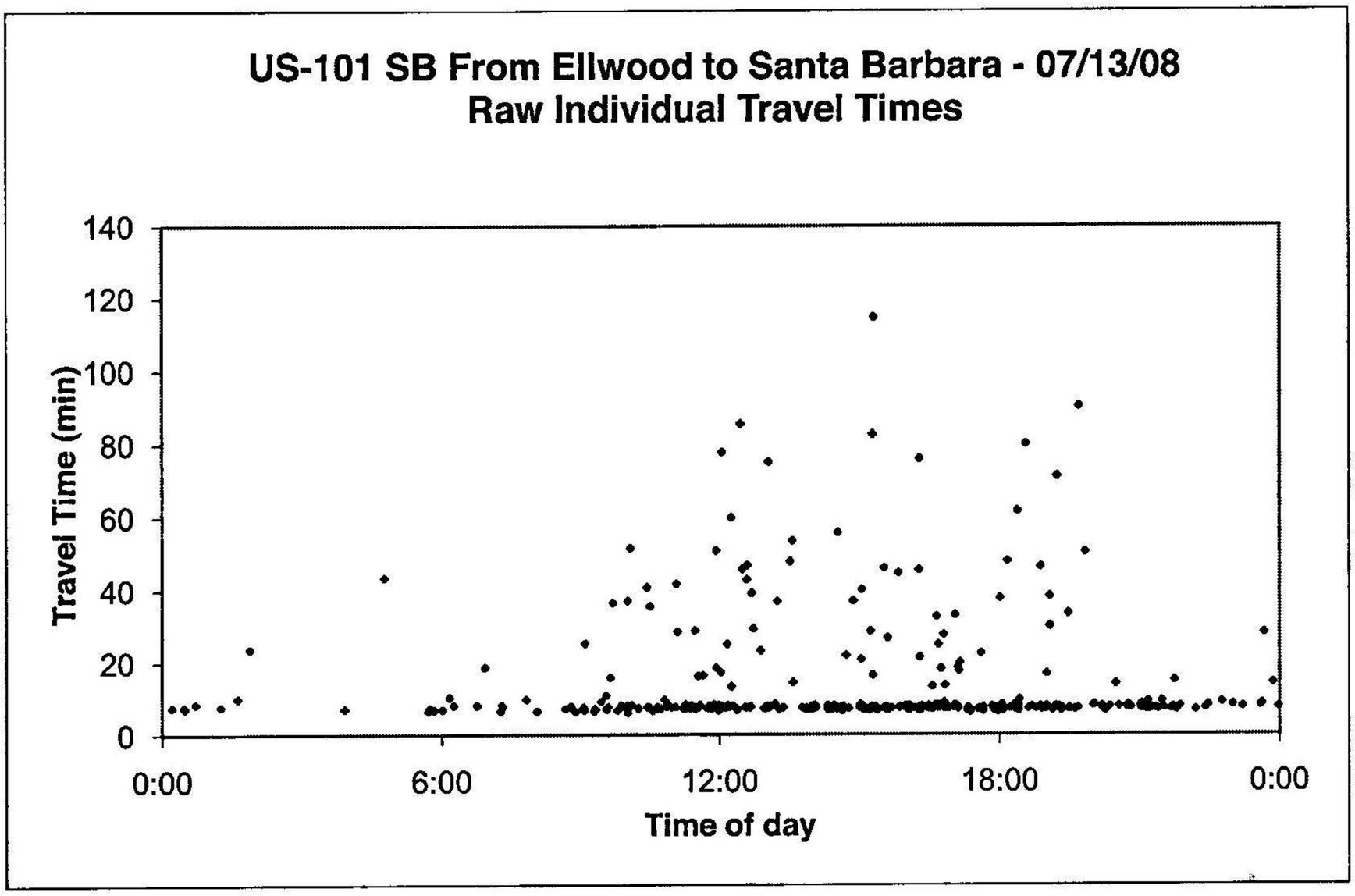

US-101 SB From Ellwood to Santa Barbara - 07/09/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

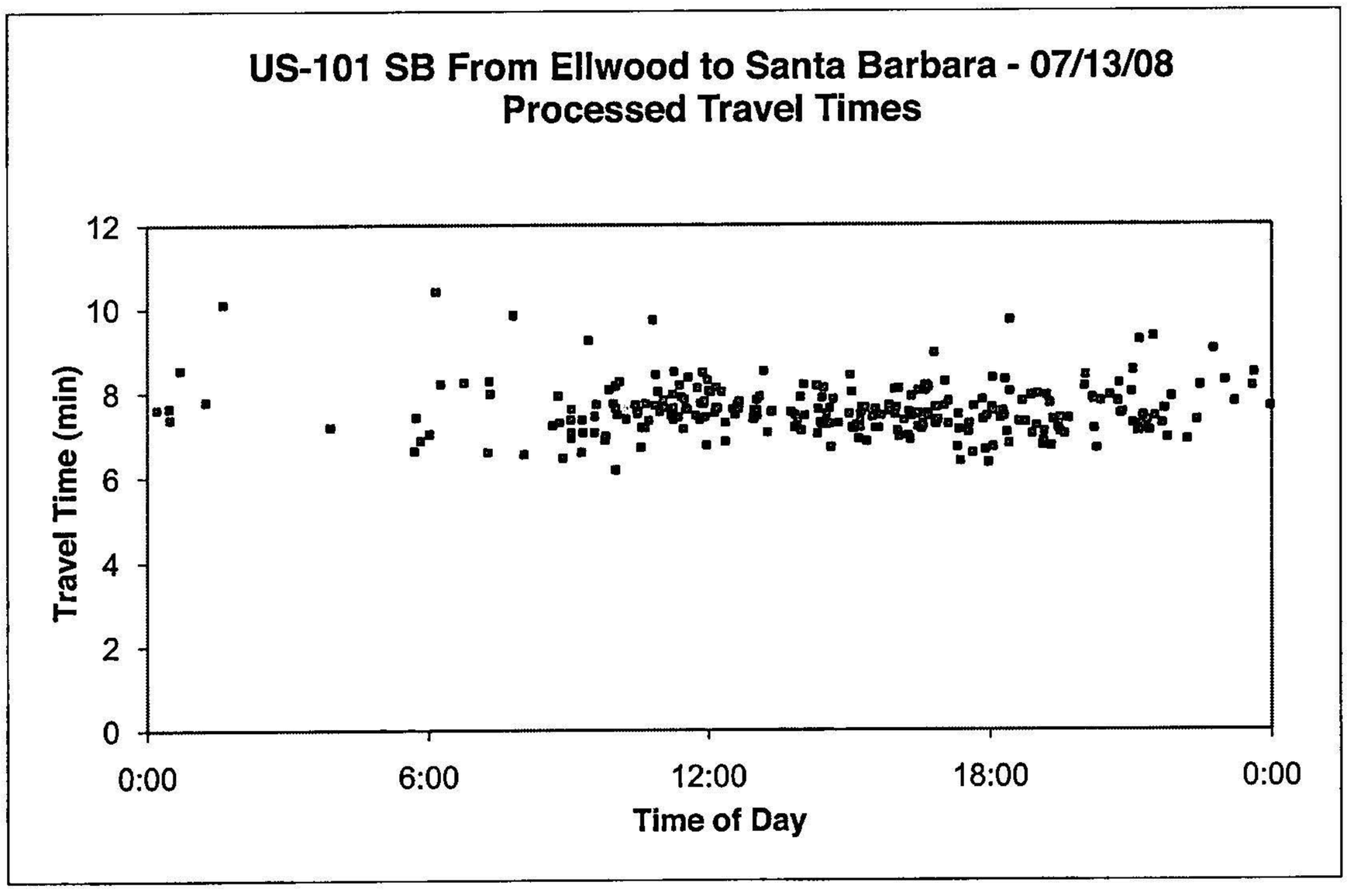

US-101 SB From Ellwood to Santa Barbara - 07/10/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

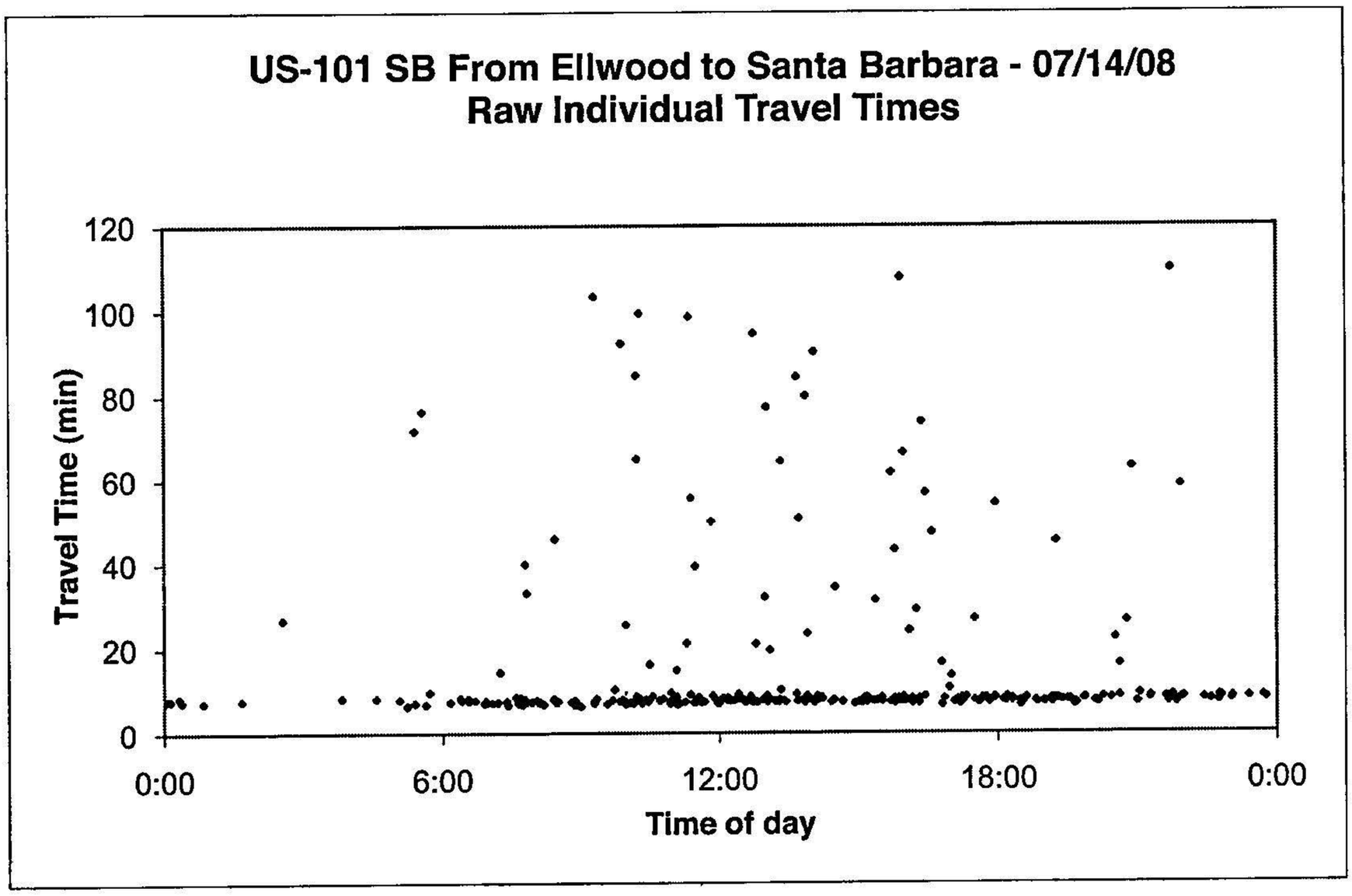

US-101 SB From Ellwood to Santa Barbara - 07/10/08
Processed Travel Times
Travel Time (min)
45
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

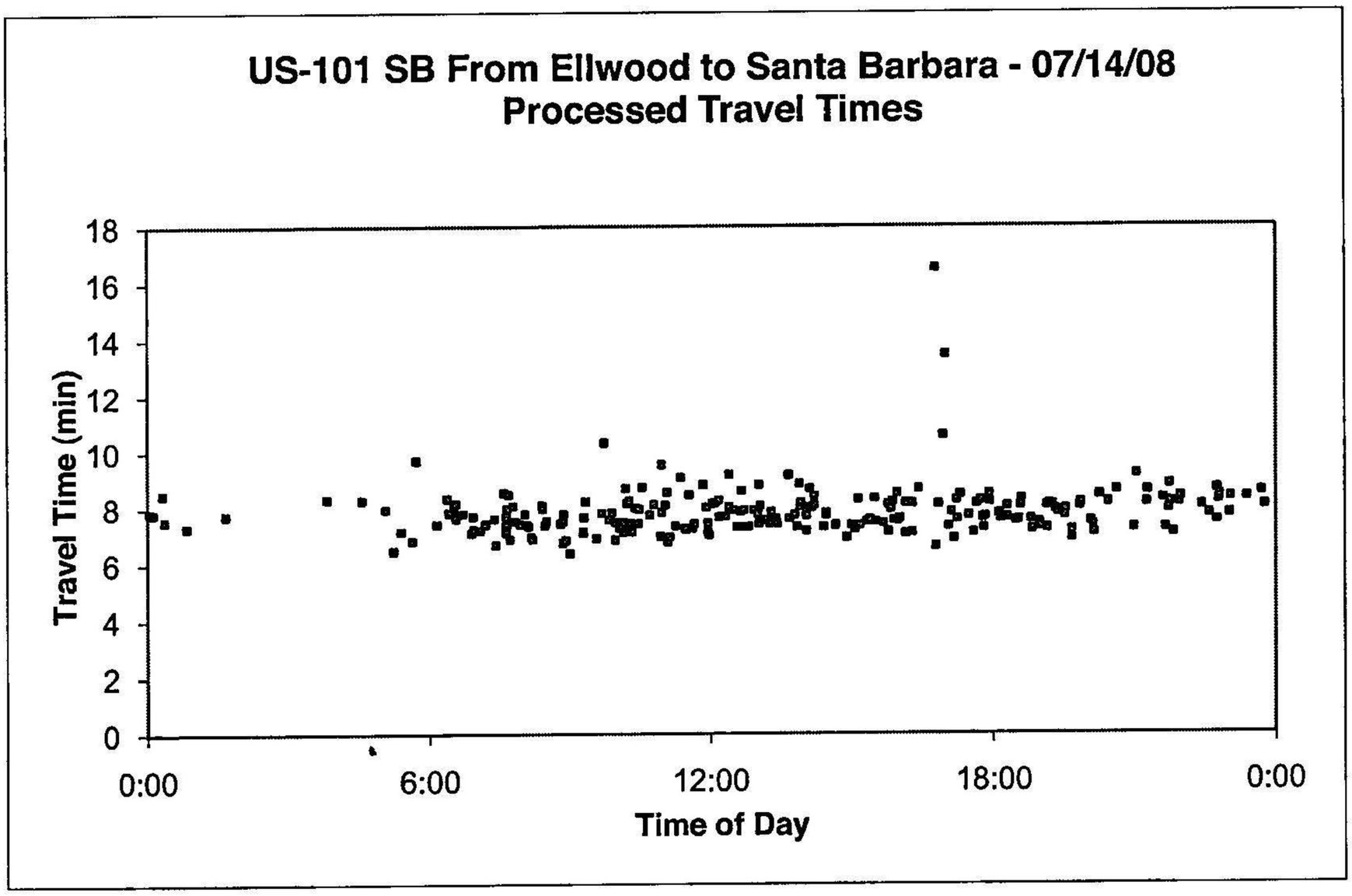

US-101 SB From Ellwood to Santa Barbara - 07/12/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

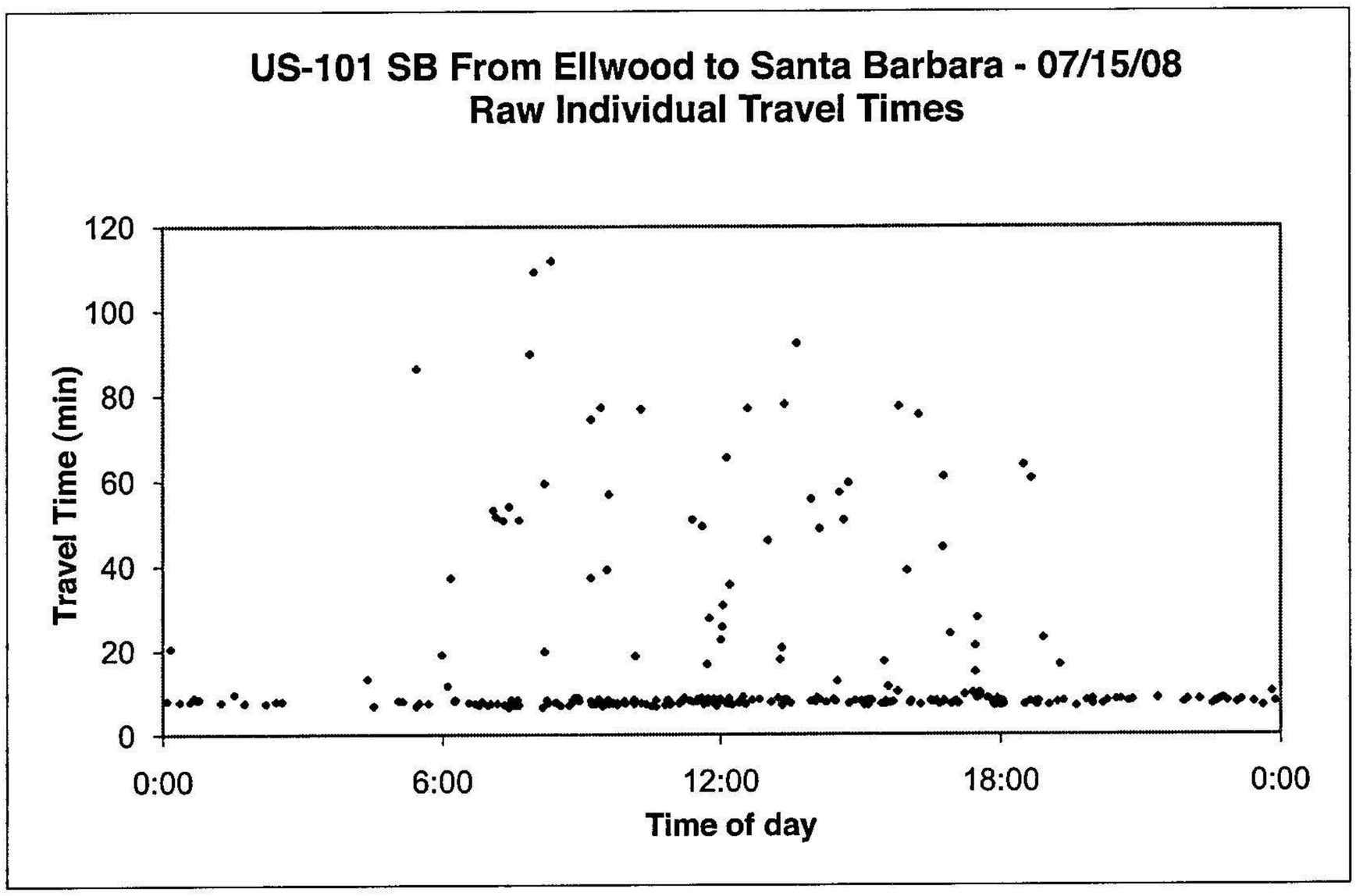

US-101 SB From Ellwood to Santa Barbara - 07/12/08
Processed Travel Times
Travel Time (min)
20
18
16
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

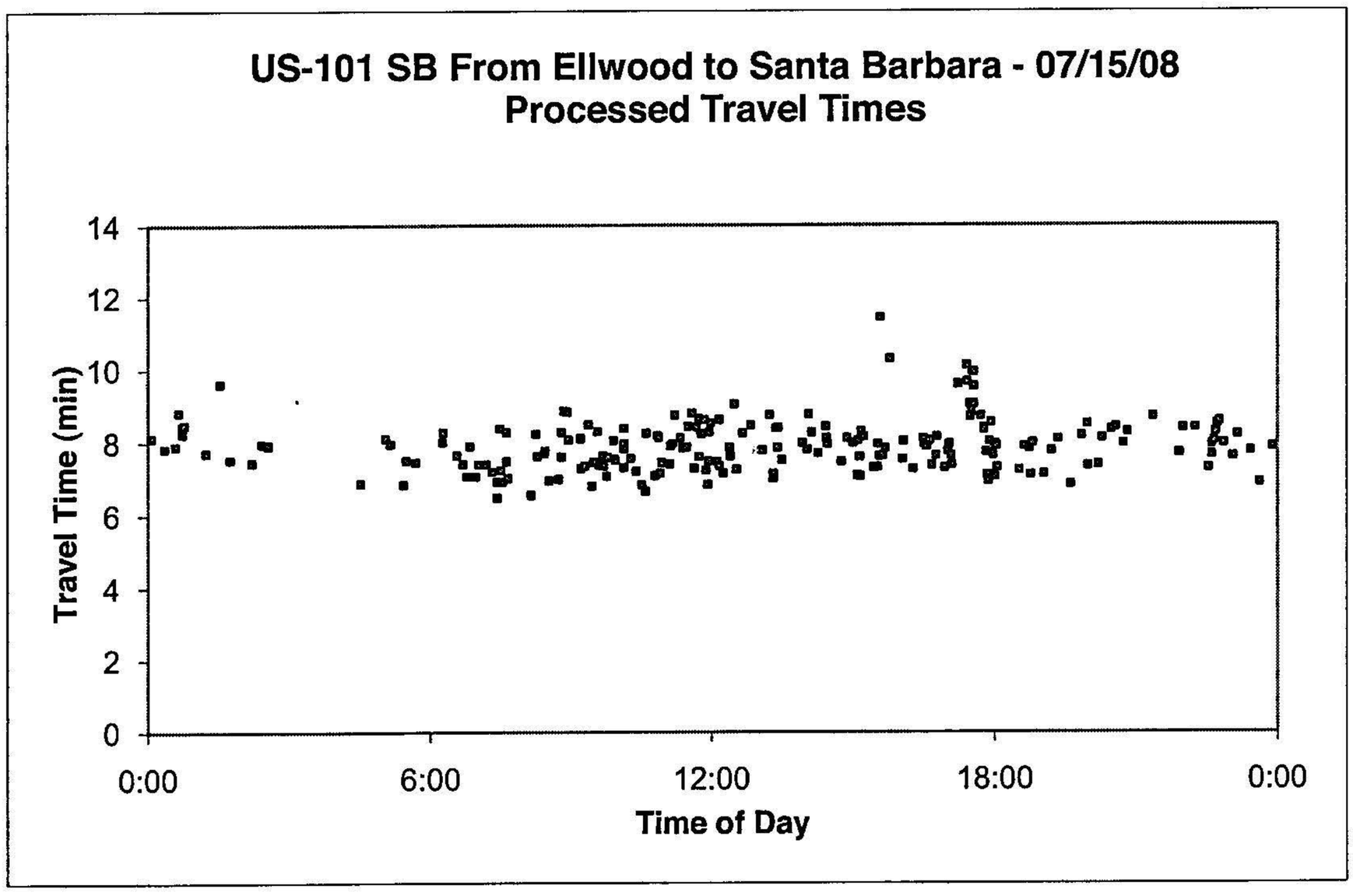

US-101 SB From Ellwood to Santa Barbara - 07/13/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

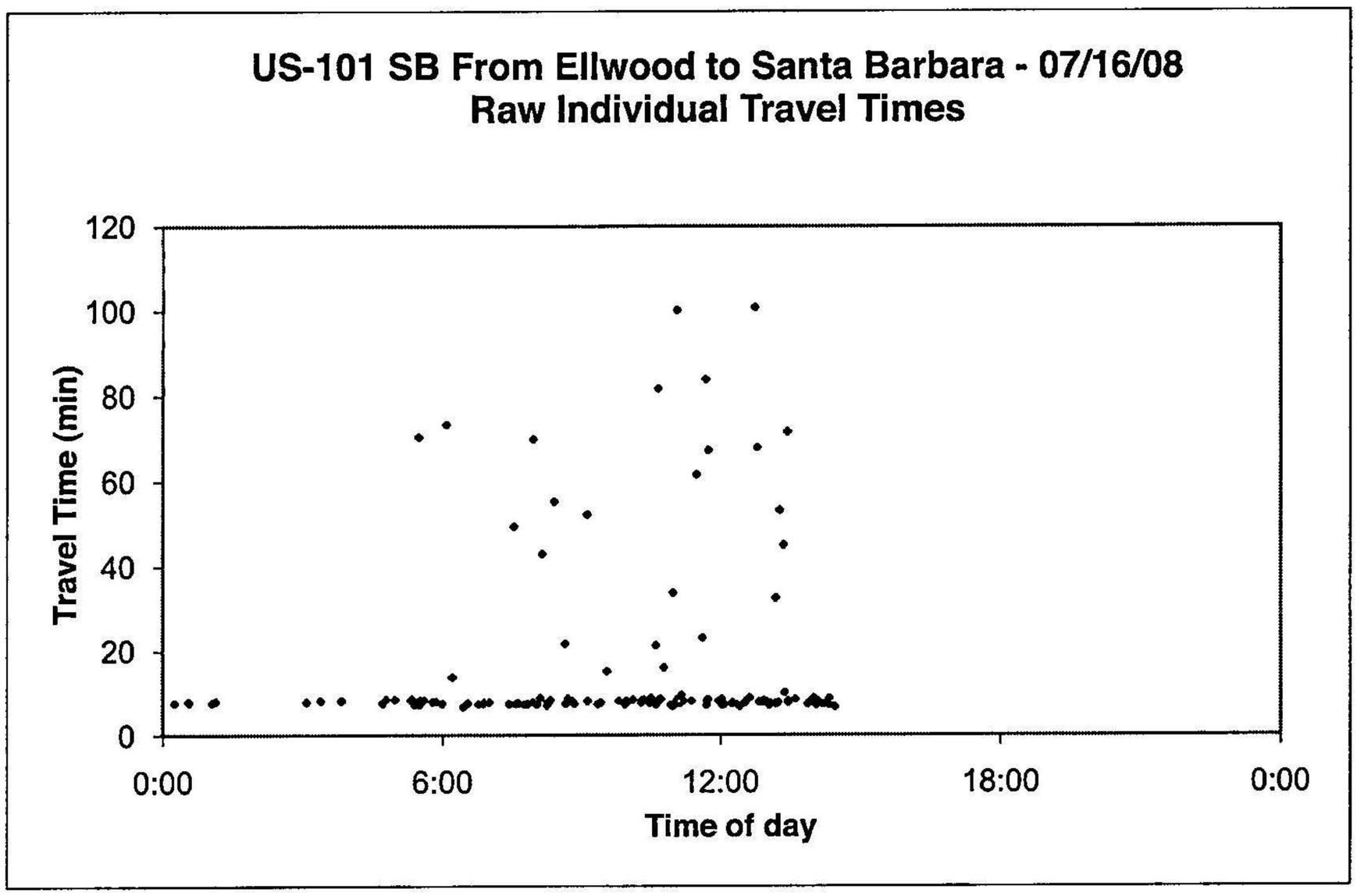

US-101 SB From Ellwood to Santa Barbara - 07/13/08
Processed Travel Times
Travel Time (min)
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

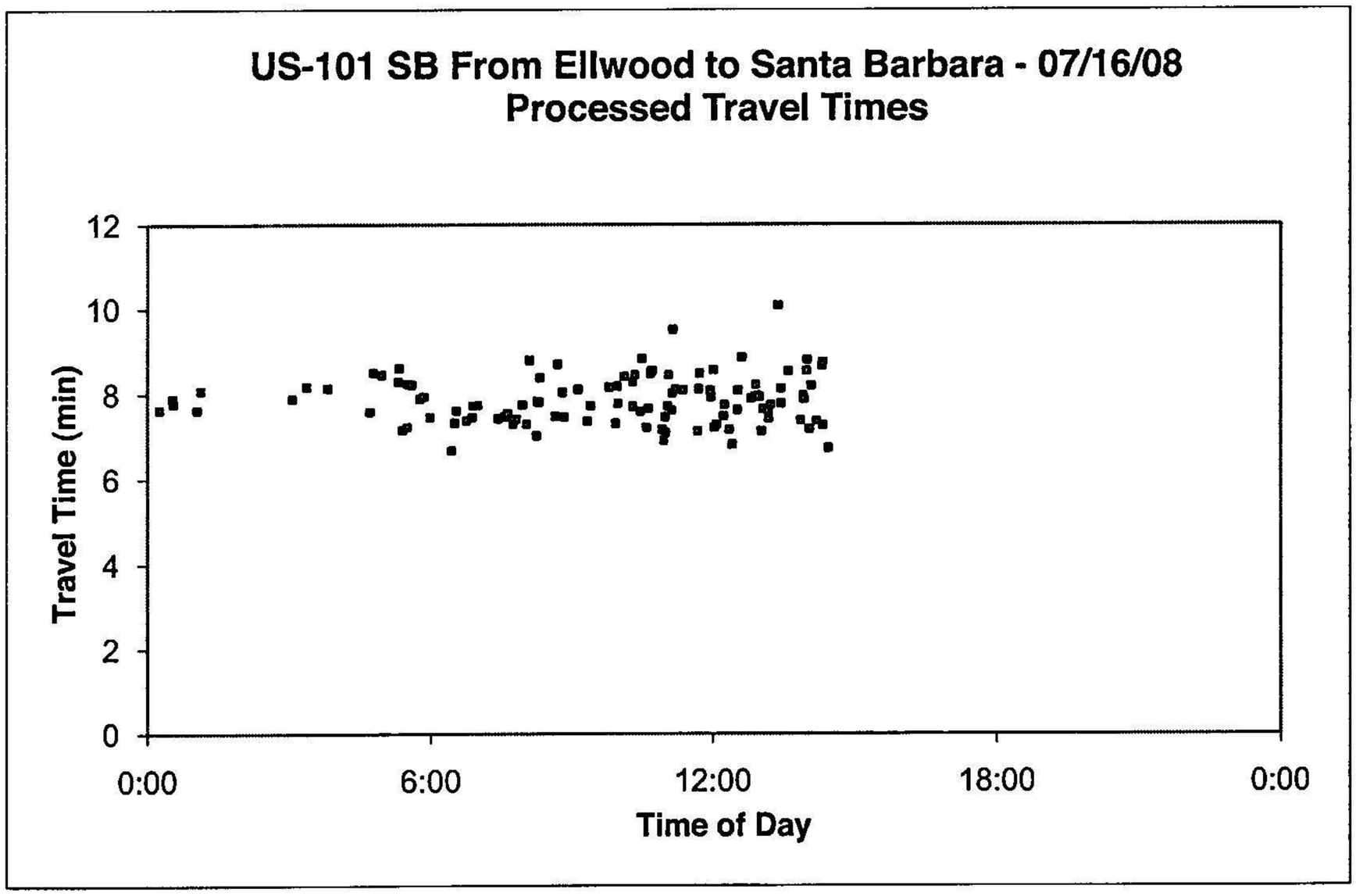

US-101 SB From Ellwood to Santa Barbara - 07/14/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Ellwood to Santa Barbara - 07/14/08
Processed Travel Times
Travel Time (min)
18
16
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

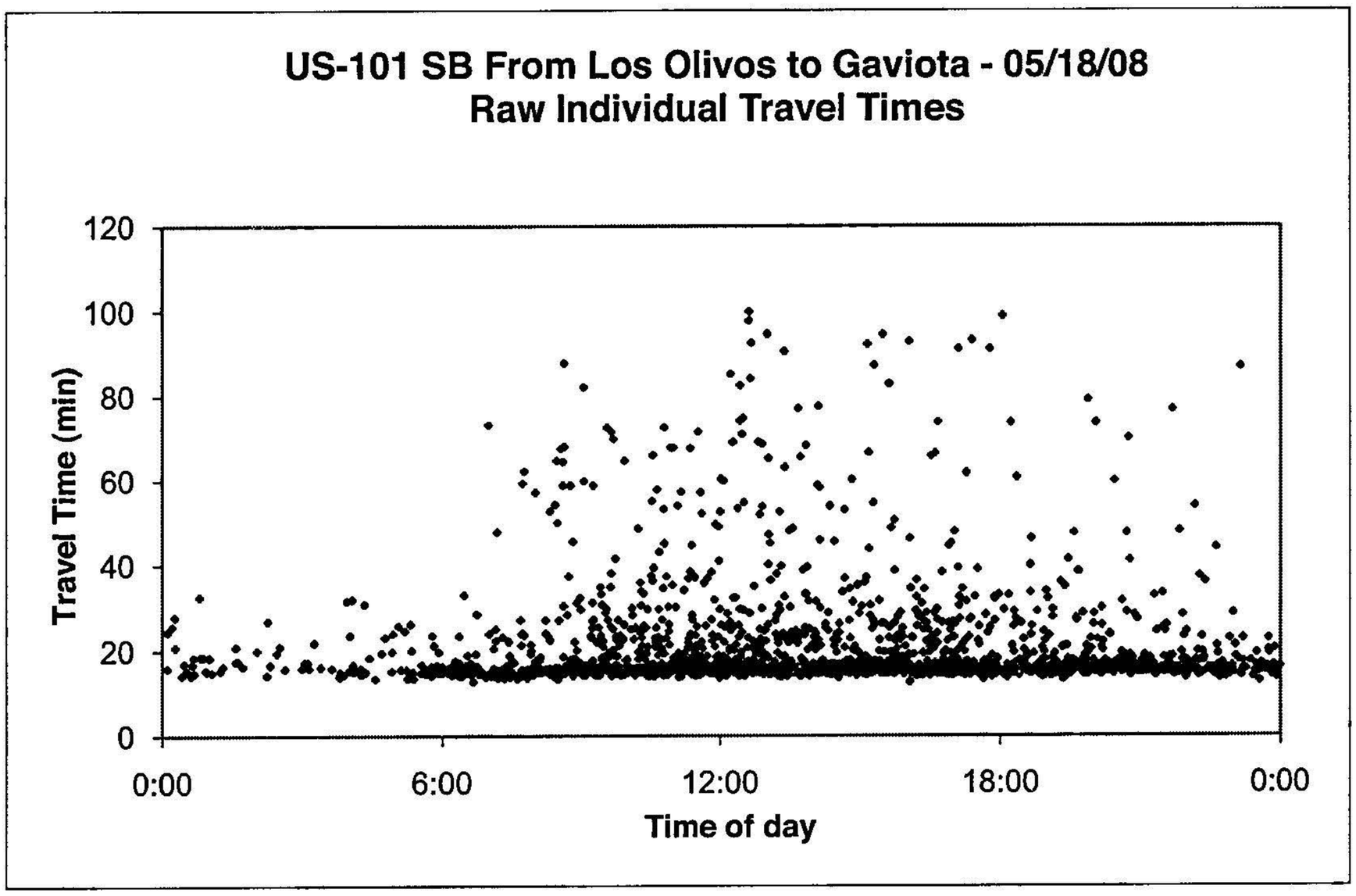

US-101 SB From Ellwood to Santa Barbara - 07/15/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

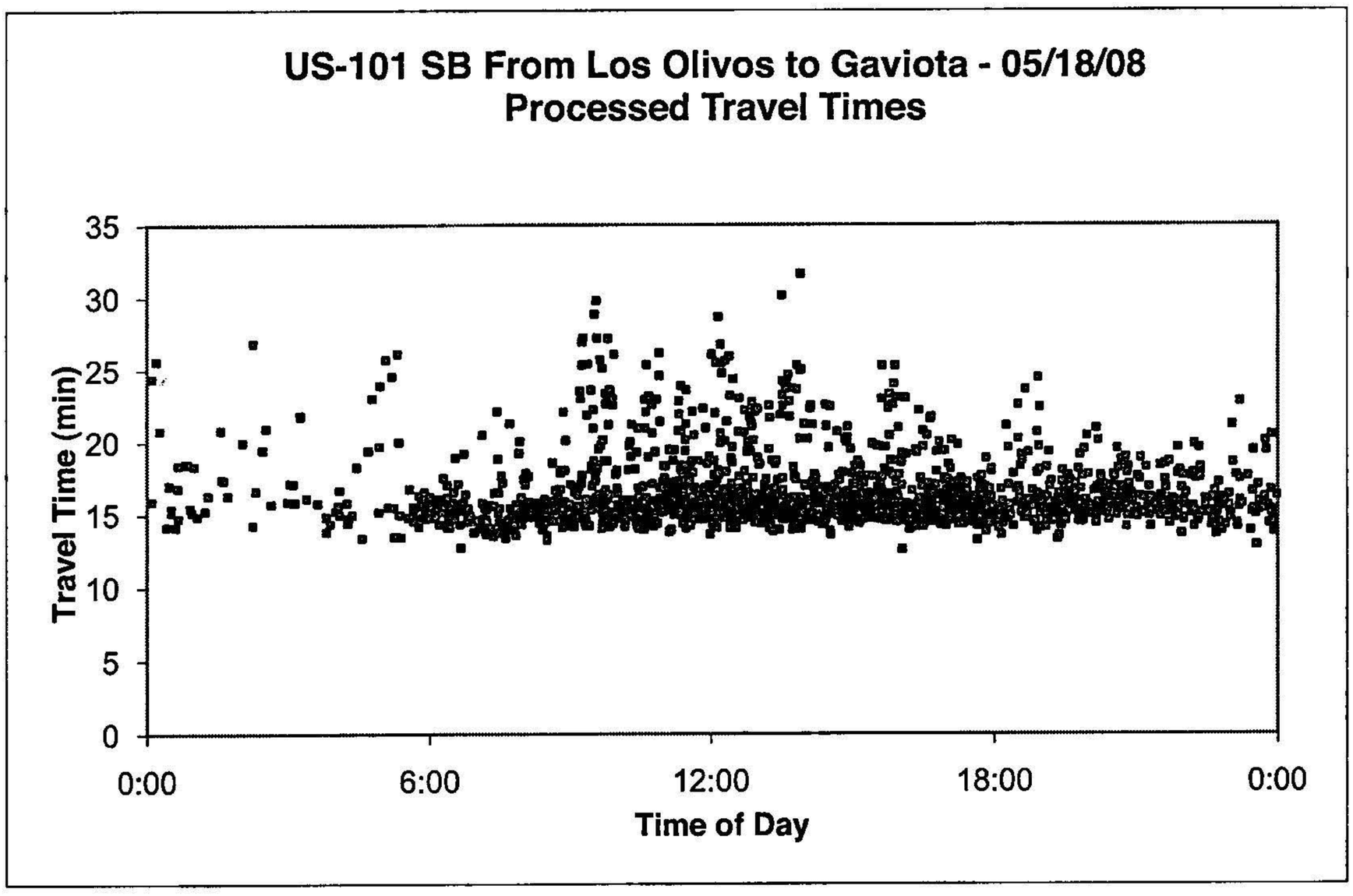

US-101 SB From Ellwood to Santa Barbara - 07/15/08
Processed Travel Times
Travel Time (min)
14
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

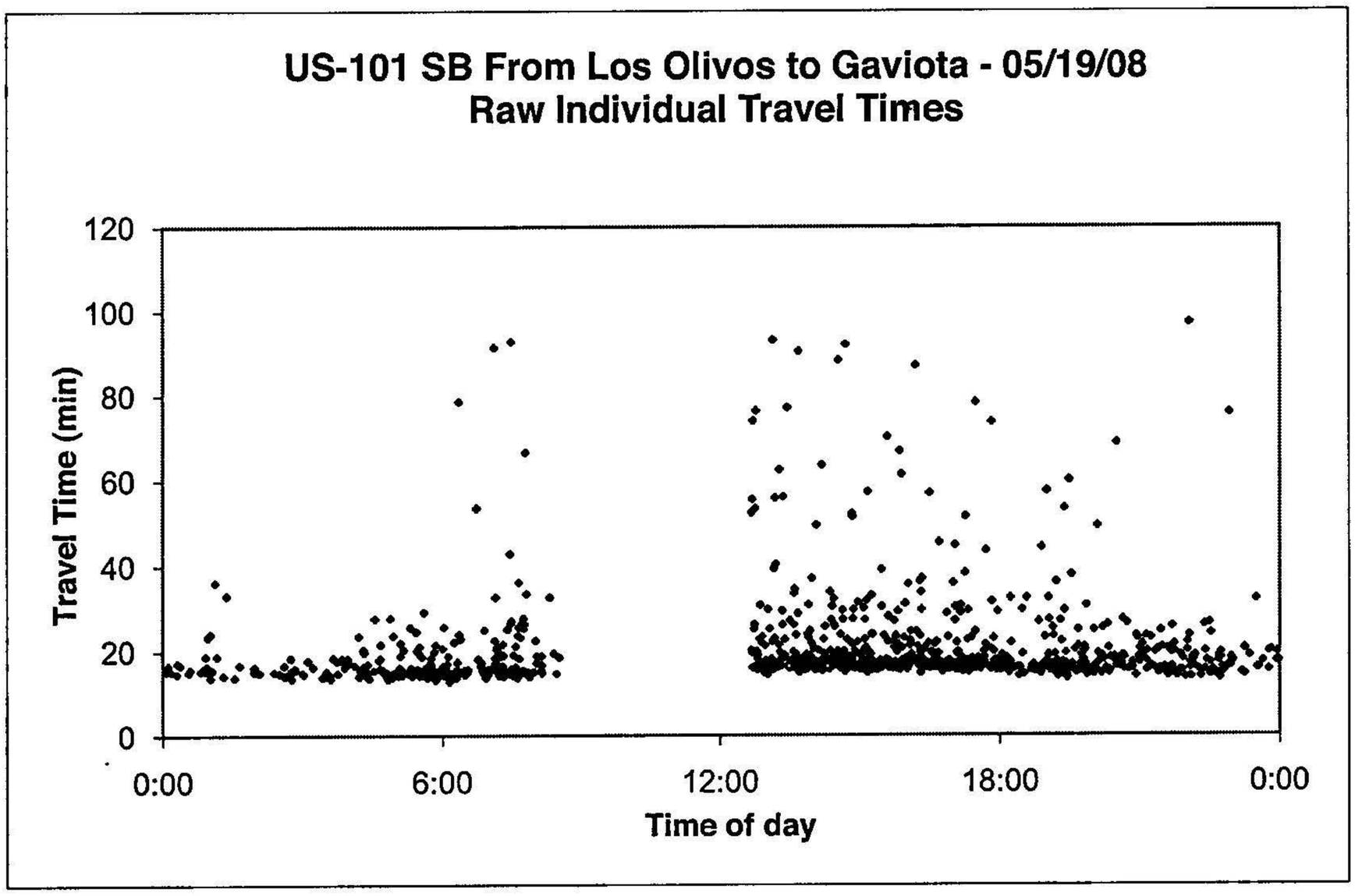

US-101 SB From Ellwood to Santa Barbara - 07/16/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

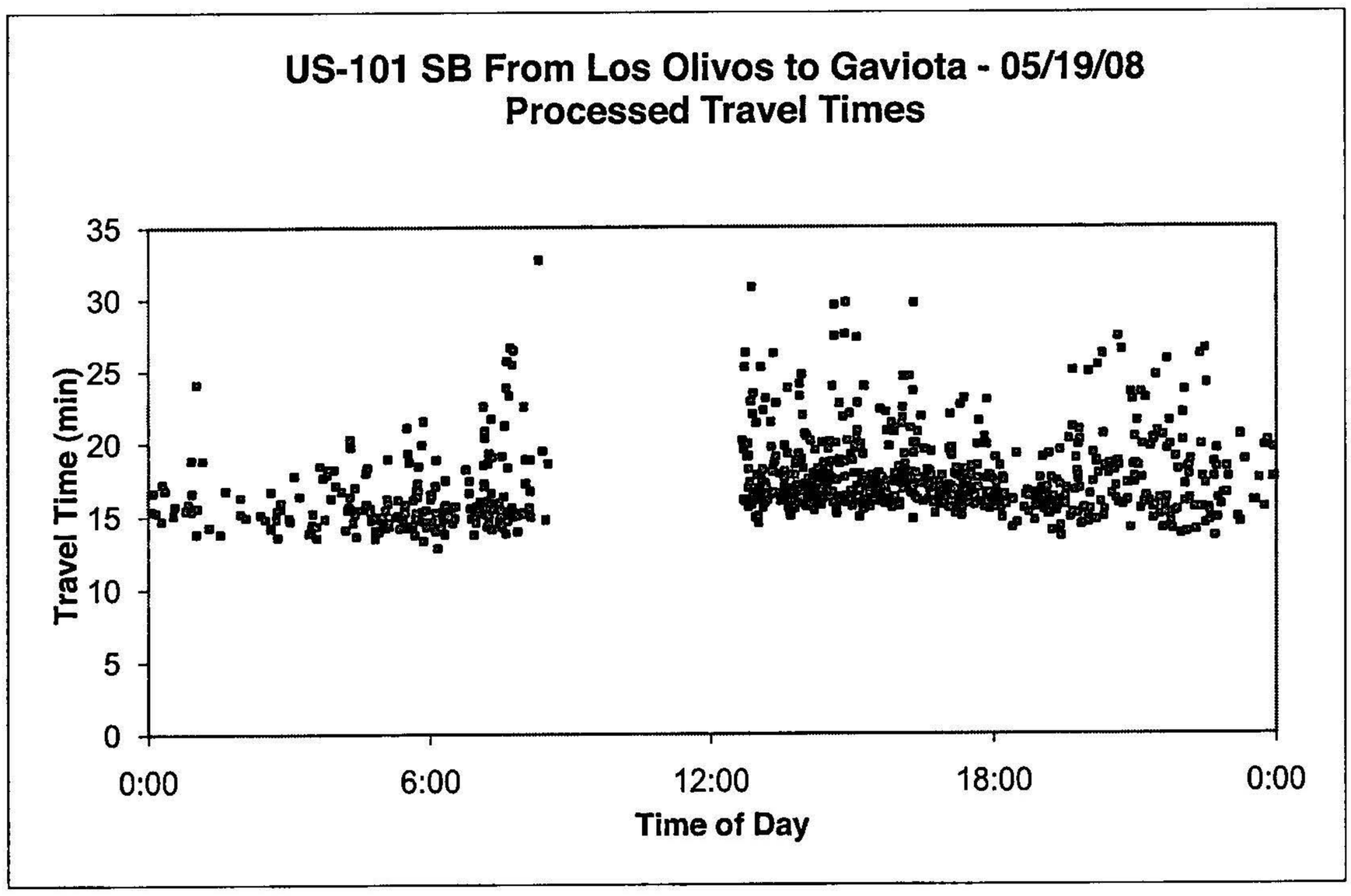

US-101 SB From Ellwood to Santa Barbara - 07/16/08
Processed Travel Times
Travel Time (min)
12
10
8
6
4
2
0
0:00
6:00
12:00
18:00
0:00
Time of Day

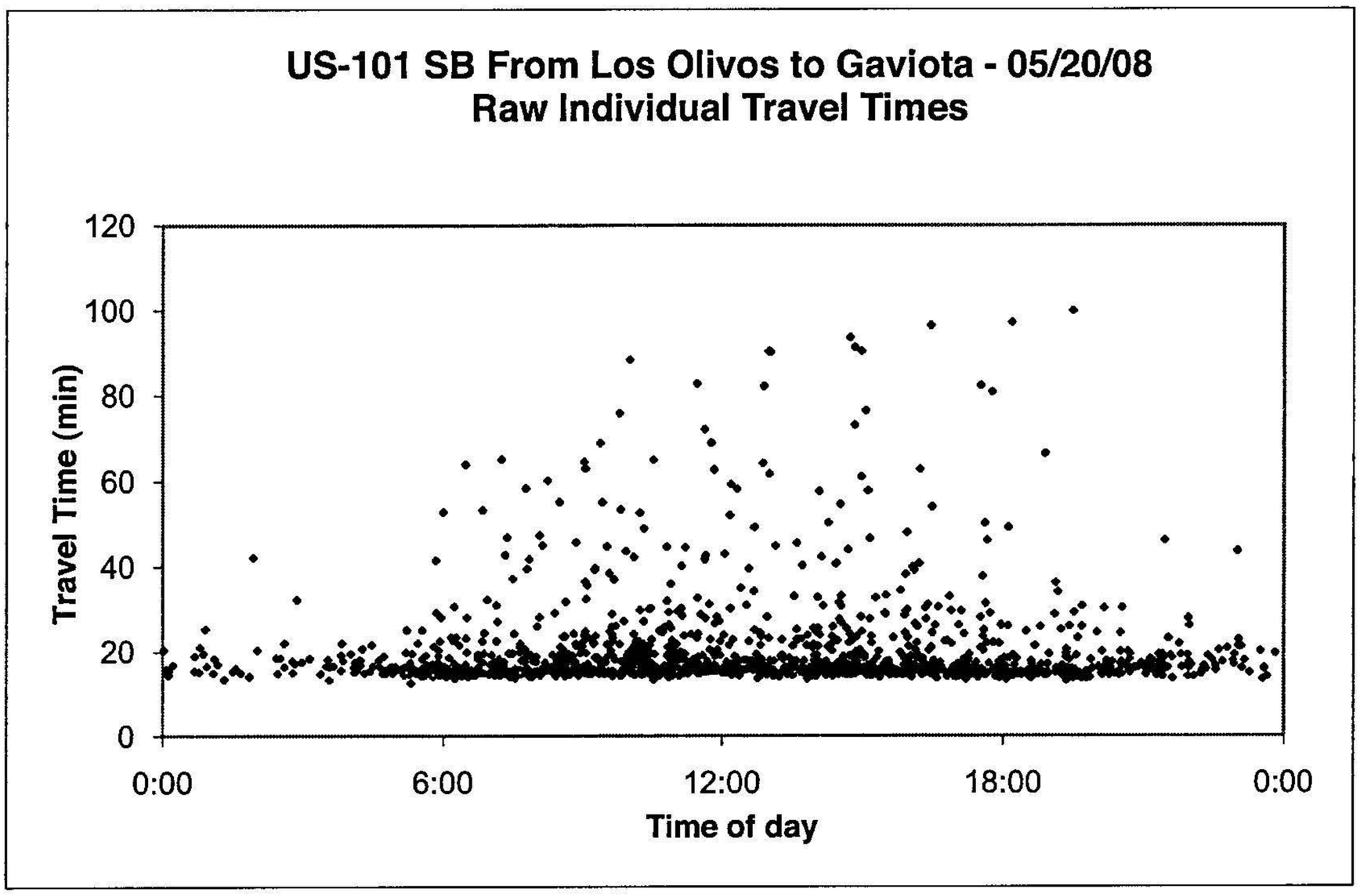
C.7 US-101 From Los Olivos to Gaviota Travel Time Distribution

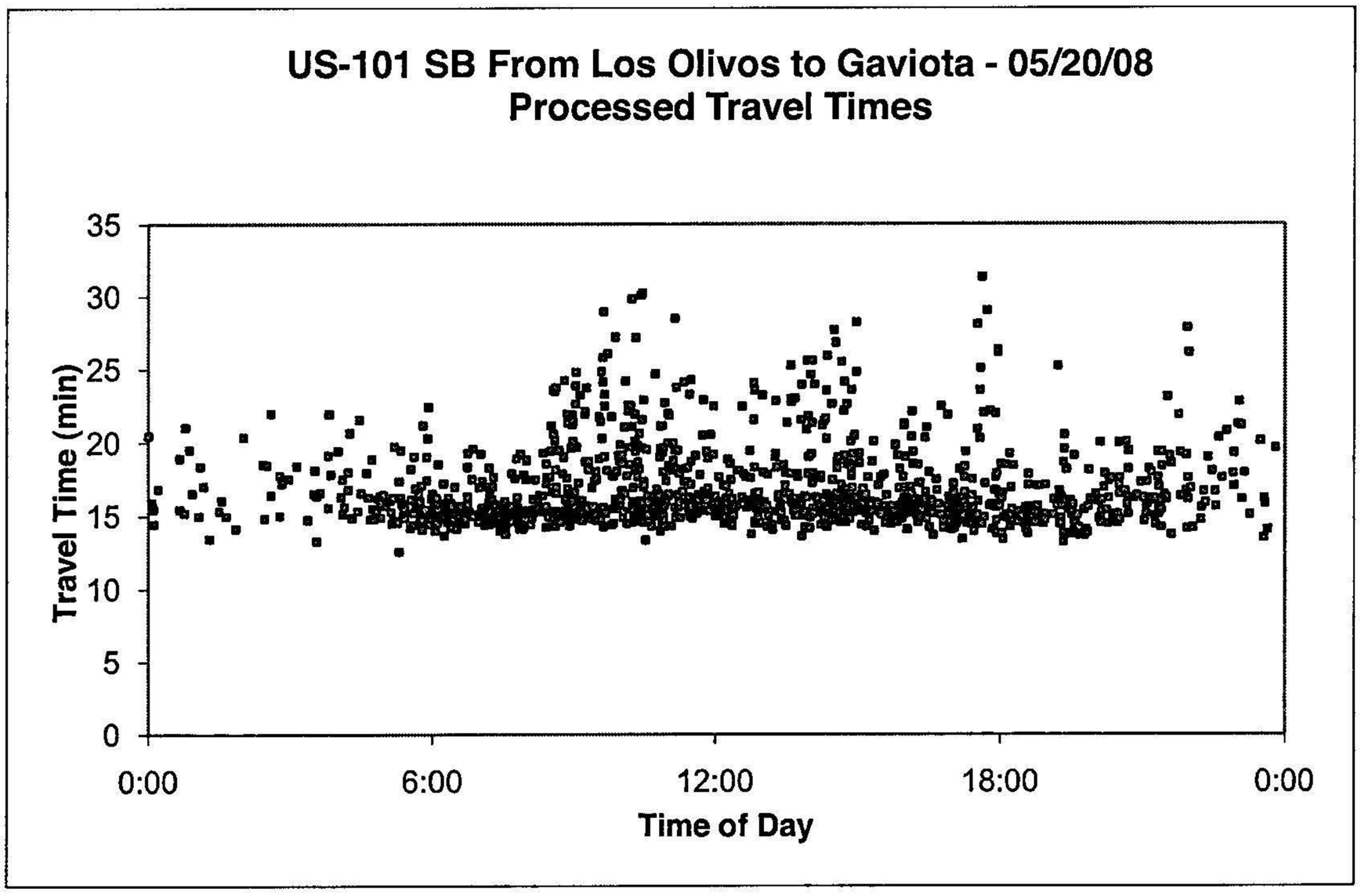


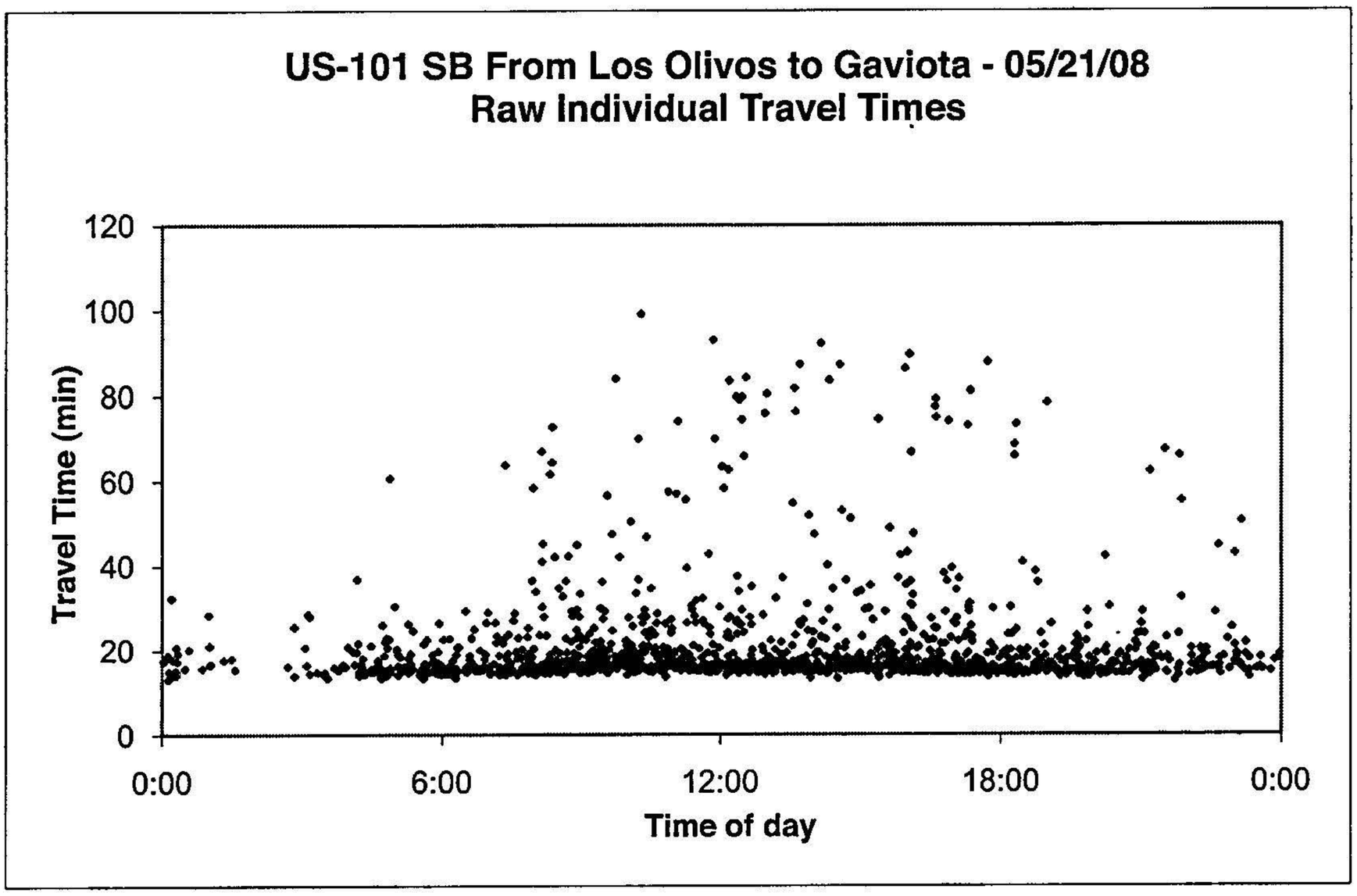


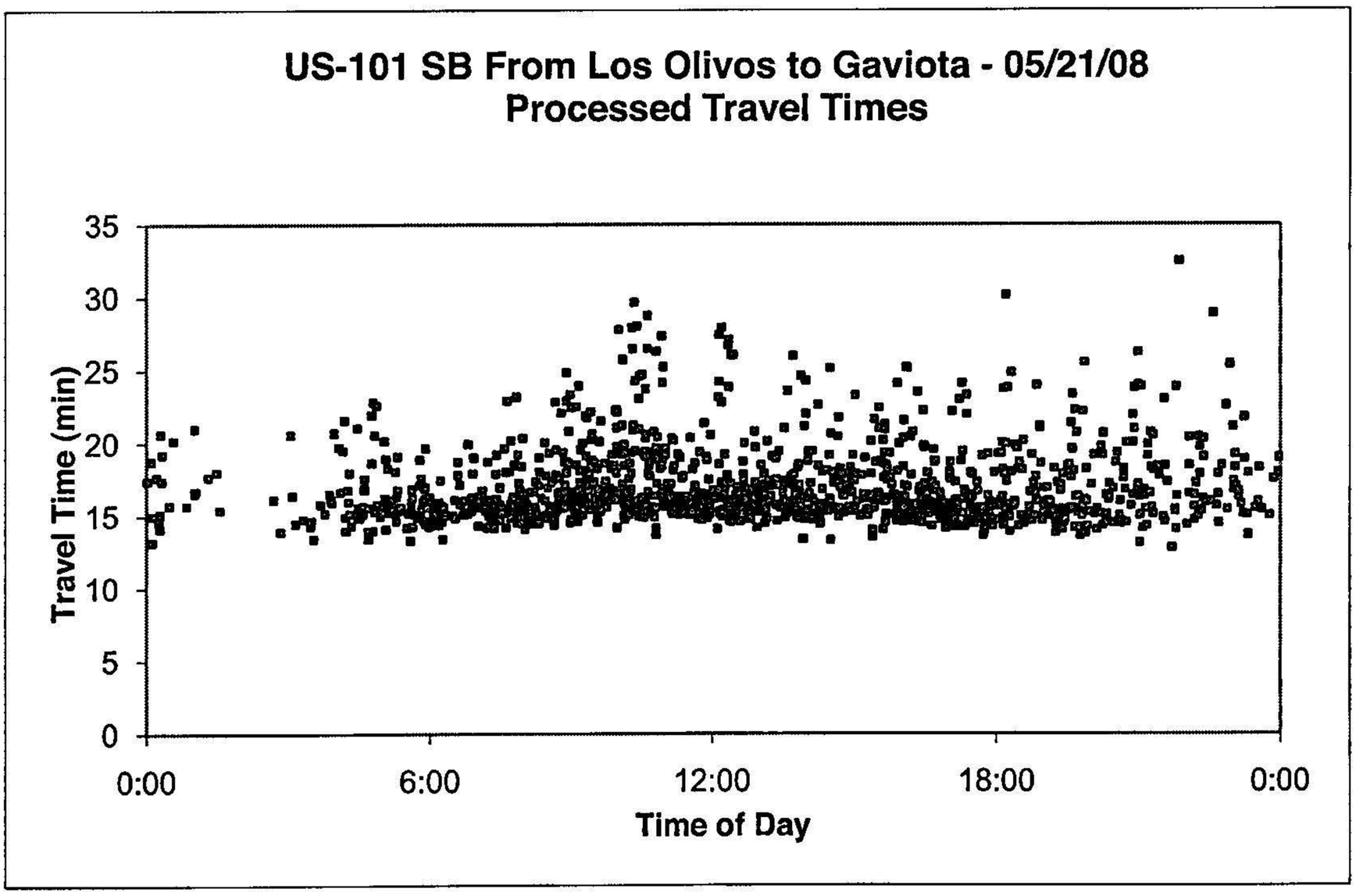

US-101 SB From Los Olivos to Gaviota - 05/19/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

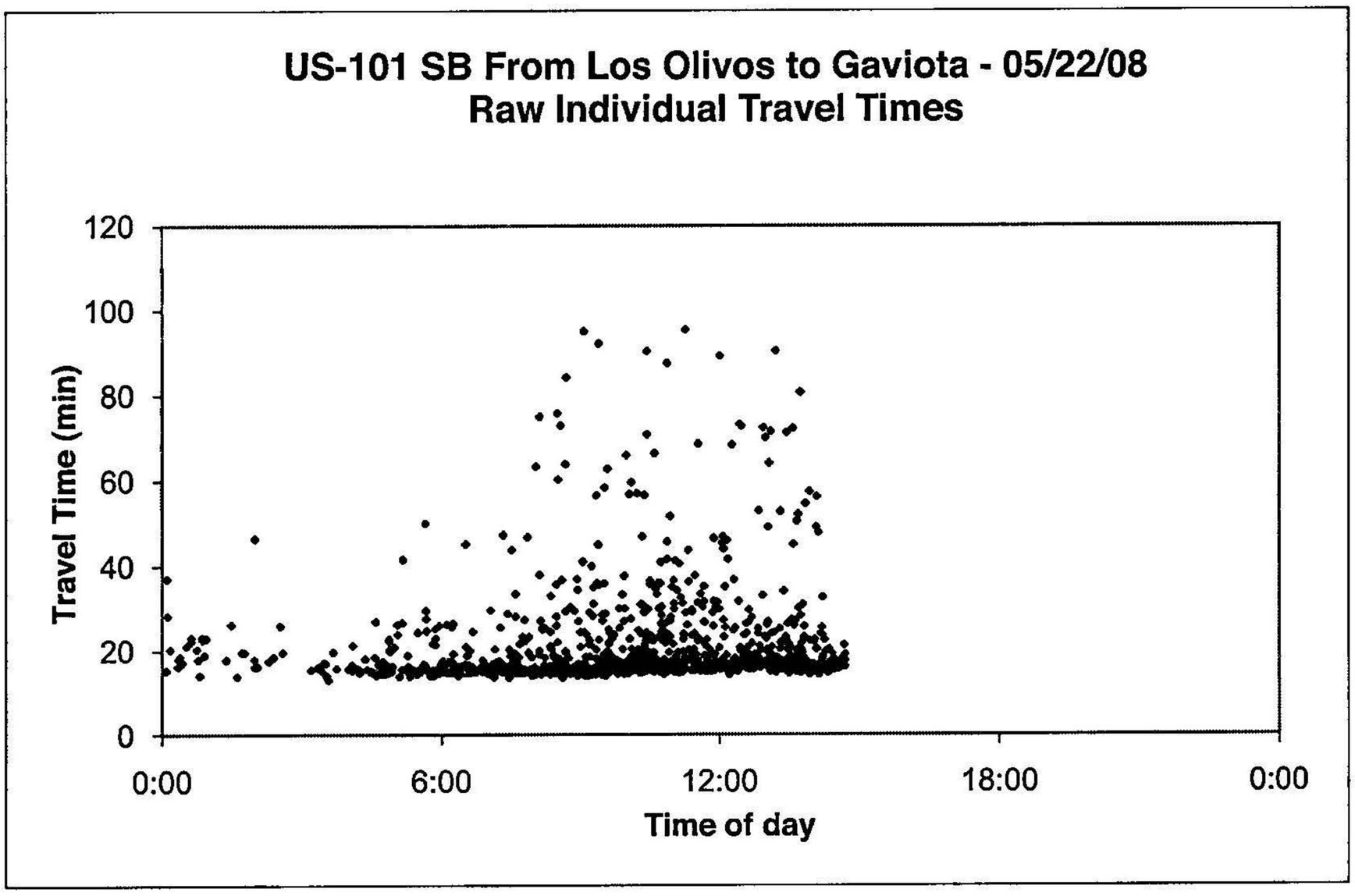

US-101 SB From Los Olivos to Gaviota - 05/19/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

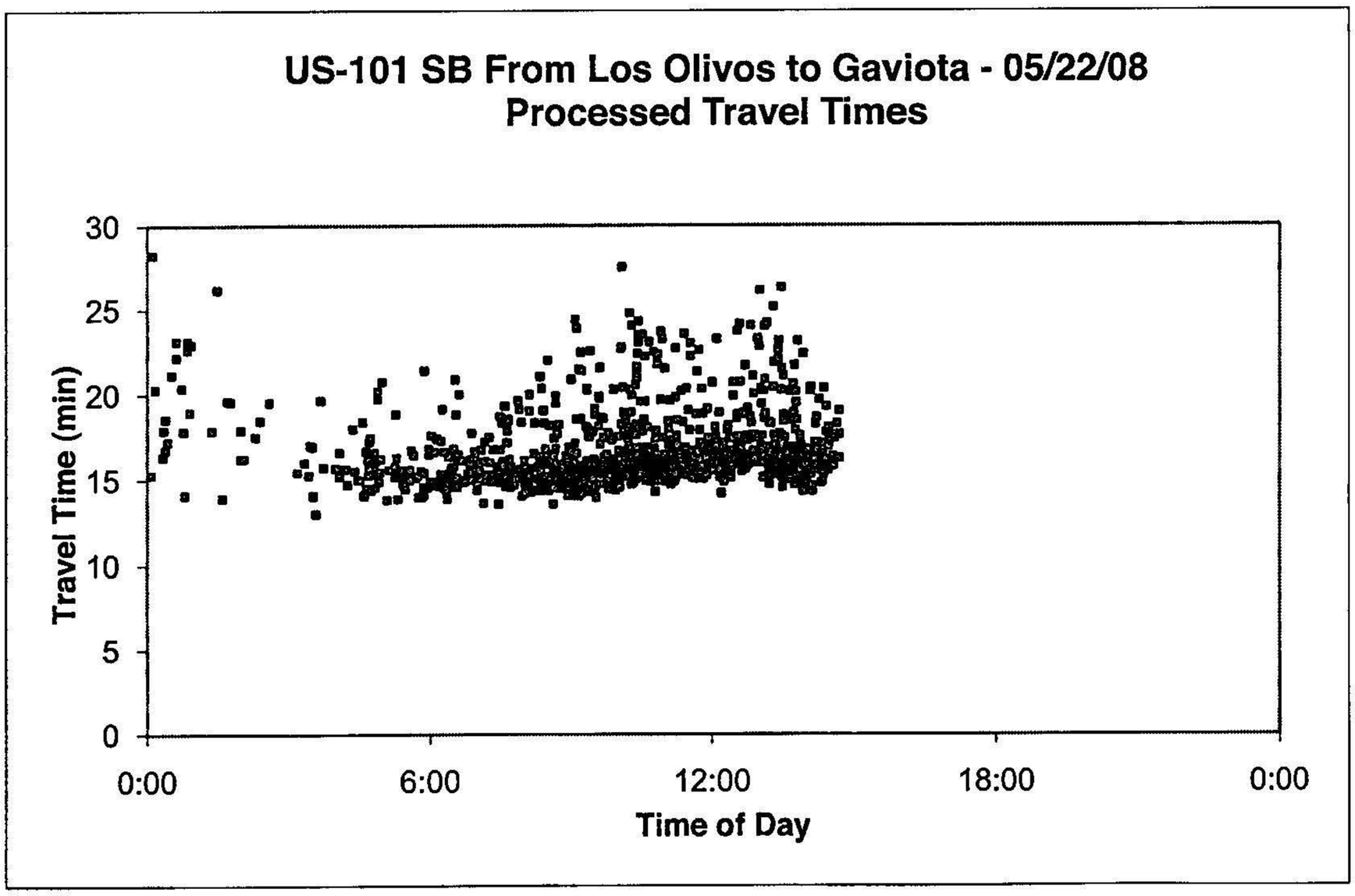

US-101 SB From Los Olivos to Gaviota - 05/20/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

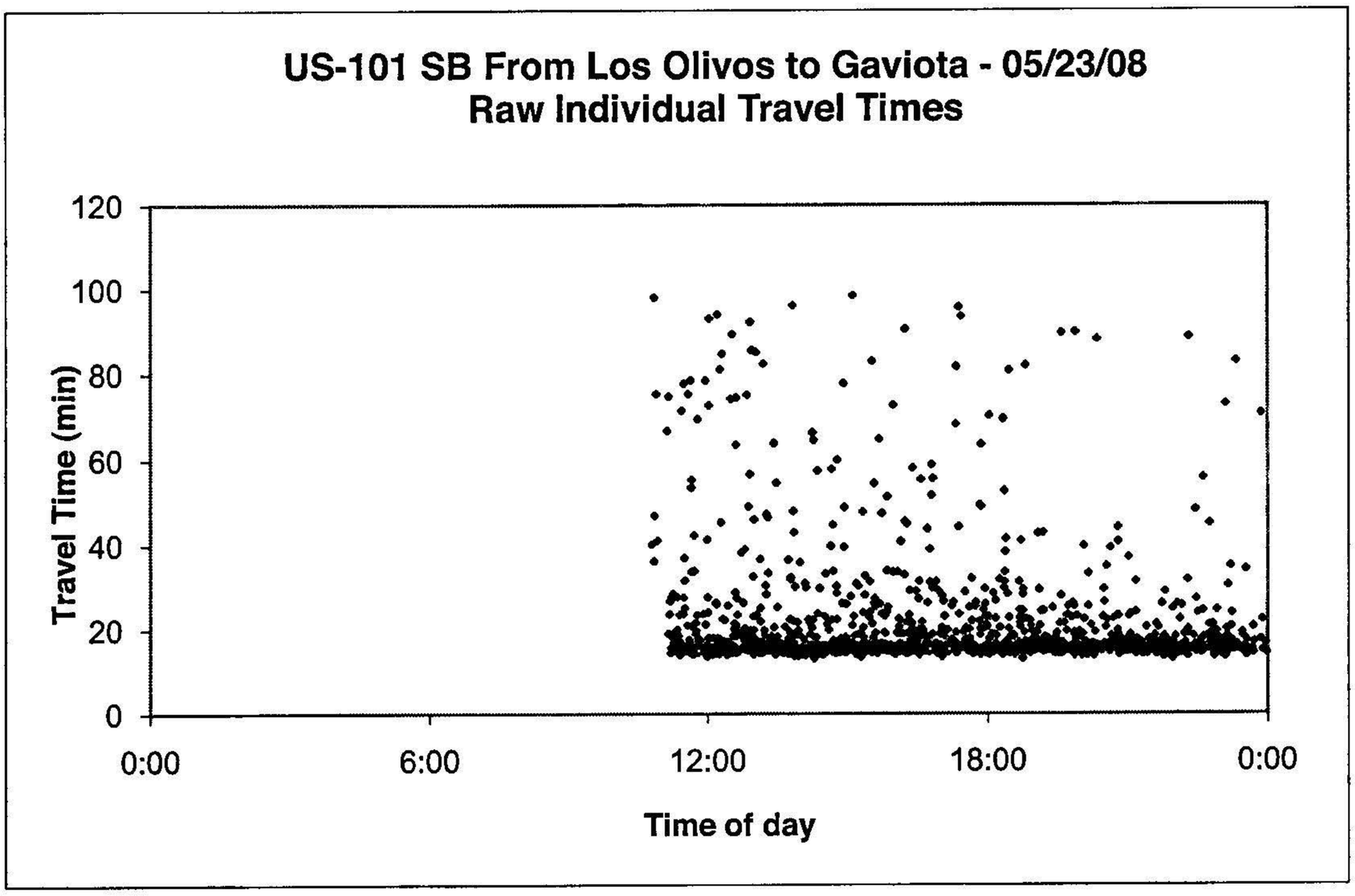

US-101 SB From Los Olivos to Gaviota - 05/20/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

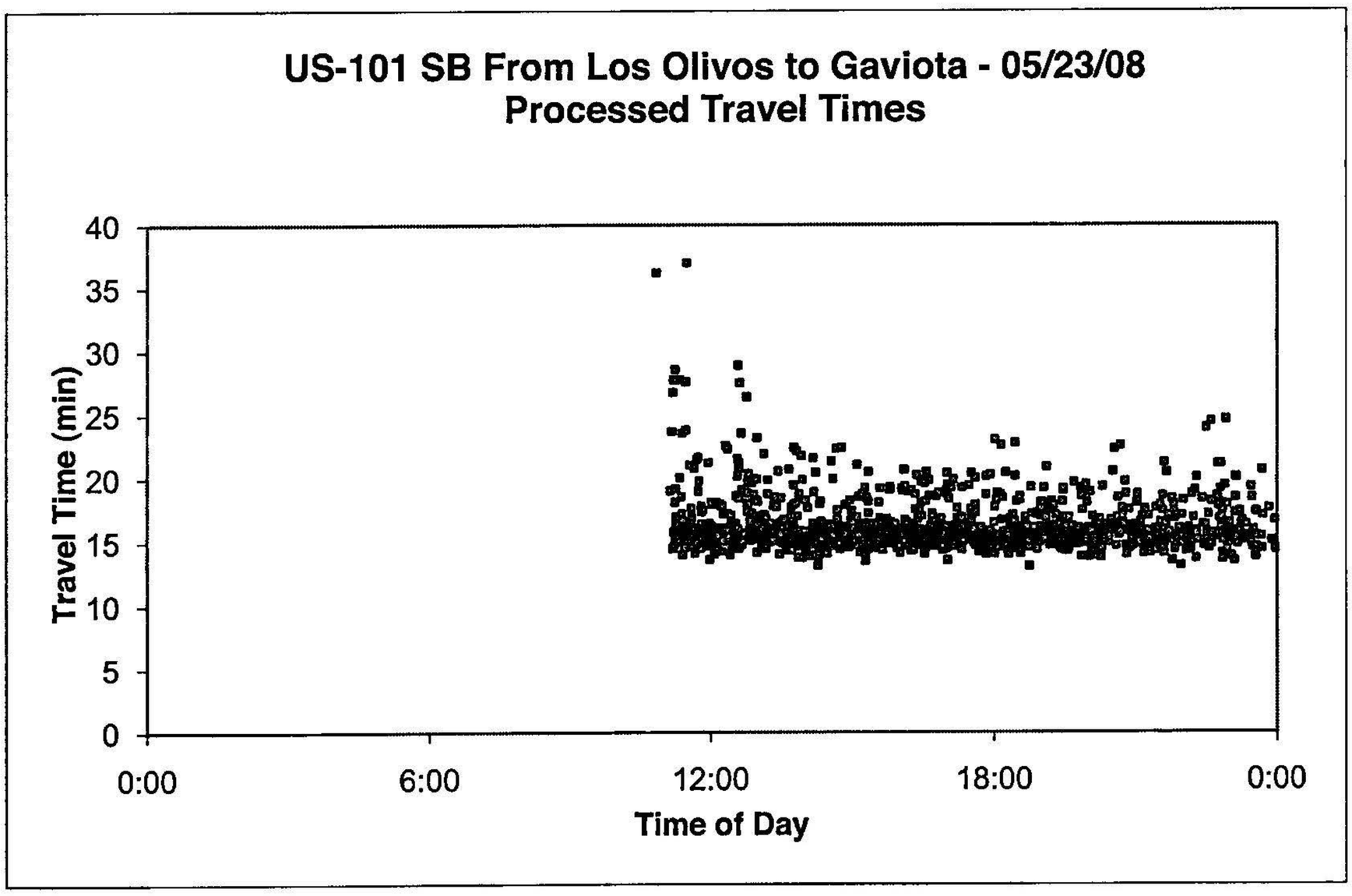

US-101 SB From Los Olivos to Gaviota - 05/21/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

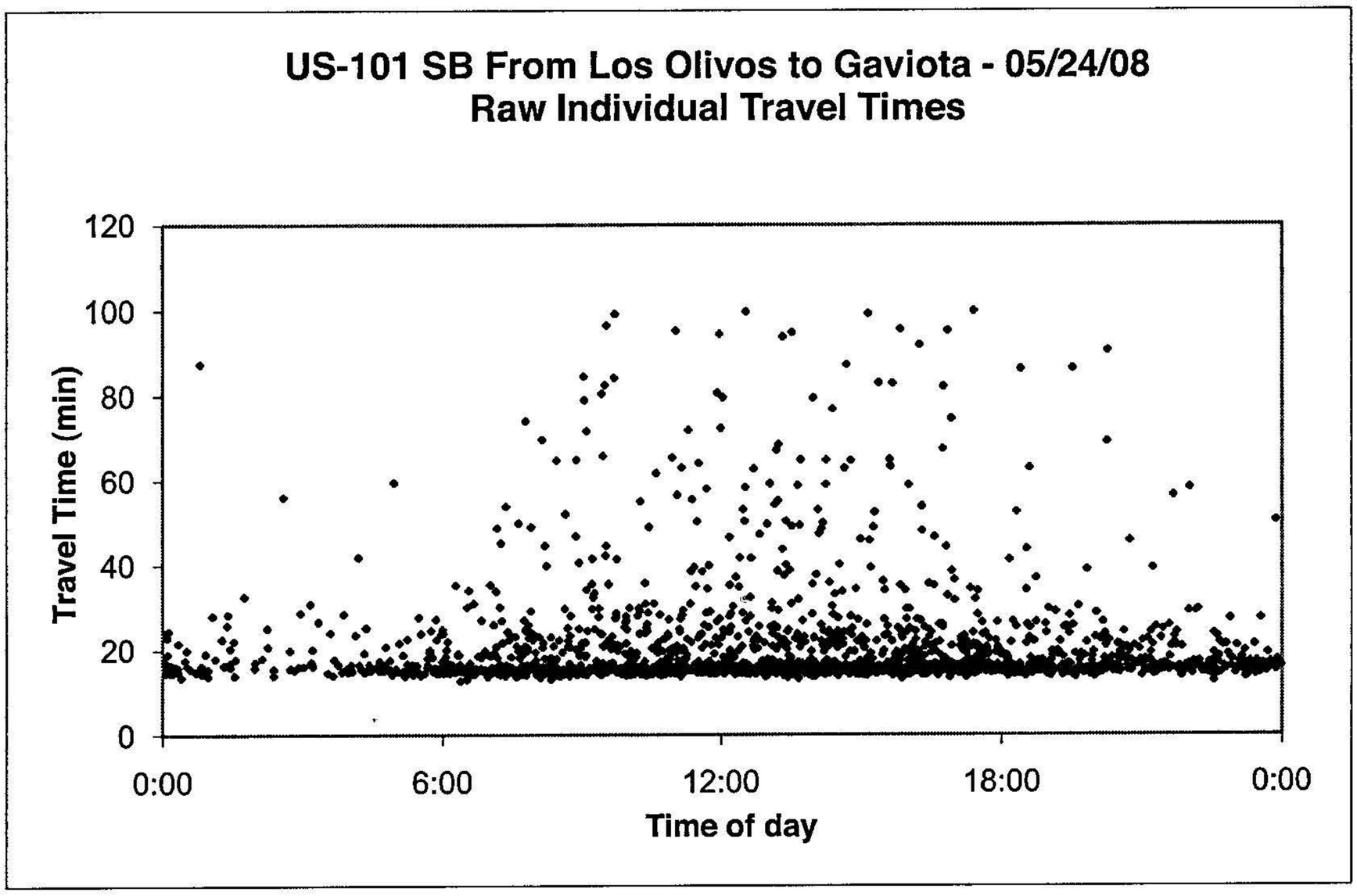

US-101 SB From Los Olivos to Gaviota - 05/21/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

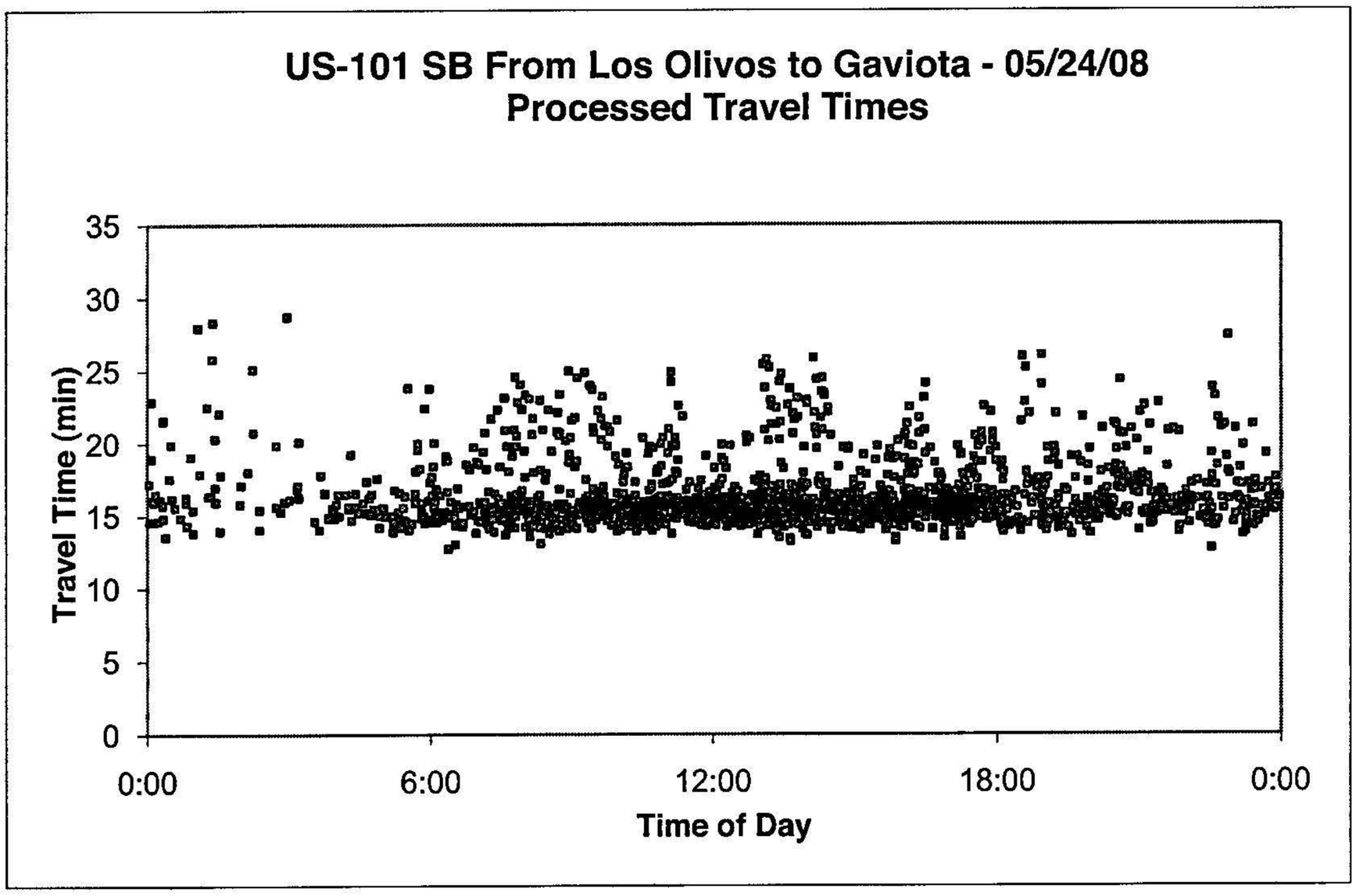

US-101 SB From Los Olivos to Gaviota - 05/22/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

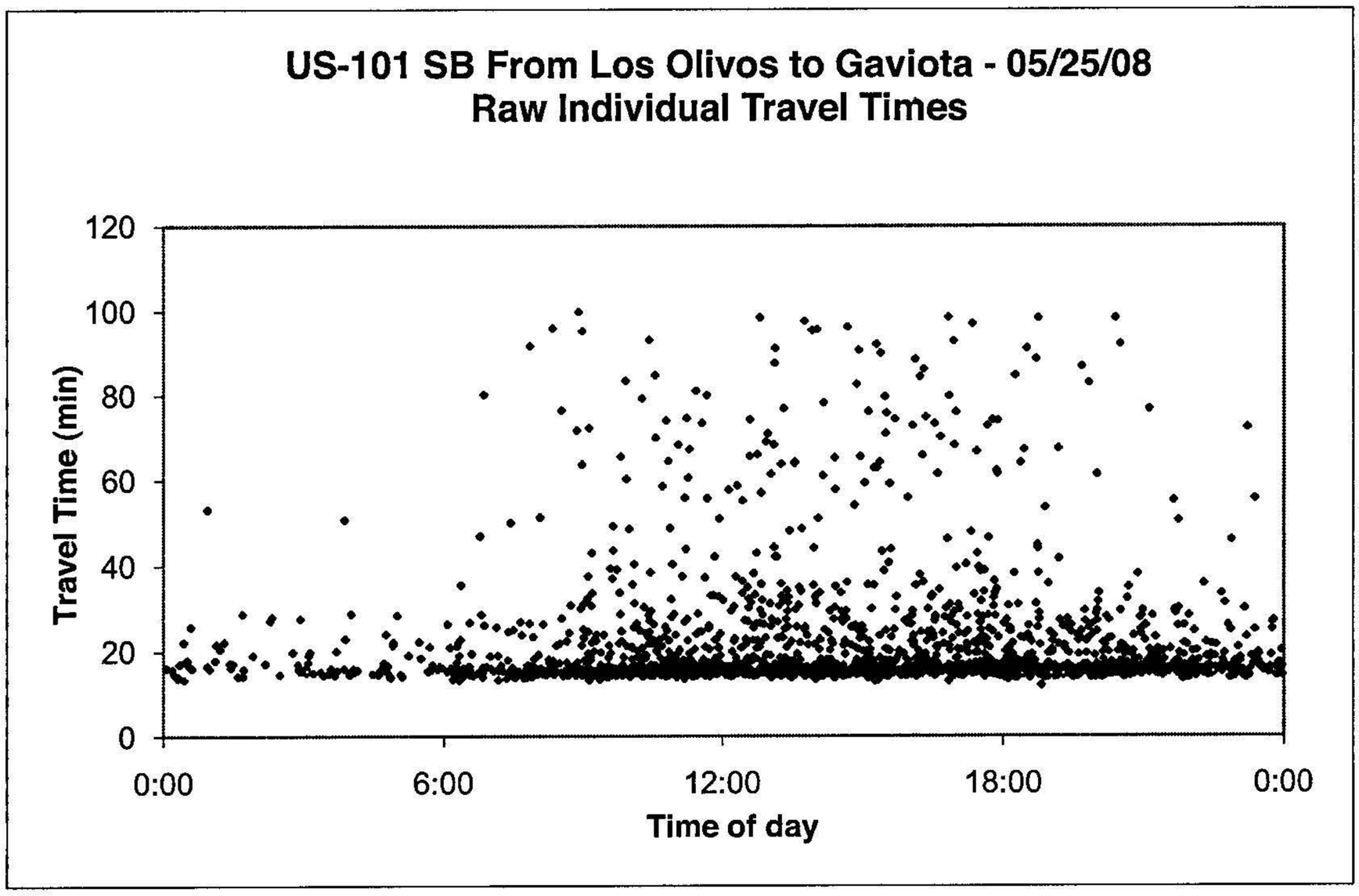

US-101 SB From Los Olivos to Gaviota - 05/22/08
Processed Travel Times
Travel Time (min)
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

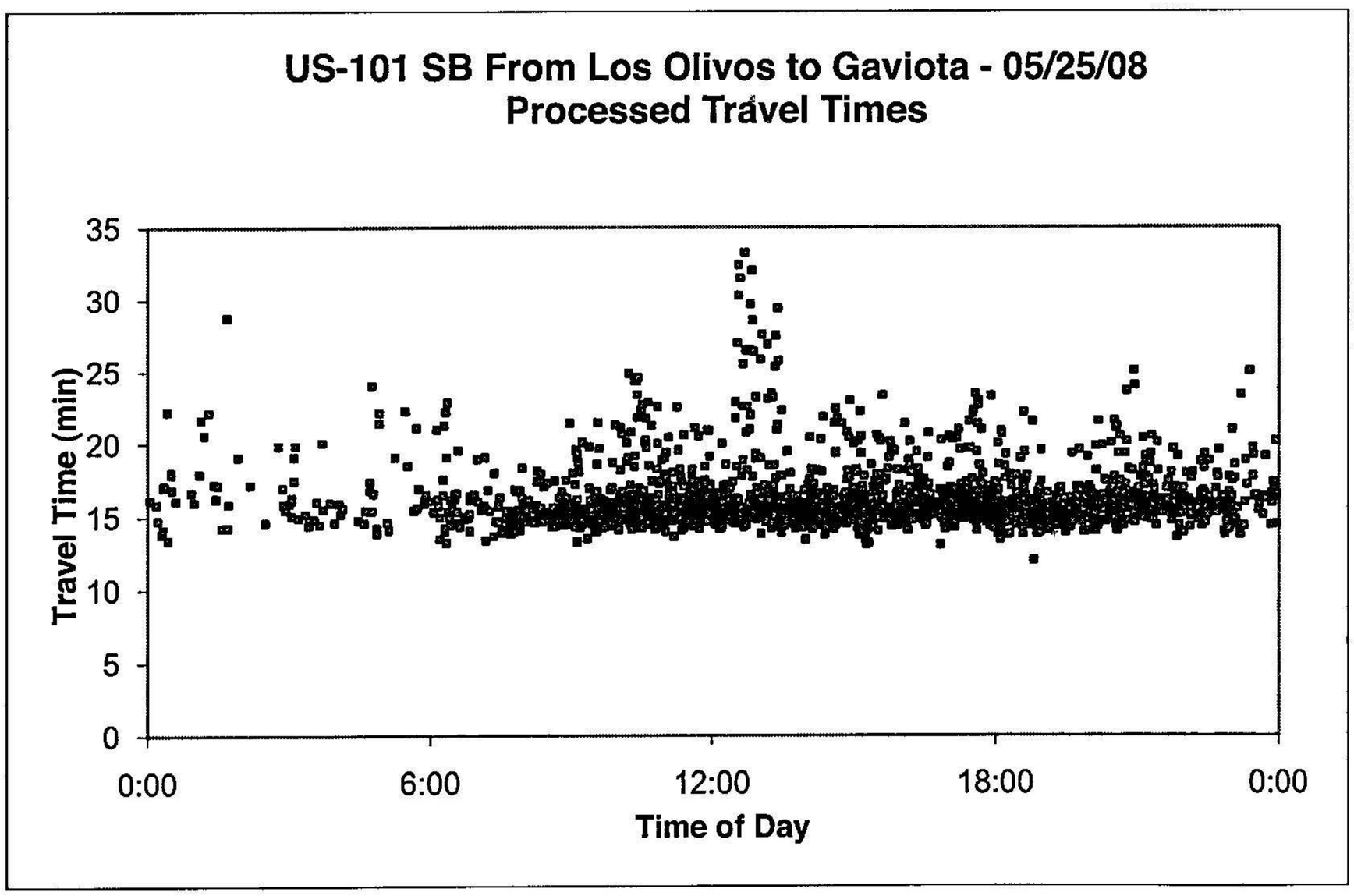

US-101 SB From Los Olivos to Gaviota - 05/23/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

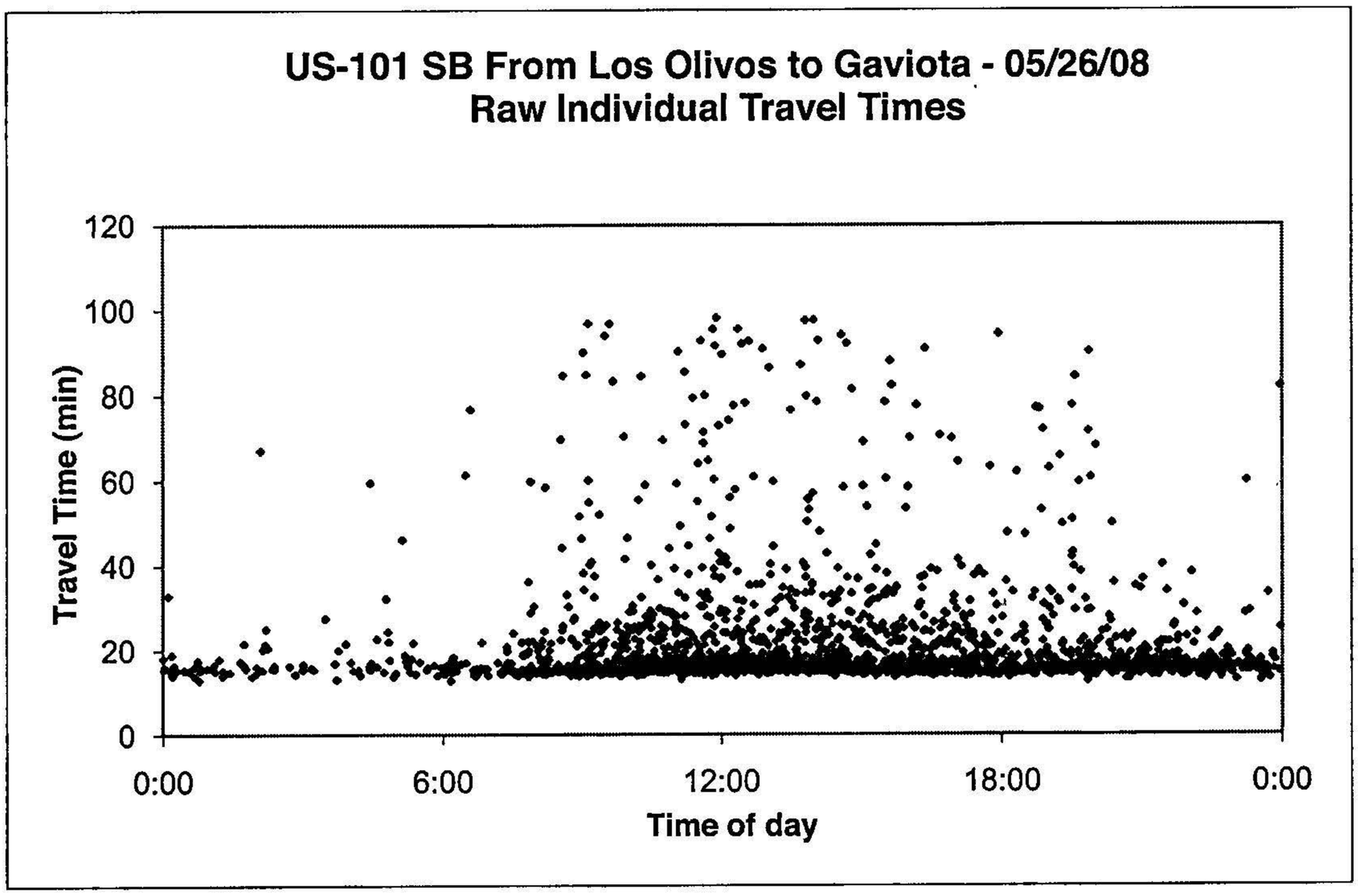

US-101 SB From Los Olivos to Gaviota - 05/23/08
Processed Travel Times
Travel Time (min)
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

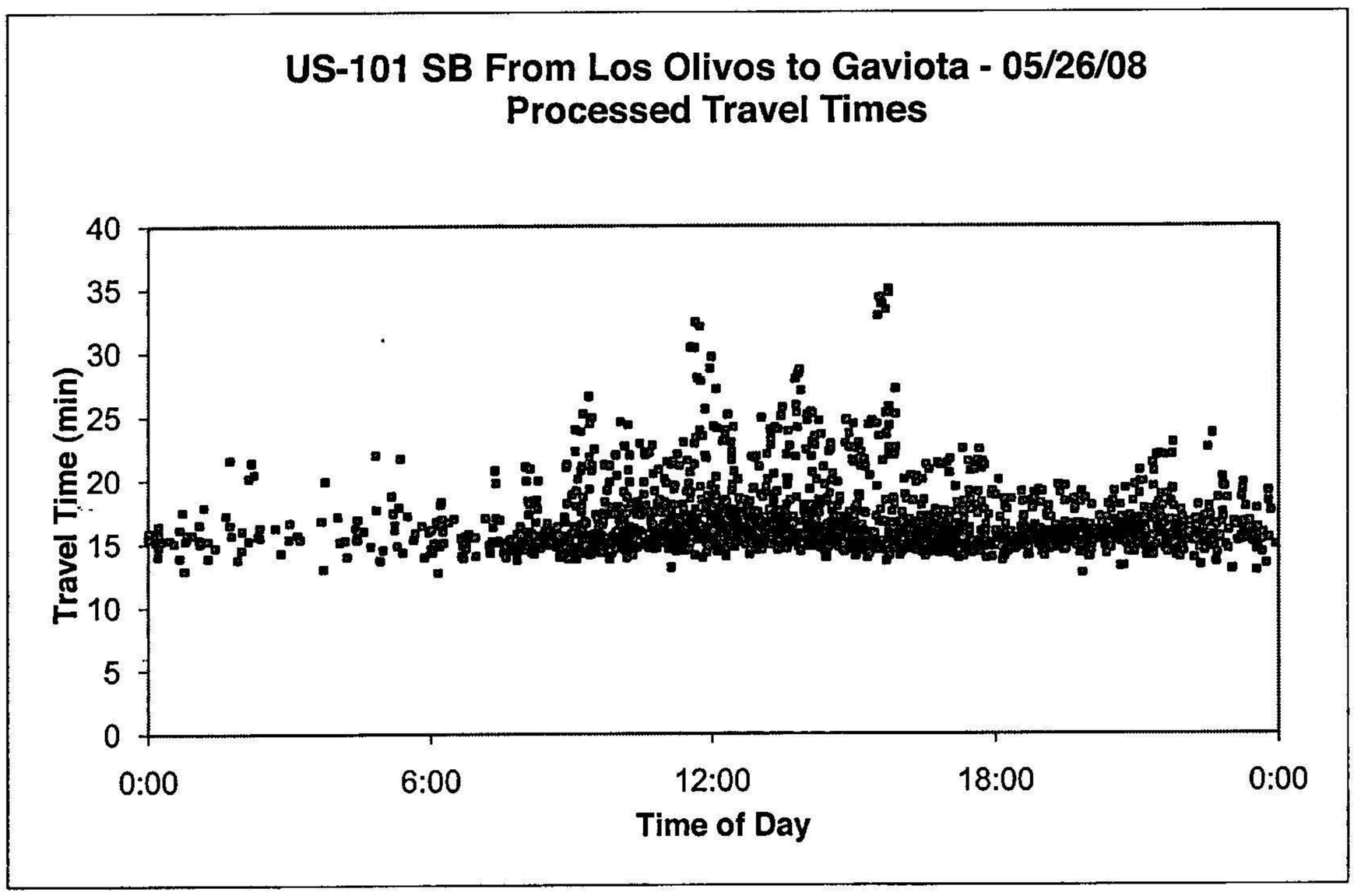

US-101 SB From Los Olivos to Gaviota - 05/24/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

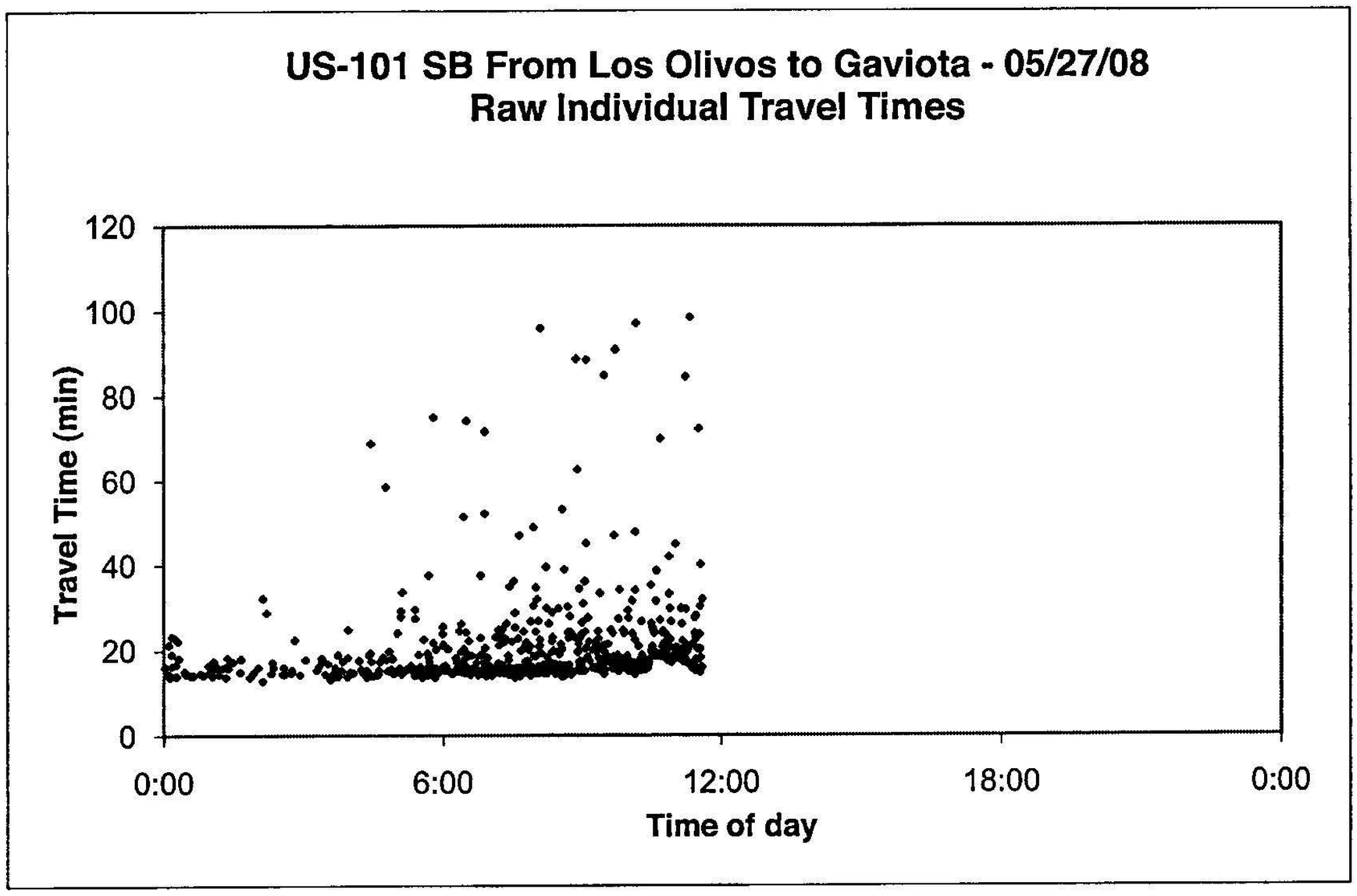

US-101 SB From Los Olivos to Gaviota - 05/24/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

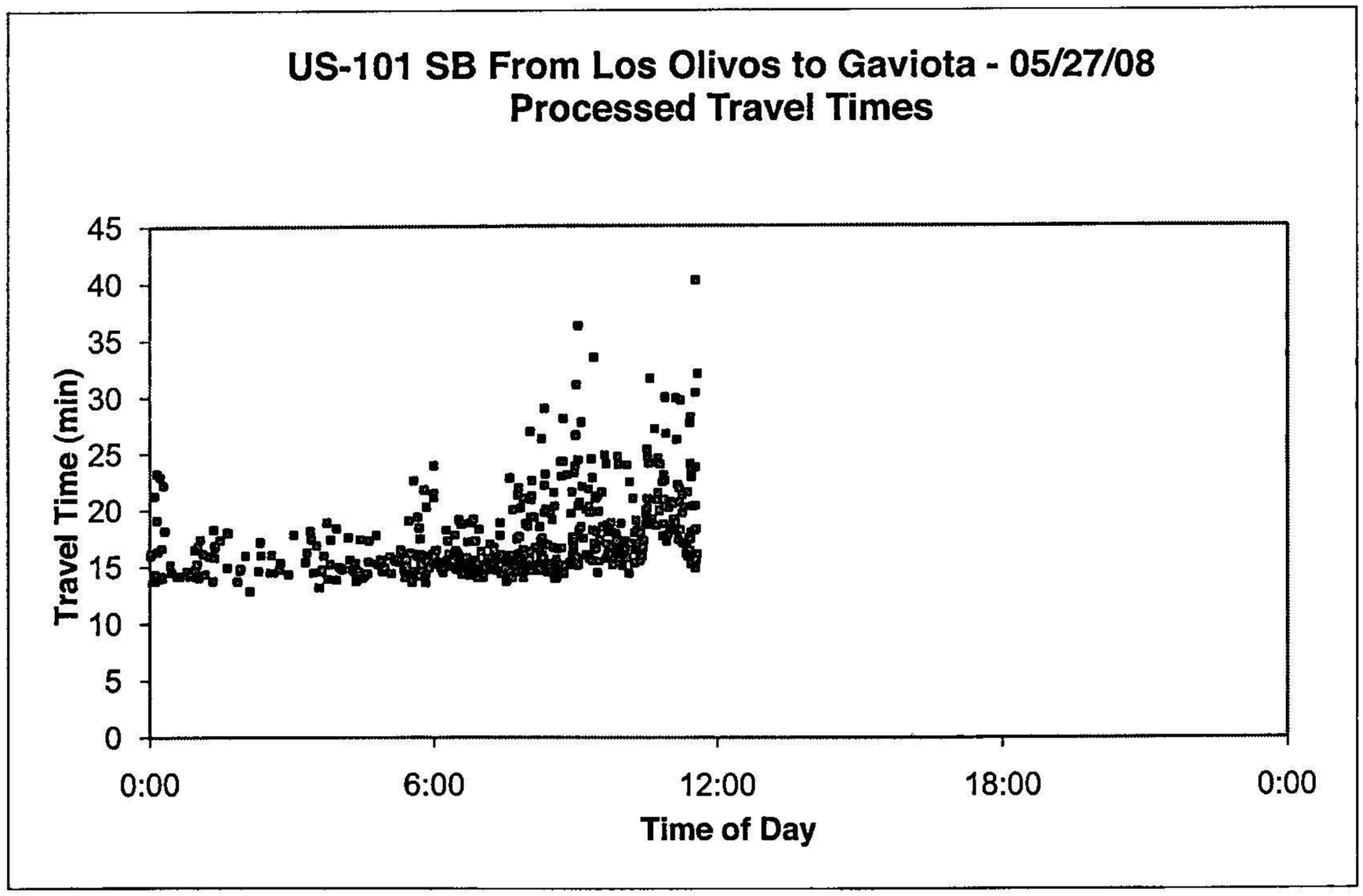

US-101 SB From Los Olivos to Gaviota - 05/25/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Los Olivos to Gaviota - 05/25/08
Processed Travel Times
Travel Time (min)
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

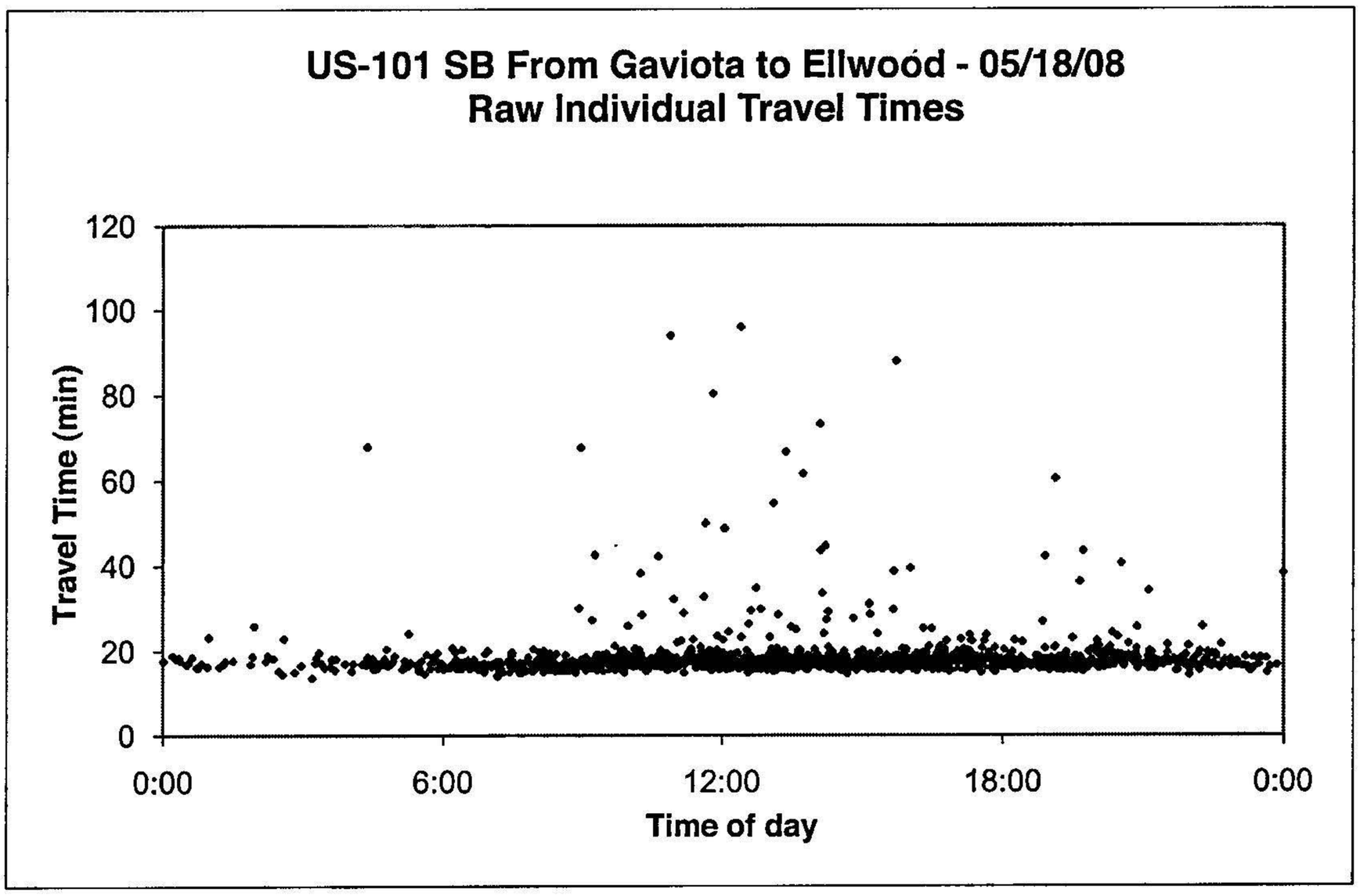

US-101 SB From Los Olivos to Gaviota - 05/26/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

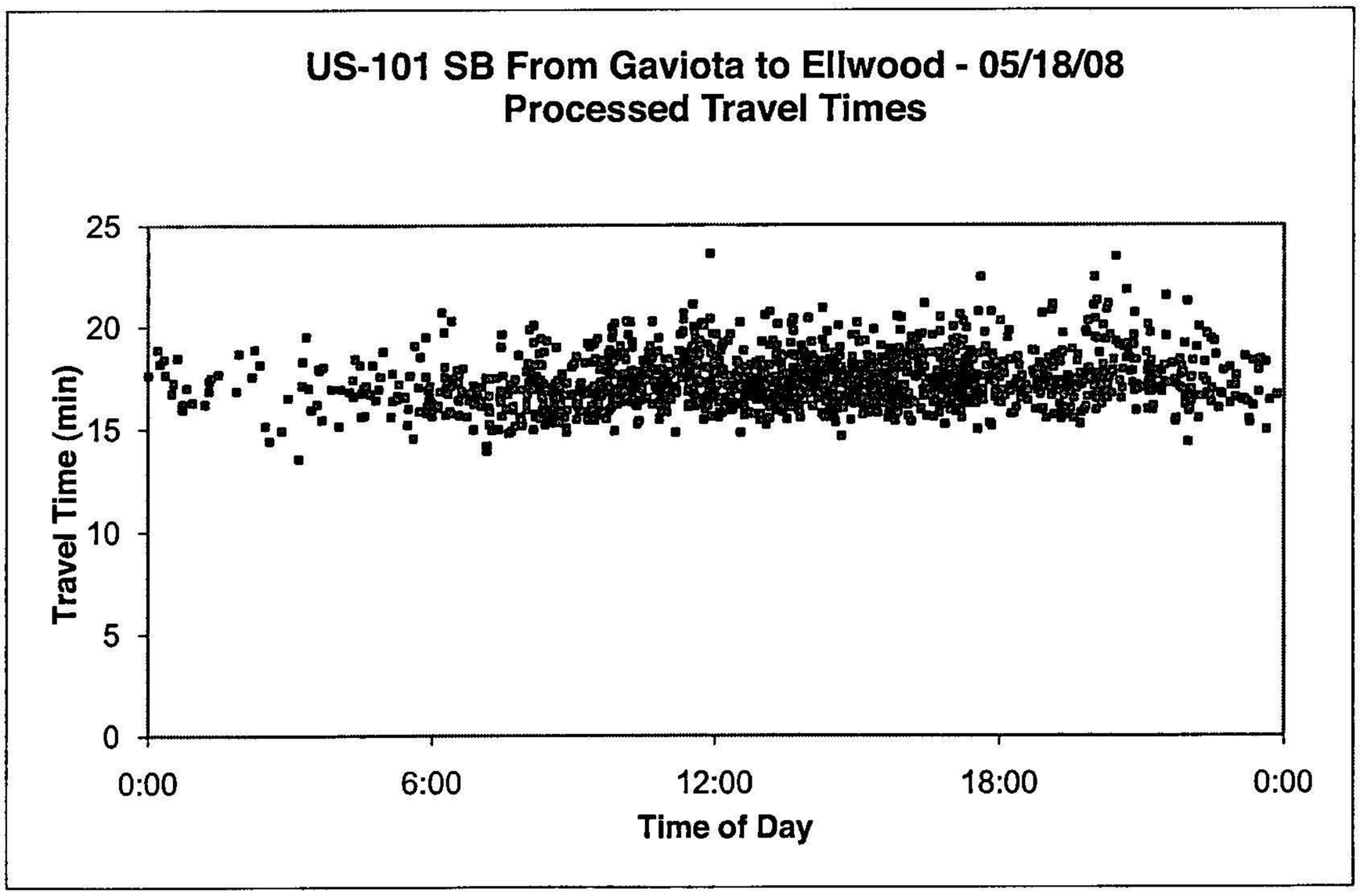

US-101 SB From Los Olivos to Gaviota - 05/26/08
Processed Travel Times
Travel Time (min)
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

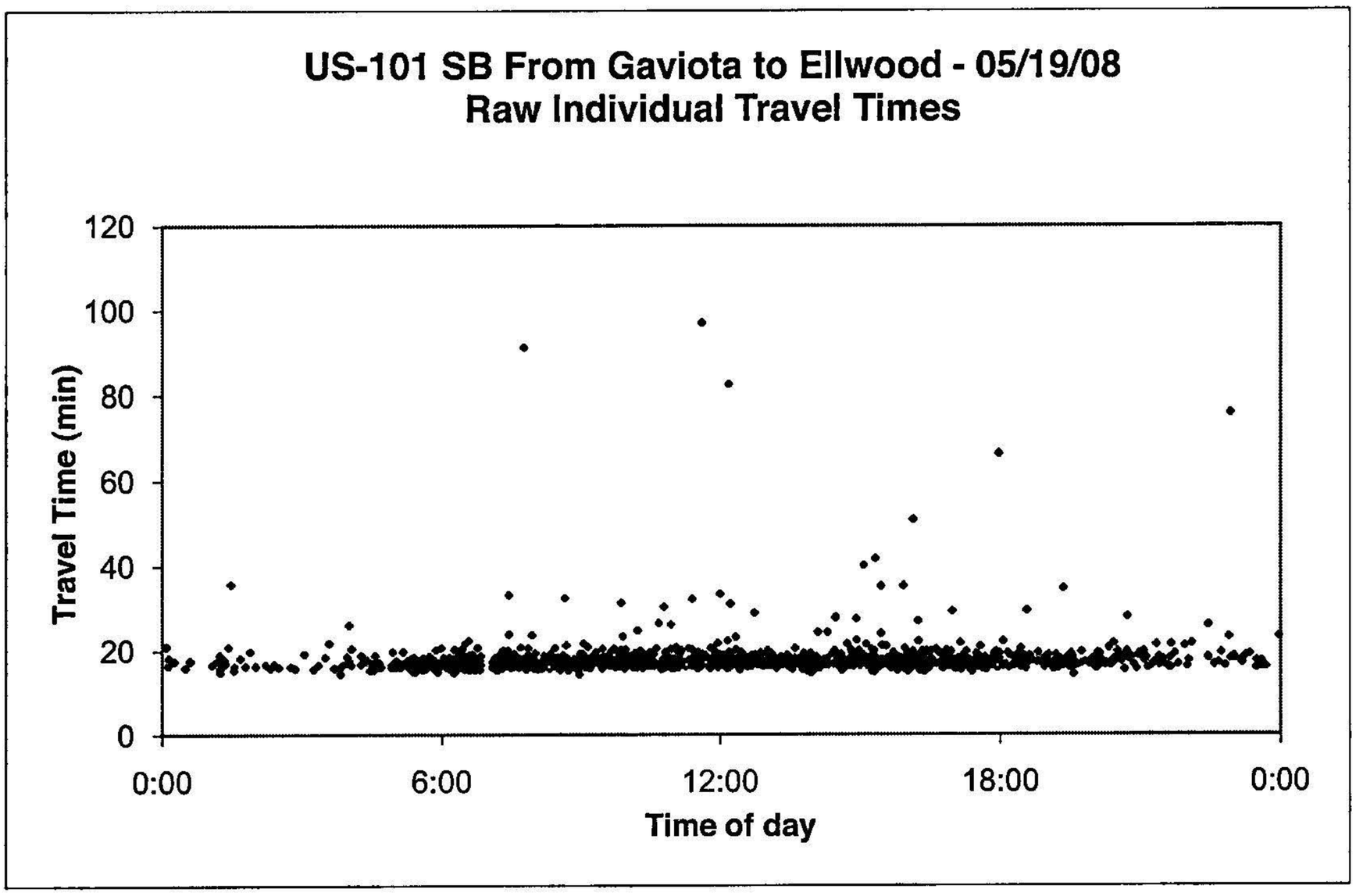

US-101 SB From Los Olivos to Gaviota - 05/27/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

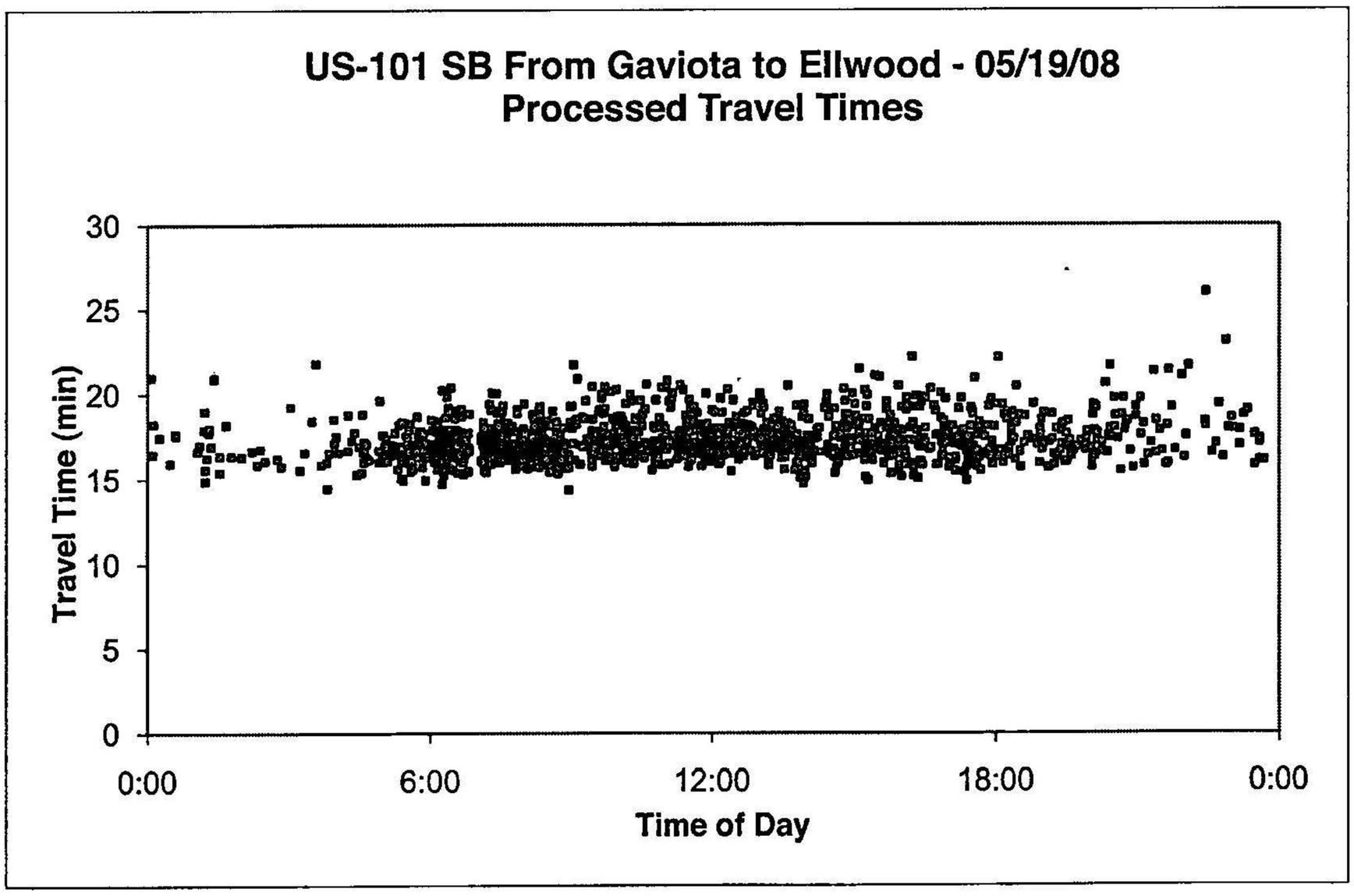

US-101 SB From Los Olivos to Gaviota - 05/27/08
Processed Travel Times
Travel Time (min)
45
40
35
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

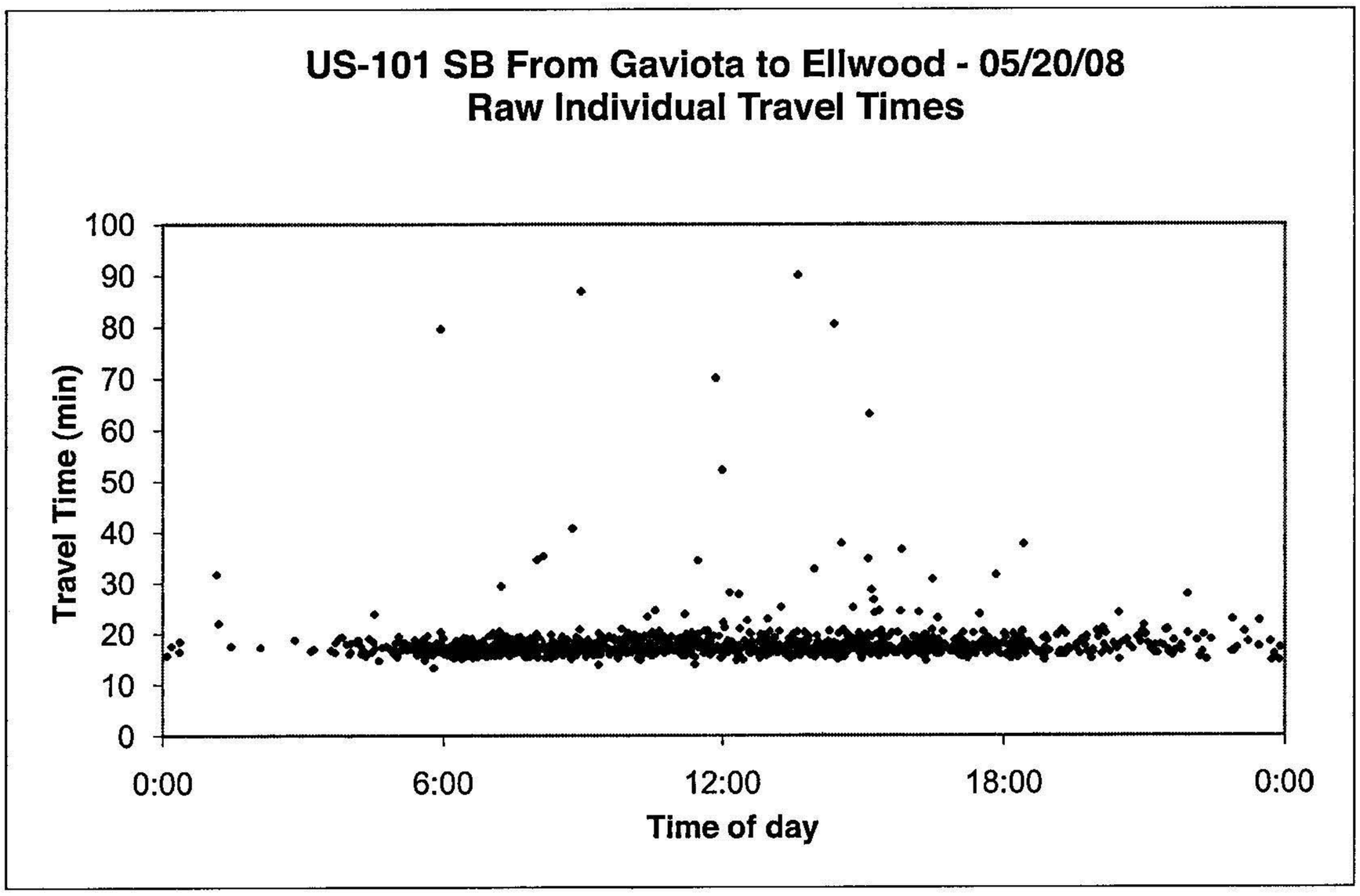
C.8 US-101 From Gaviota to Ellwood Travel Time Distribution

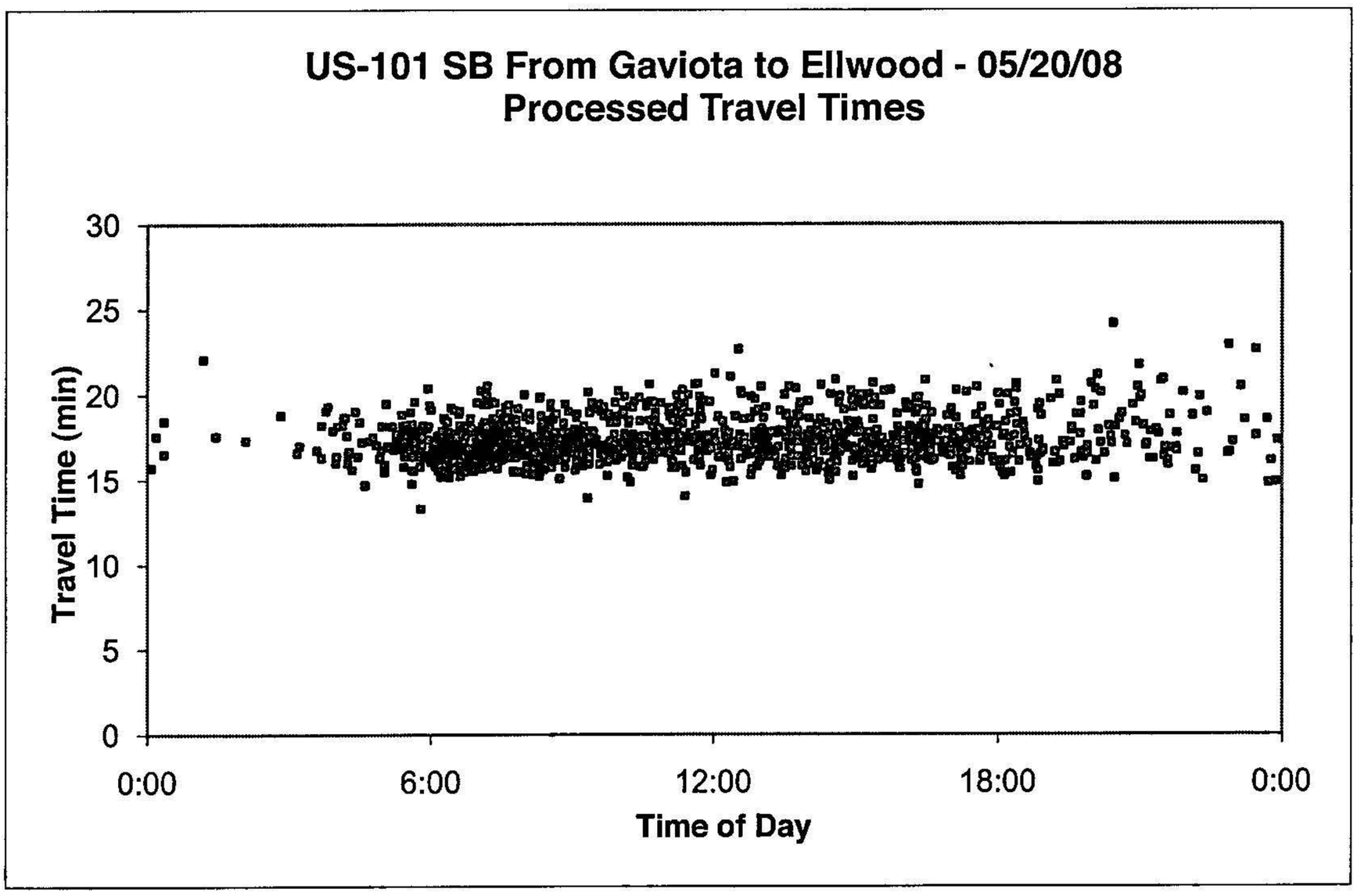


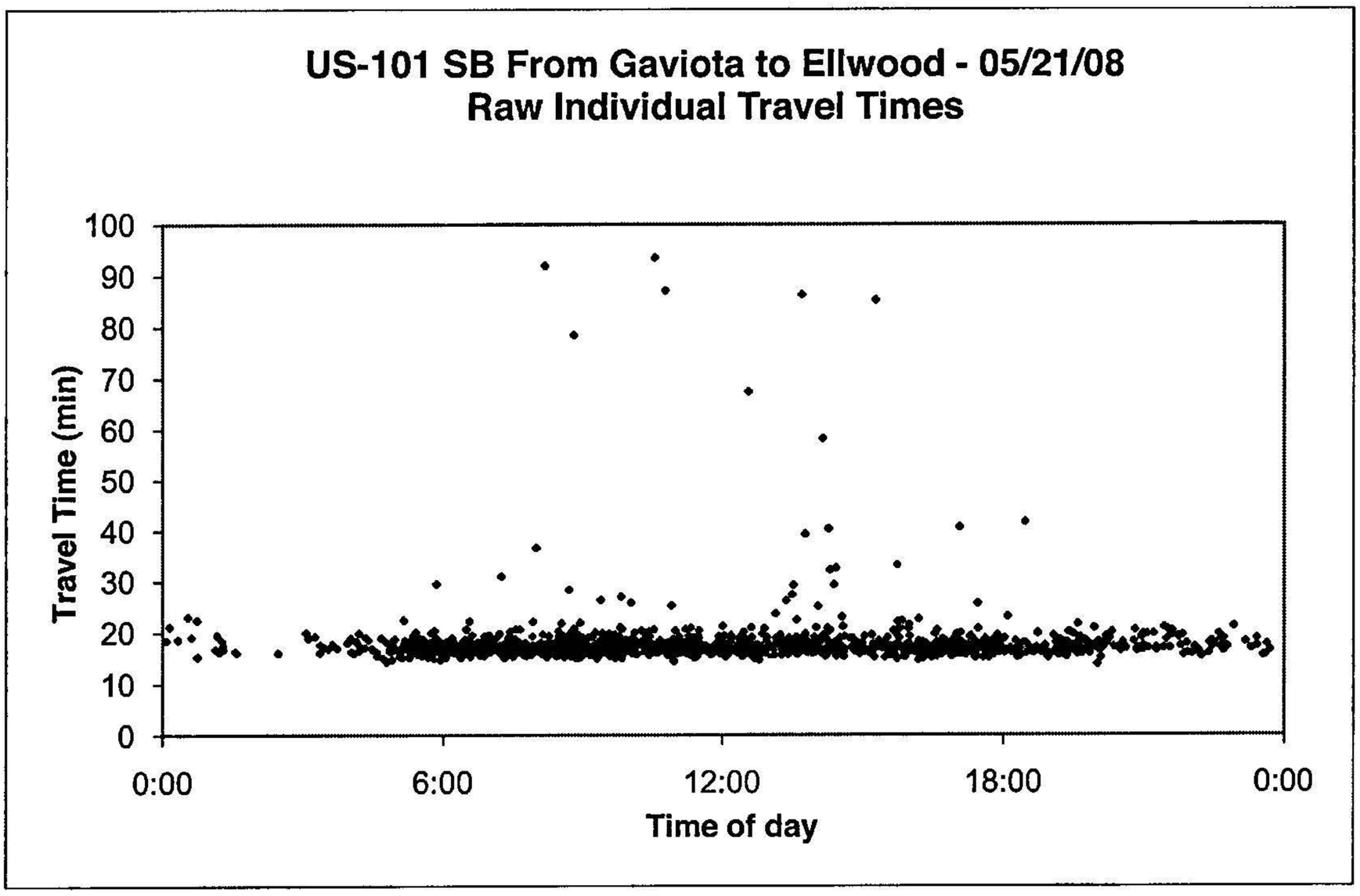


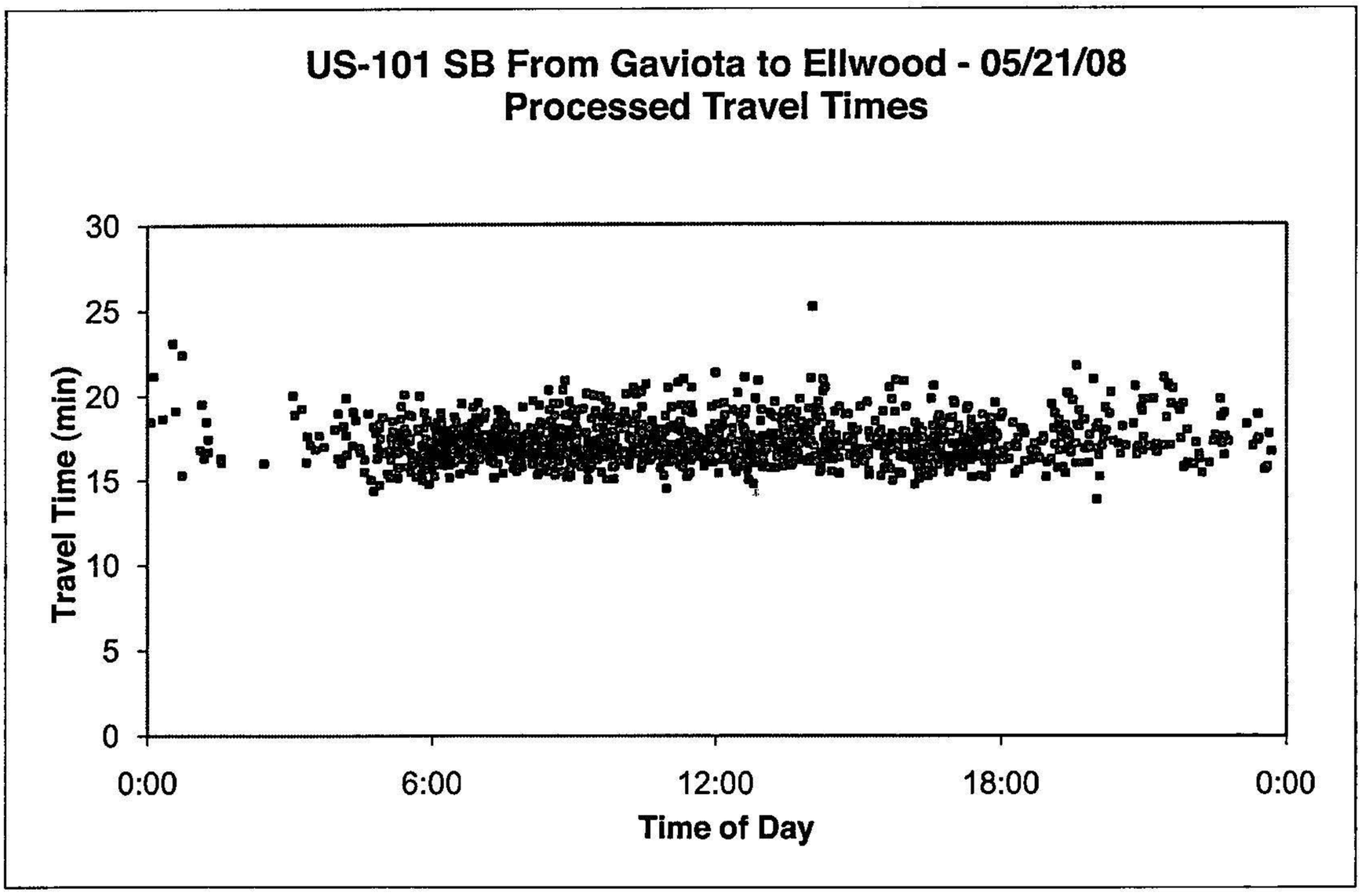

US-101 SB From Gaviota to Ellwood - 05/19/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

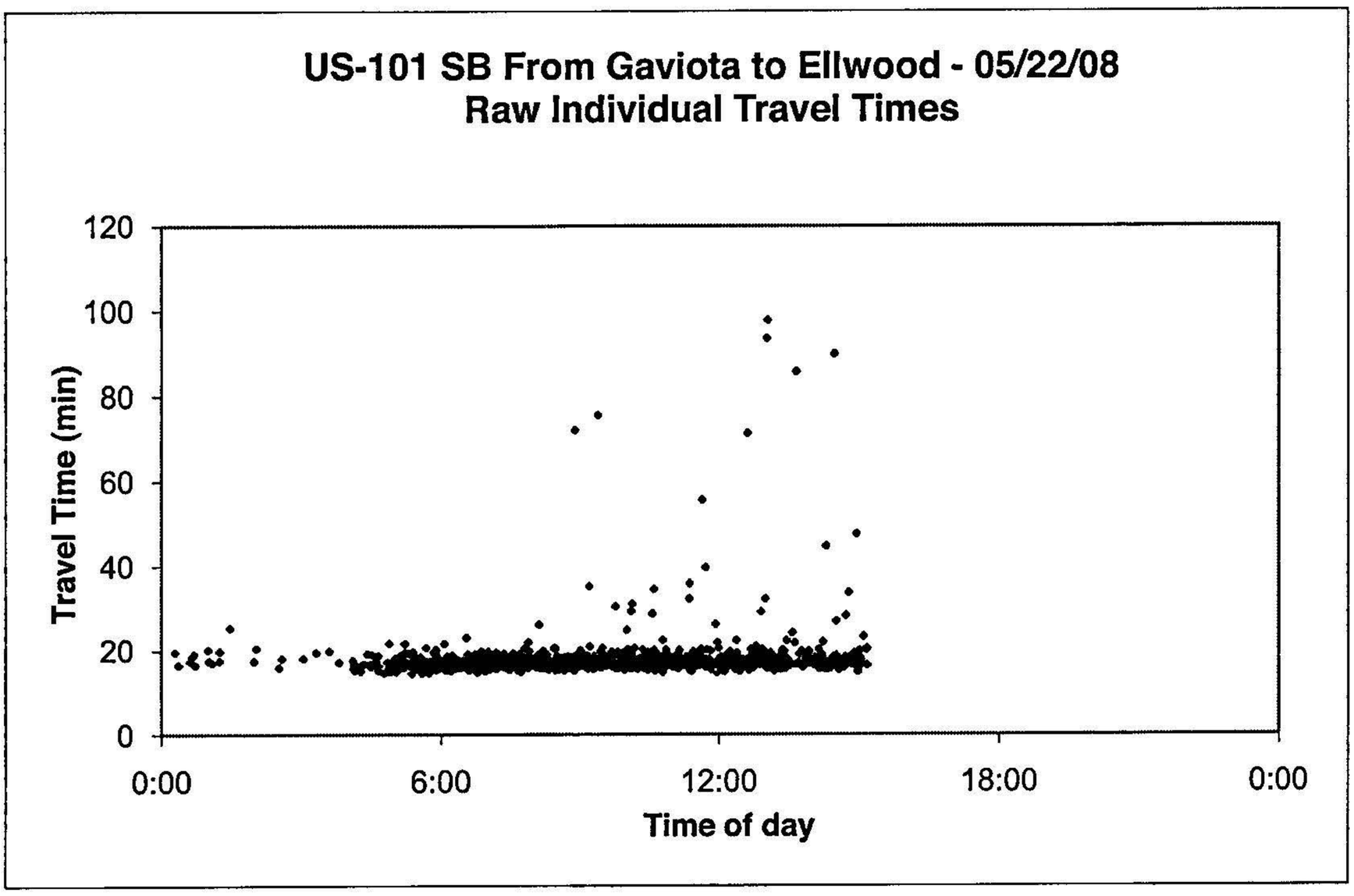

US-101 SB From Gaviota to Ellwood - 05/19/08
Processed Travel Times
Travel Time (min)
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

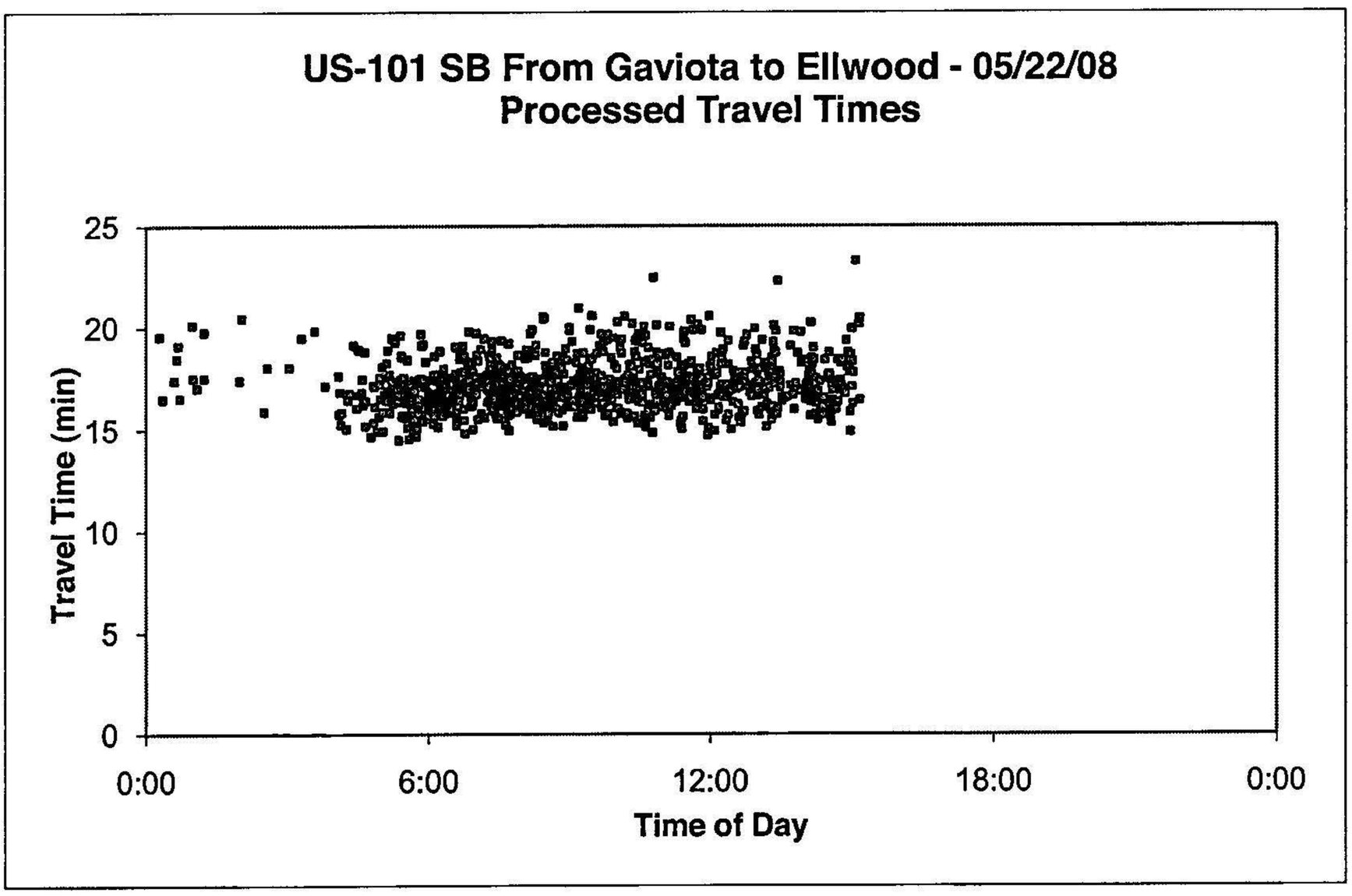

US-101 SB From Gaviota to Ellwood - 05/20/08
Raw Individual Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

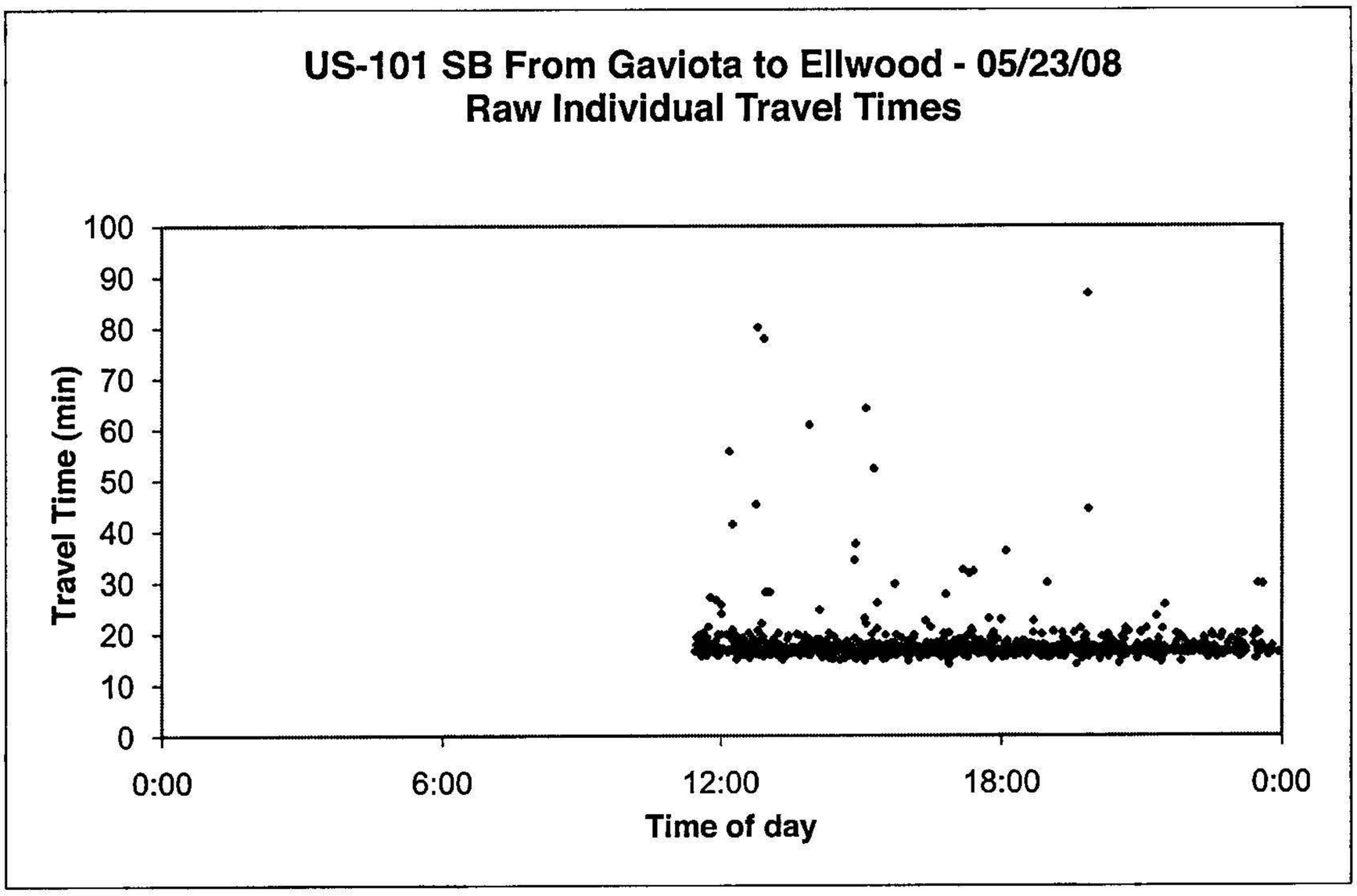

US-101 SB From Gaviota to Ellwood - 05/20/08
Processed Travel Times
Travel Time (min)
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

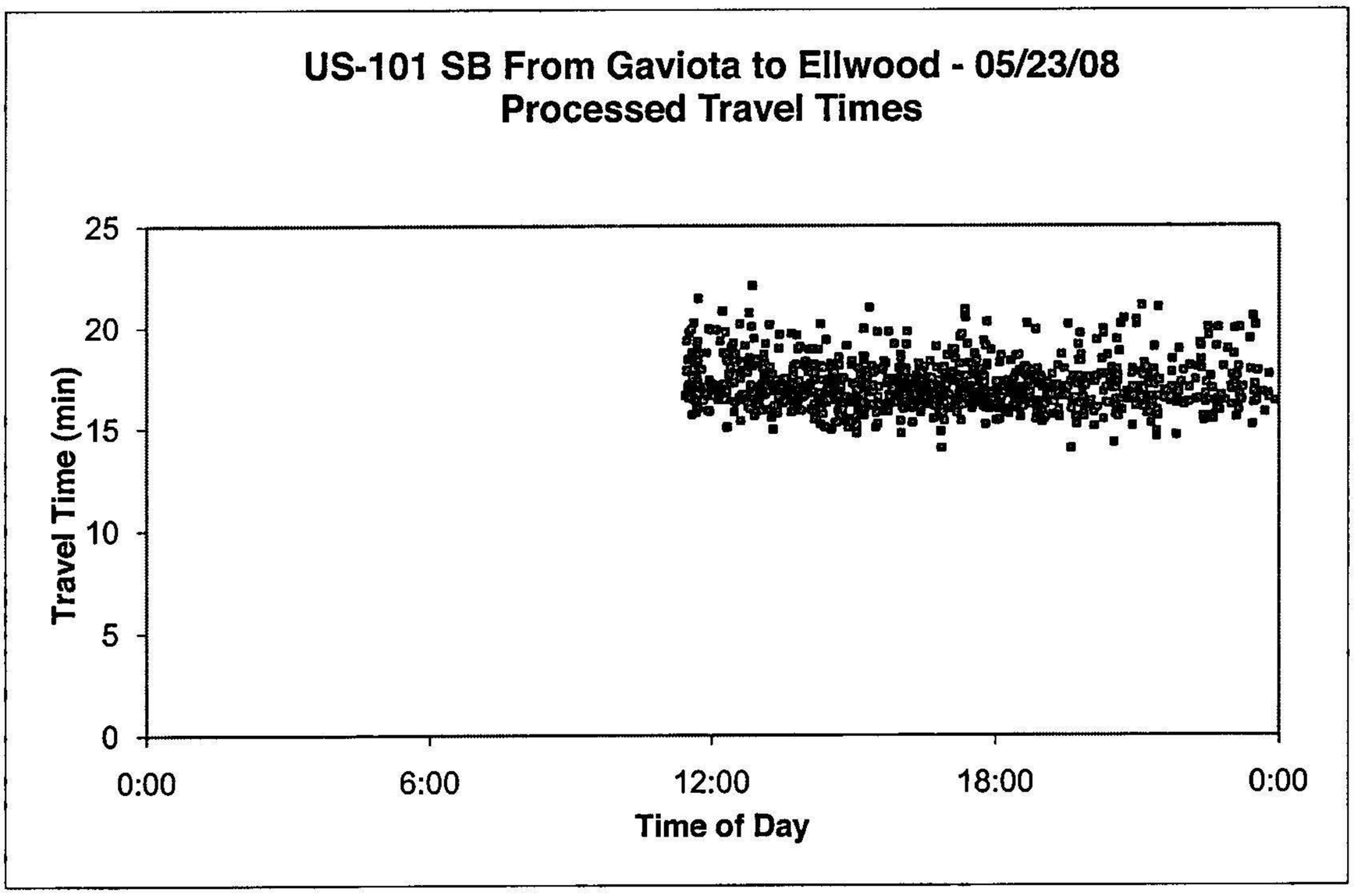

US-101 SB From Gaviota to Ellwood - 05/21/08
Raw Individual Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

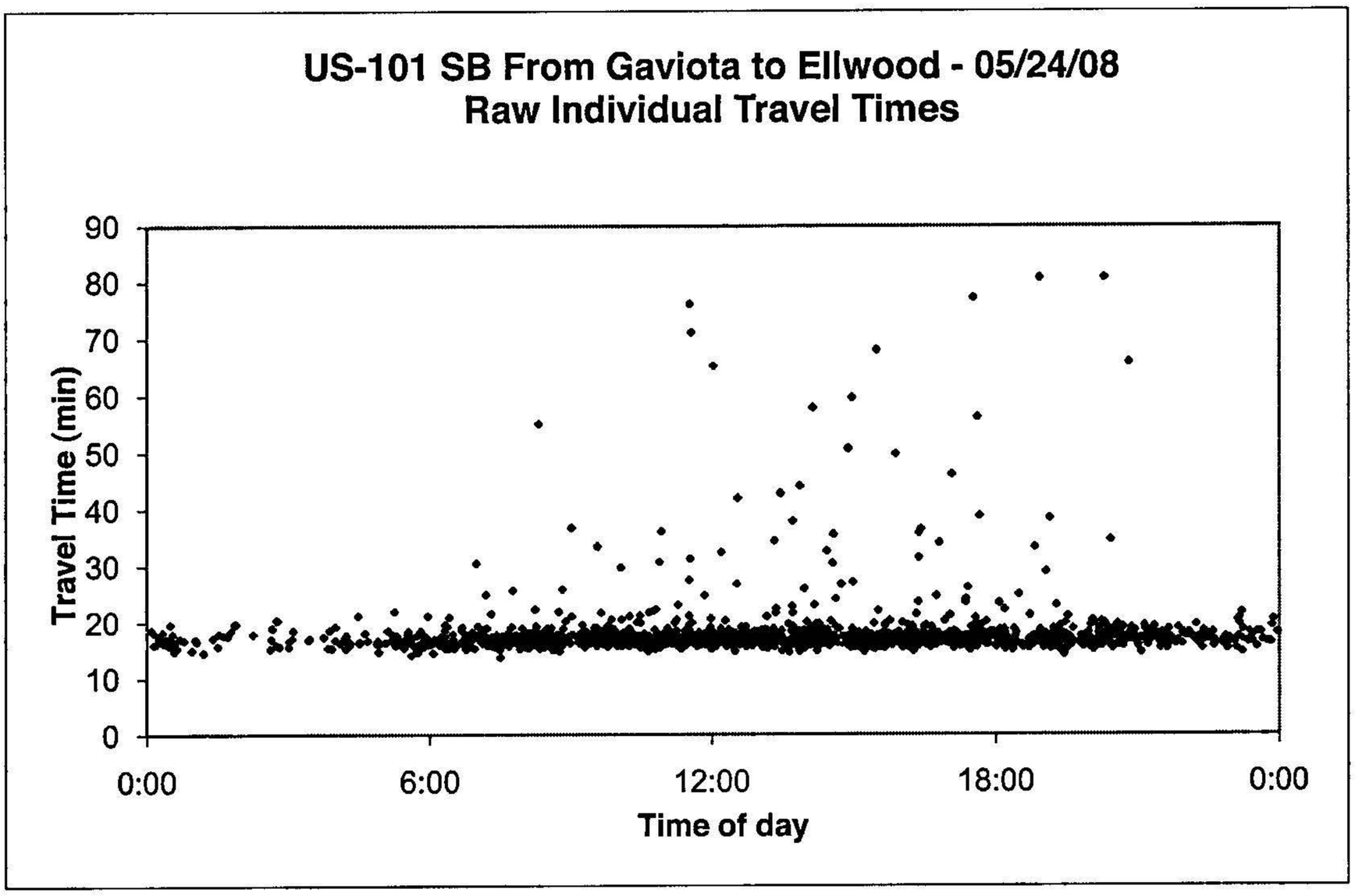

US-101 SB From Gaviota to Ellwood - 05/21/08
Processed Travel Times
Travel Time (min)
30
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

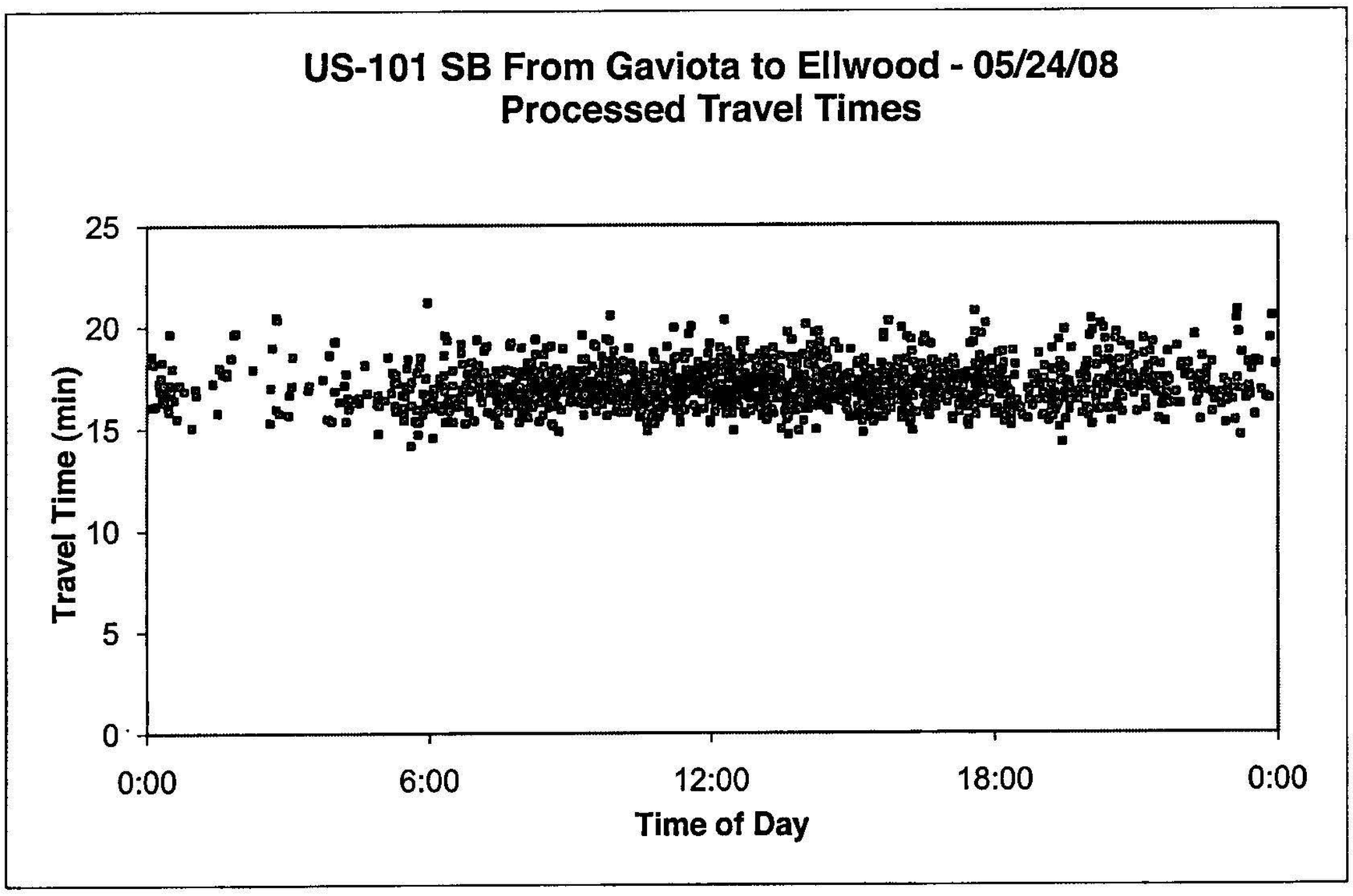

US-101 SB From Gaviota to Ellwood - 05/22/08
Raw Individual Travel Times
Travel Time (min)
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

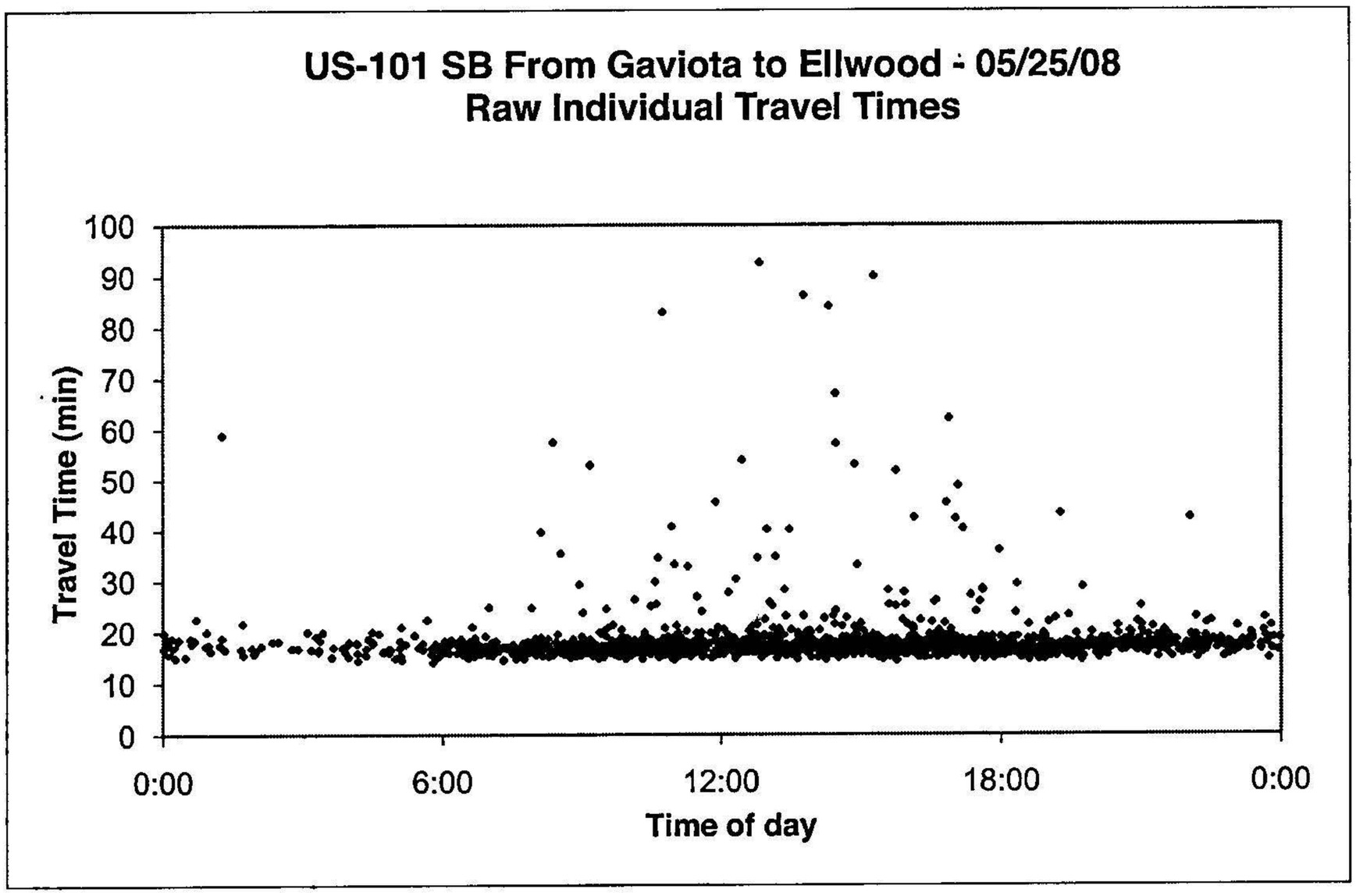

US-101 SB From Gaviota to Ellwood - 05/22/08
Processed Travel Times
Travel Time (min)
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

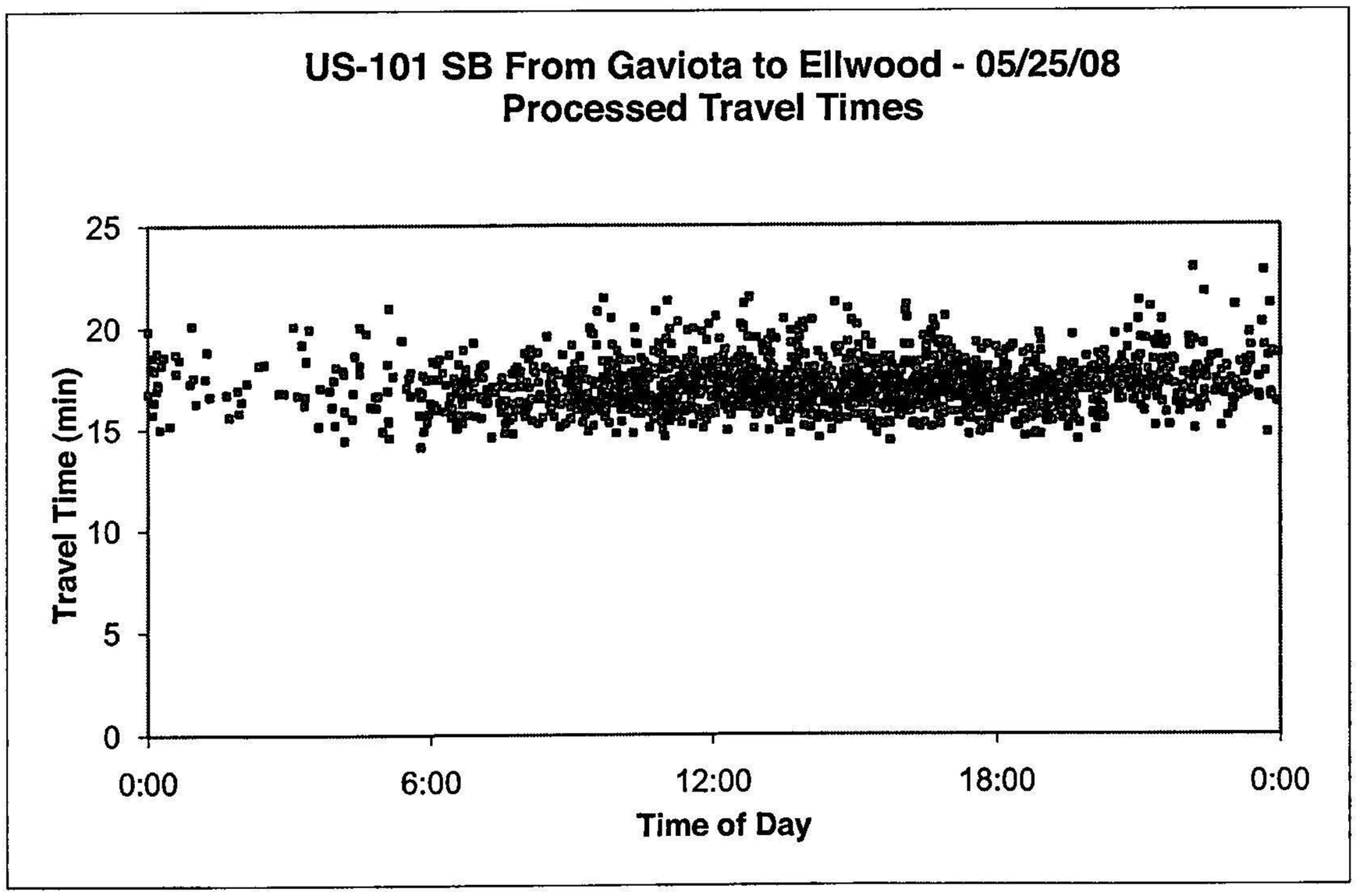

US-101 SB From Gaviota to Ellwood - 05/23/08
Raw Individual Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Gaviota to Ellwood - 05/23/08
Processed Travel Times
Travel Time (min)
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

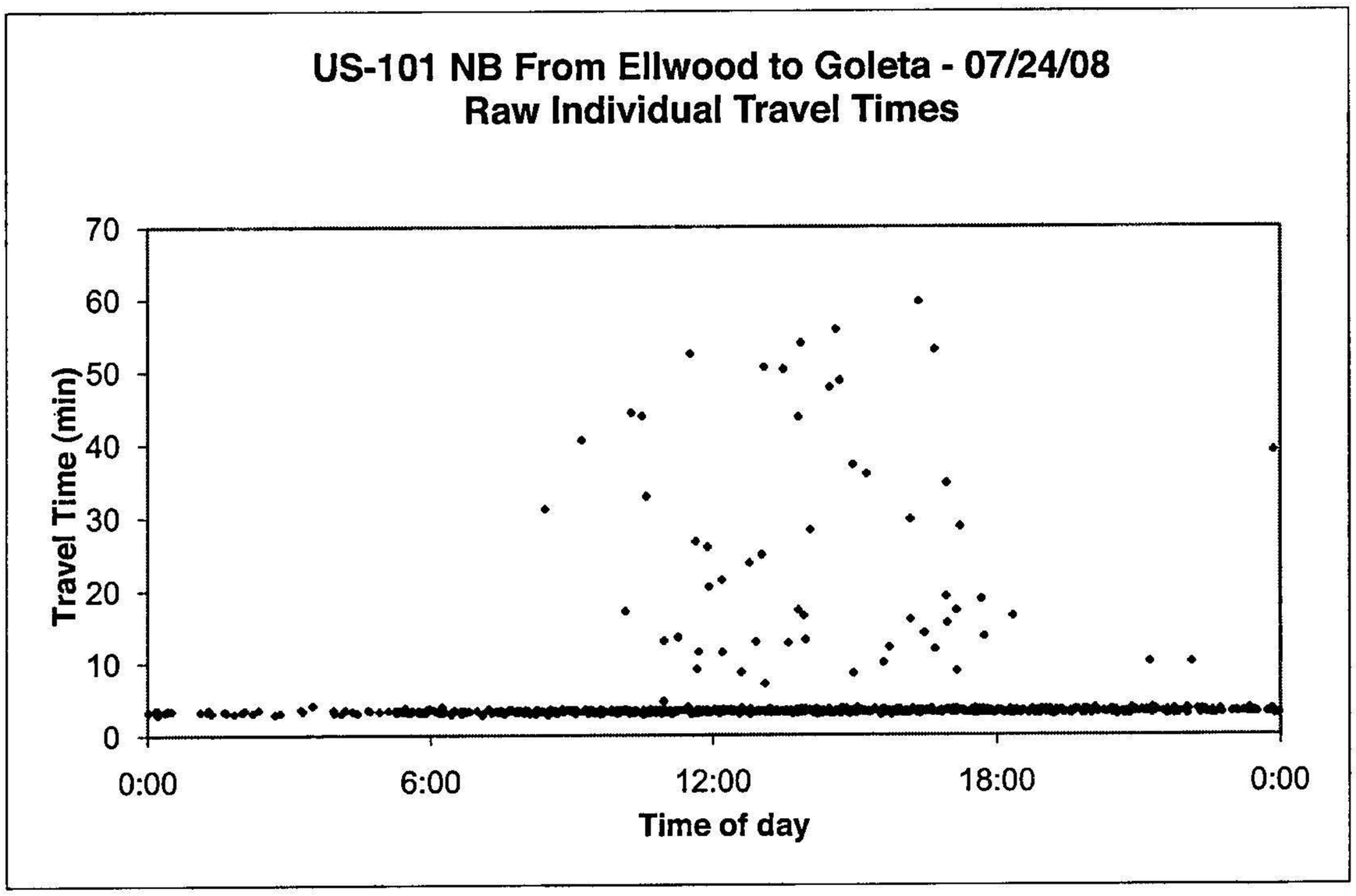

US-101 SB From Gaviota to Ellwood - 05/24/08
Raw Individual Travel Times
Travel Time (min)
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

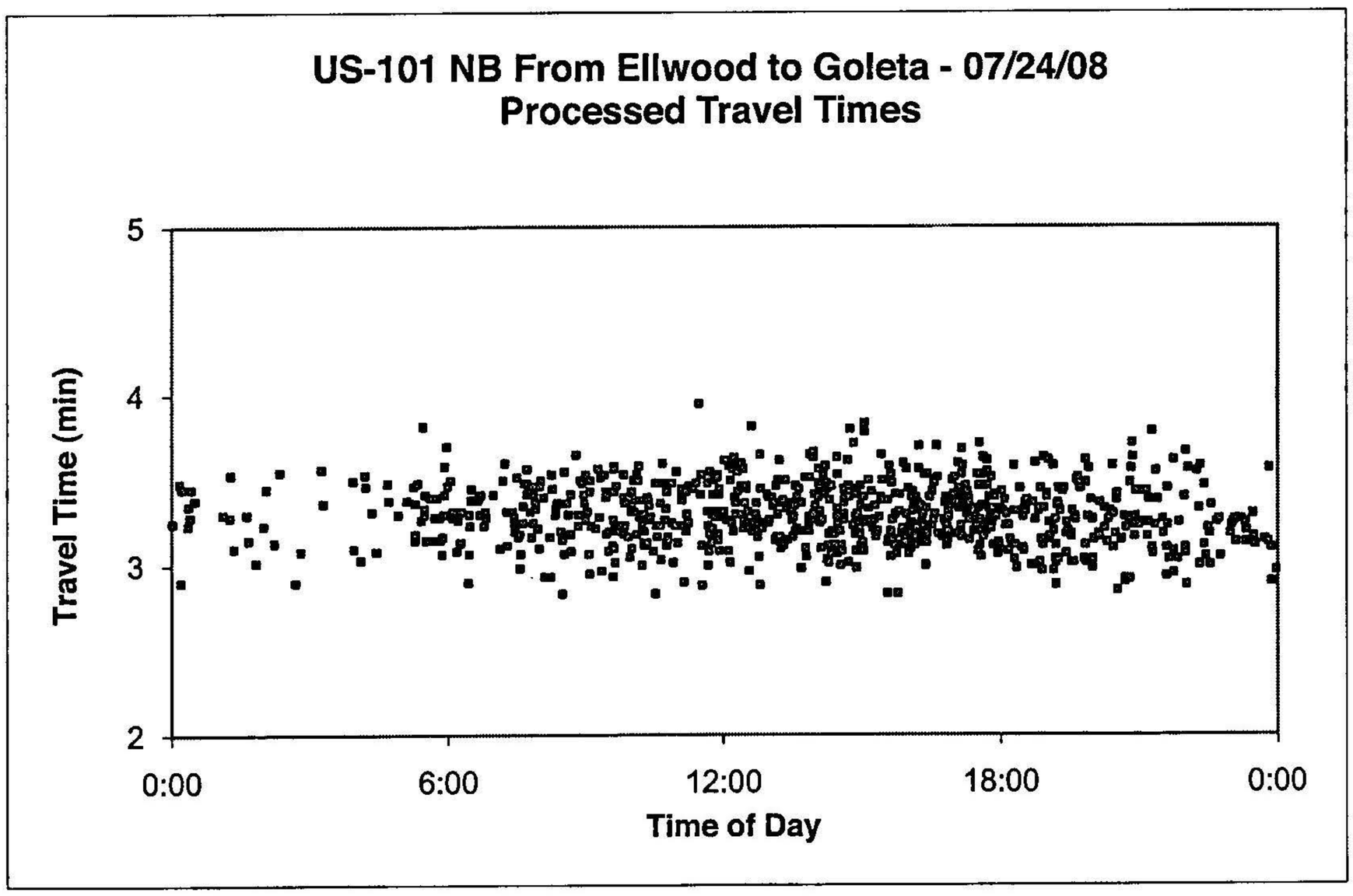

US-101 SB From Gaviota to Ellwood - 05/24/08
Processed Travel Times
Travel Time (min)
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

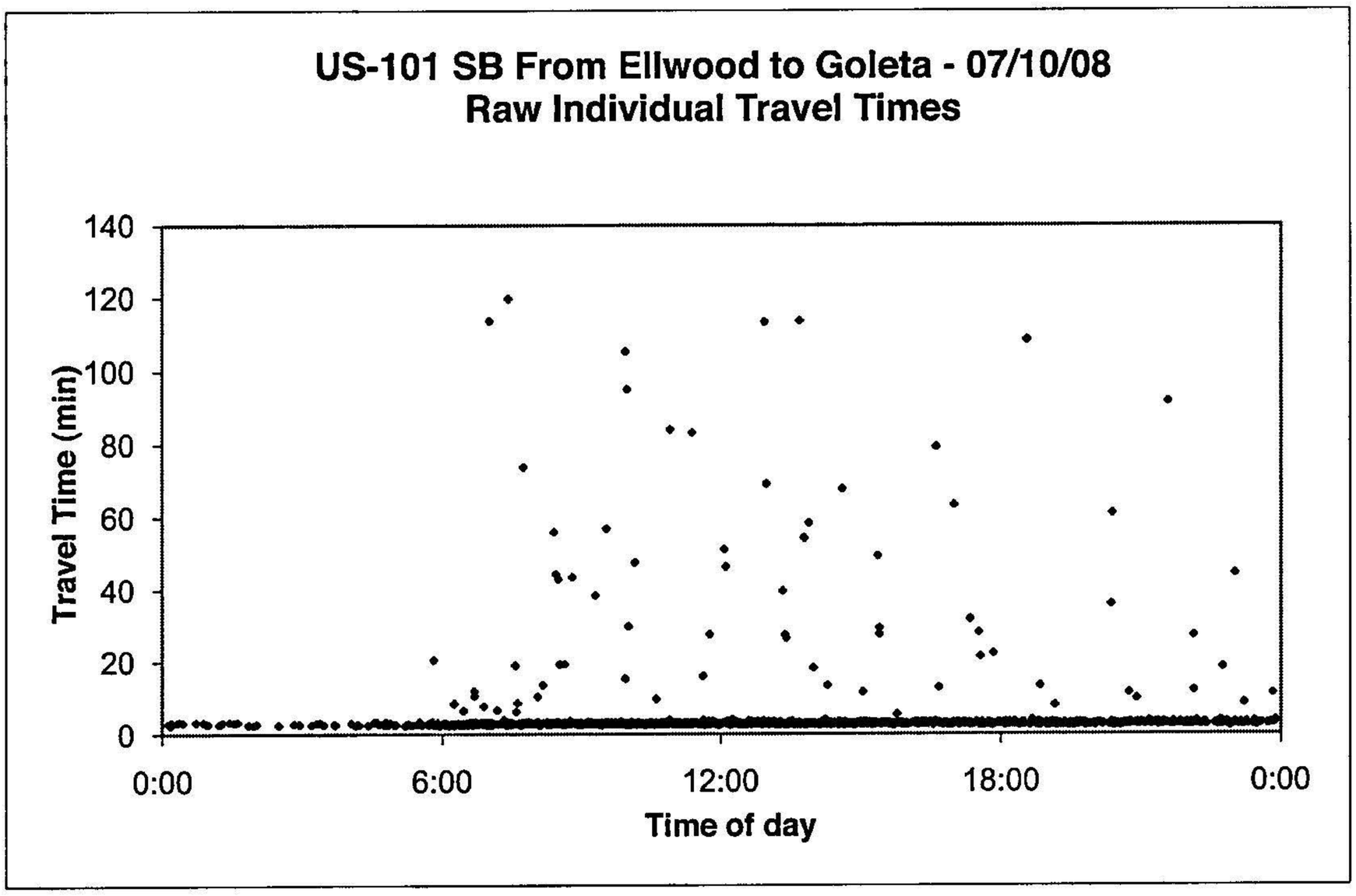

US-101 SB From Gaviota to Ellwood - 05/25/08
Raw Individual Travel Times
Travel Time (min)
100
90
80
70
60
50
40
30
20
10
0
0:00
6:00
12:00
18:00
0:00
Time of day

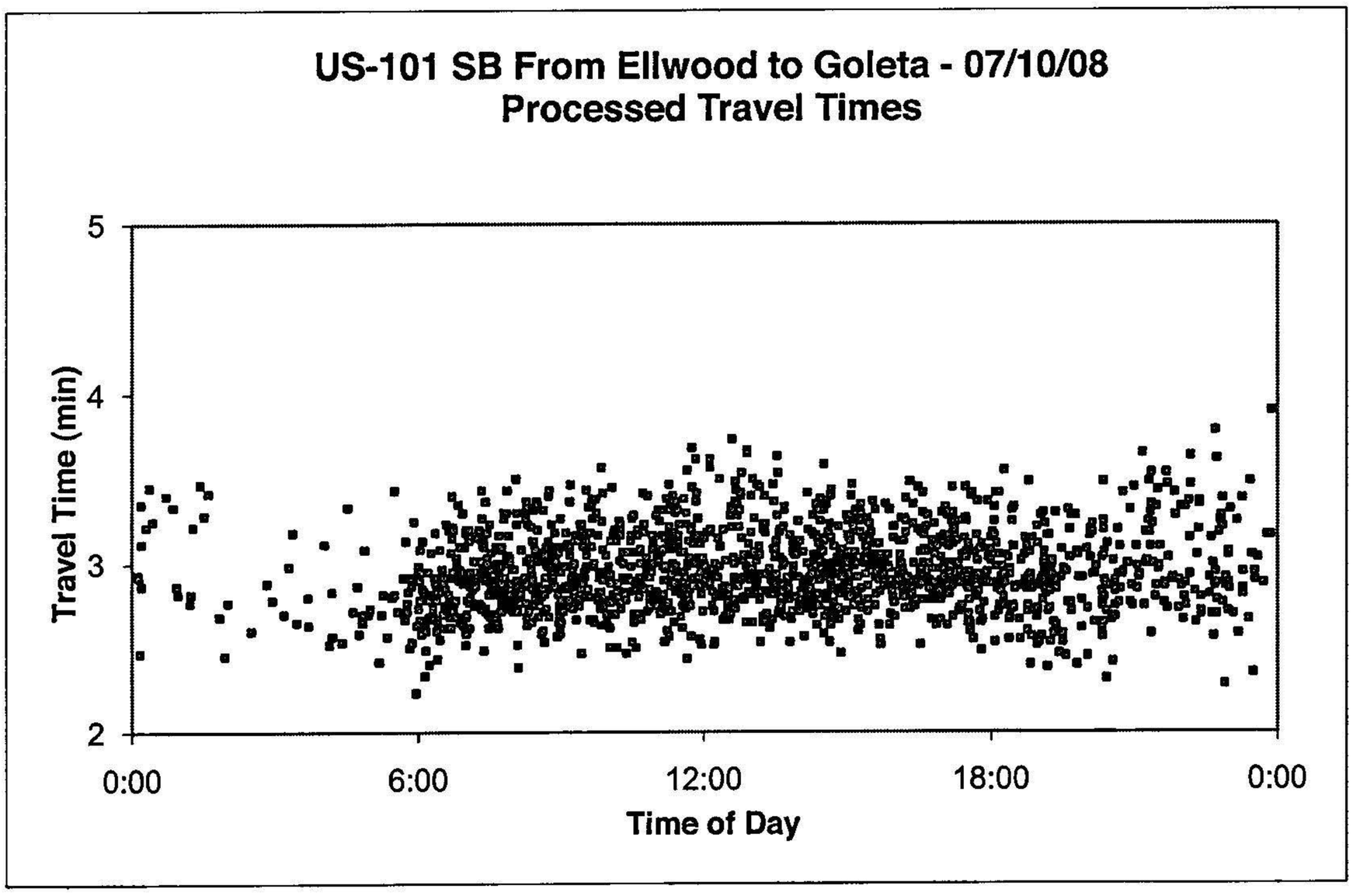

US-101 SB From Gaviota to Ellwood - 05/25/08
Processed Travel Times
Travel Time (min)
25
20
15
10
5
0
0:00
6:00
12:00
18:00
0:00
Time of Day

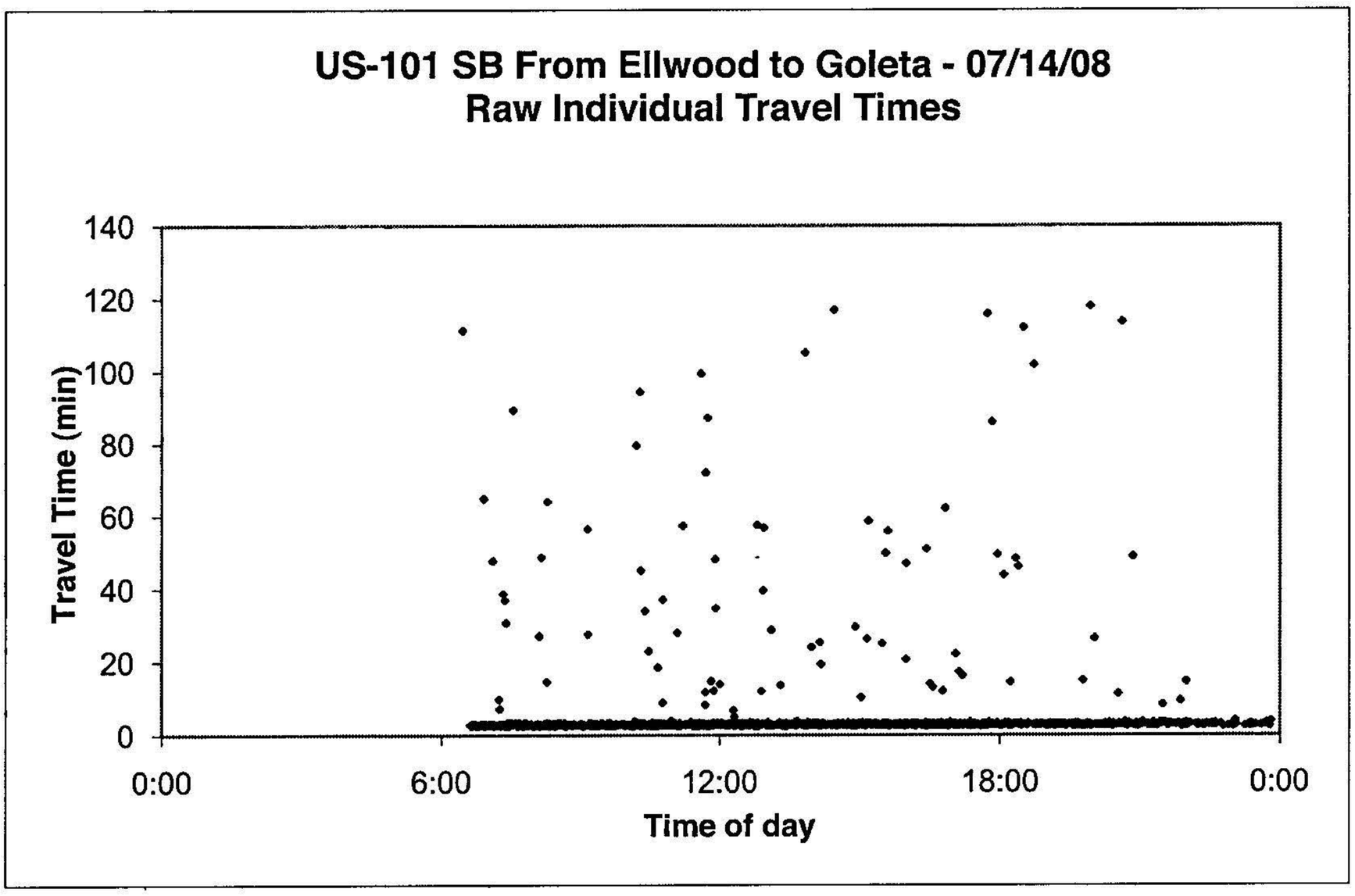
C.9 US-101 From Ellwood to Goleta Travel Time Distribution

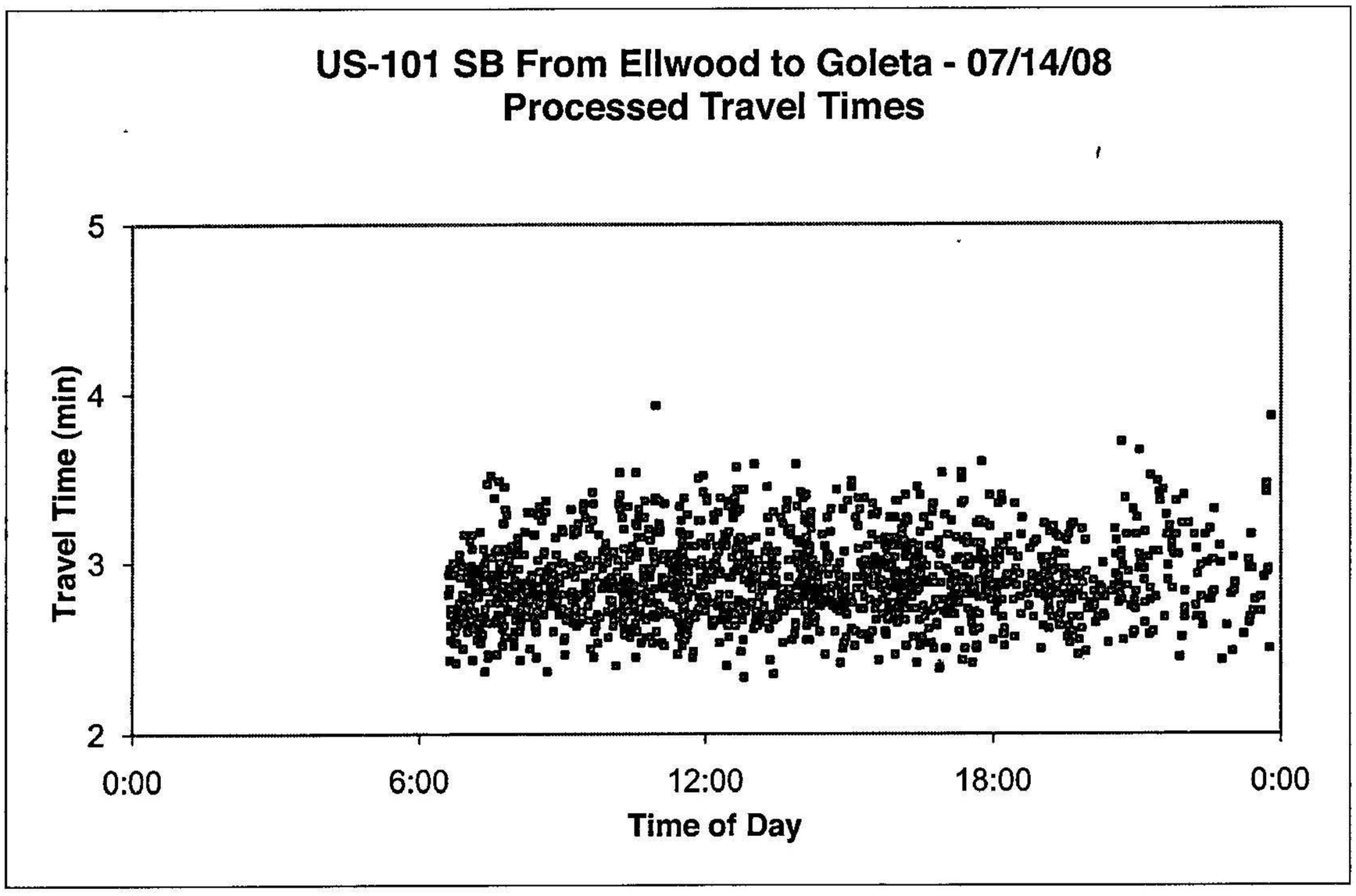


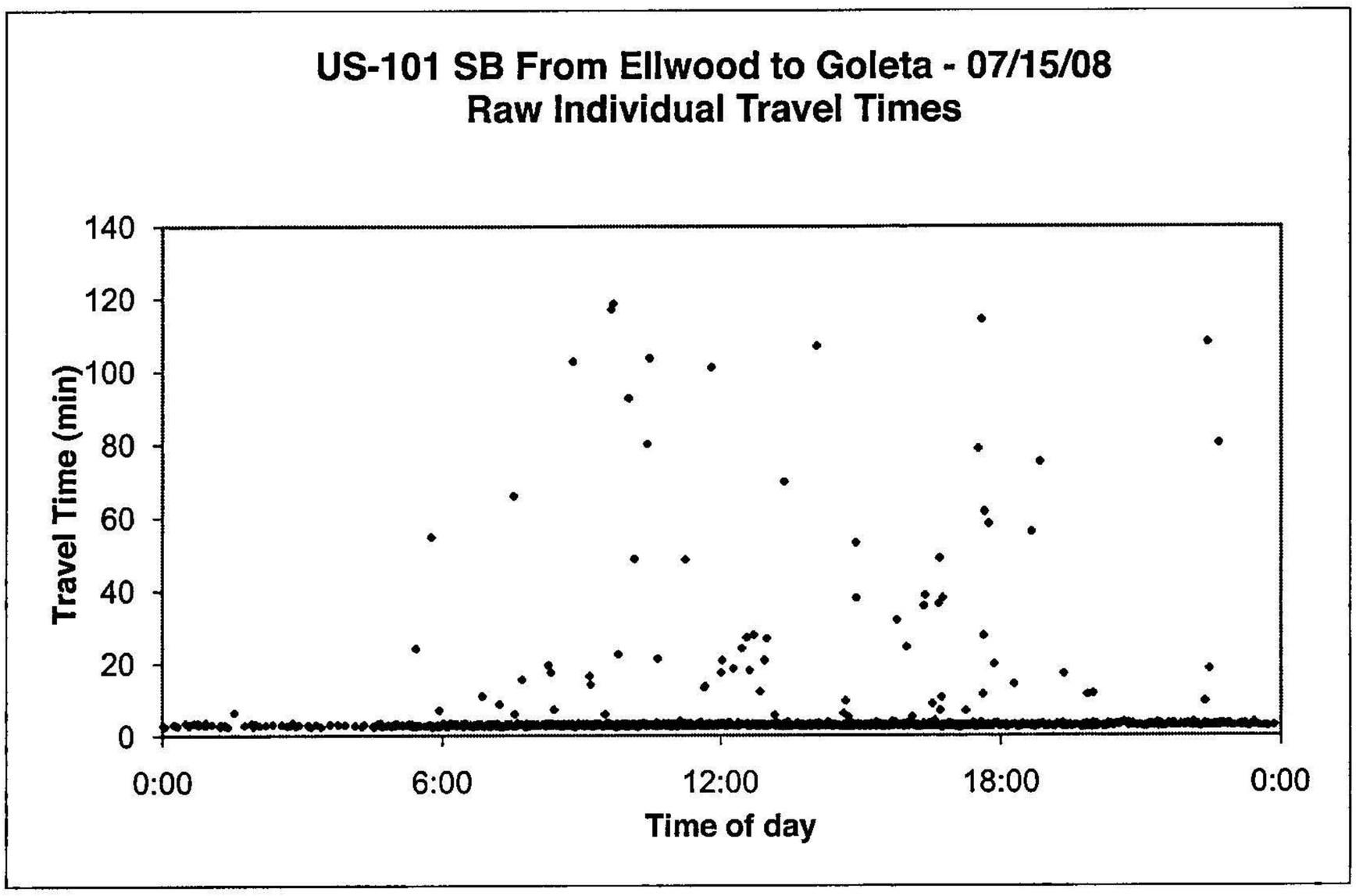


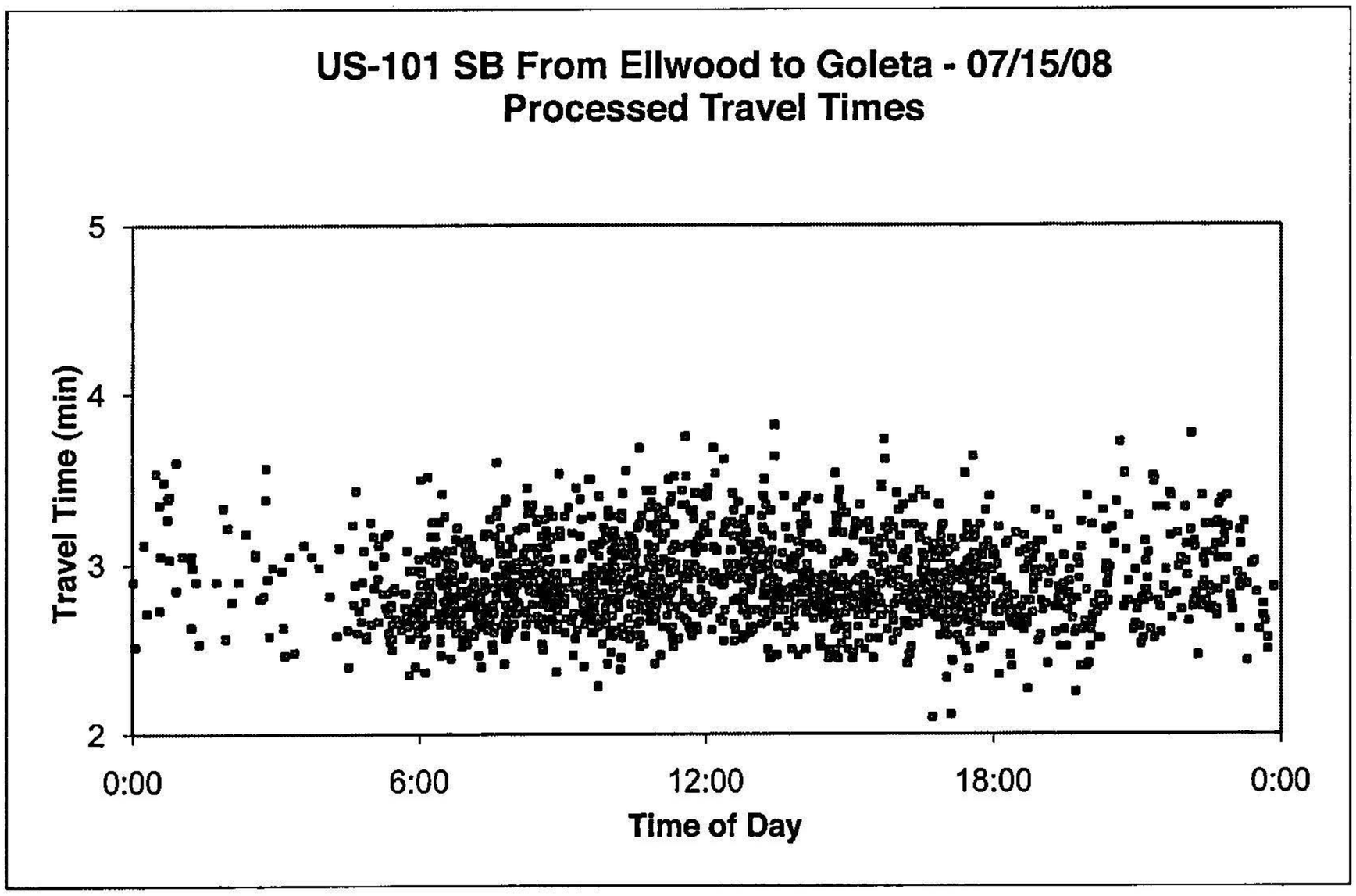

US-101 SB From Ellwood to Goleta - 07/10/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

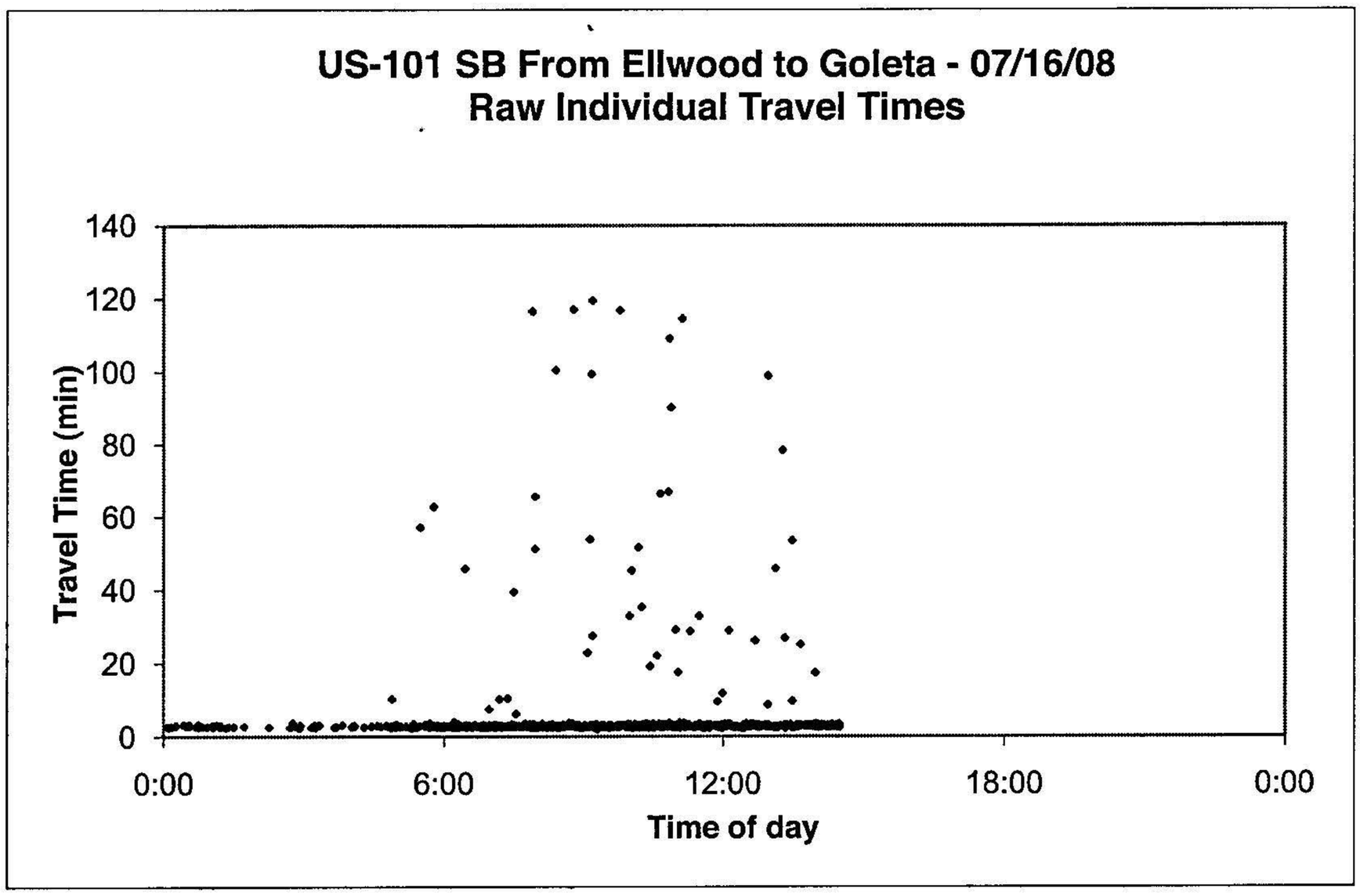

US-101 SB From Ellwood to Goleta - 07/10/08
Processed Travel Times
Travel Time (min)
5
4
3
2
0:00
6:00
12:00
18:00
0:00
Time of Day

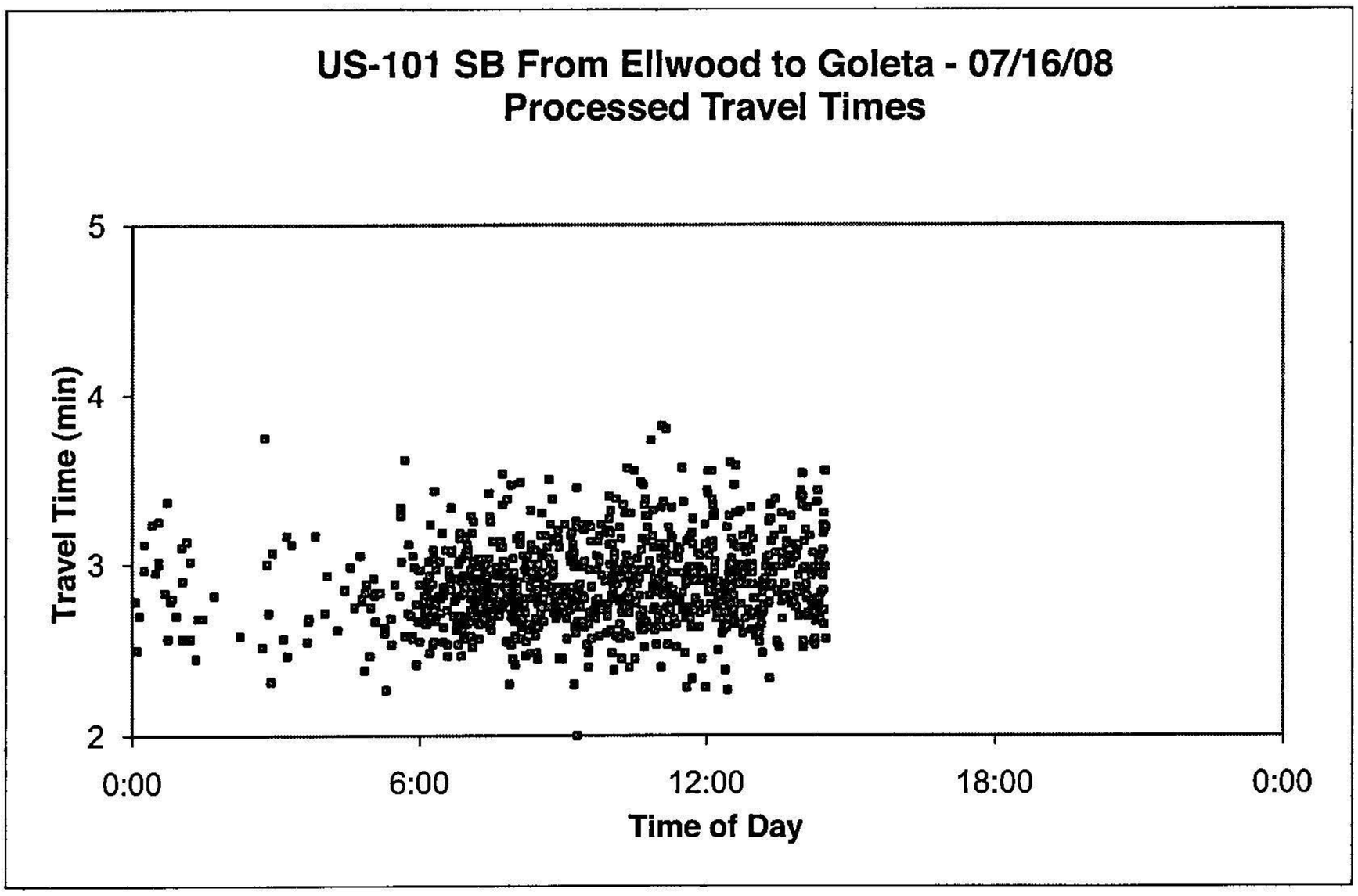

US-101 SB From Ellwood to Goleta - 07/14/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Ellwood to Goleta - 07/14/08
Processed Travel Times
Travel Time (min)
5
4
3
2
0:00
6:00
12:00
18:00
0:00
Time of Day

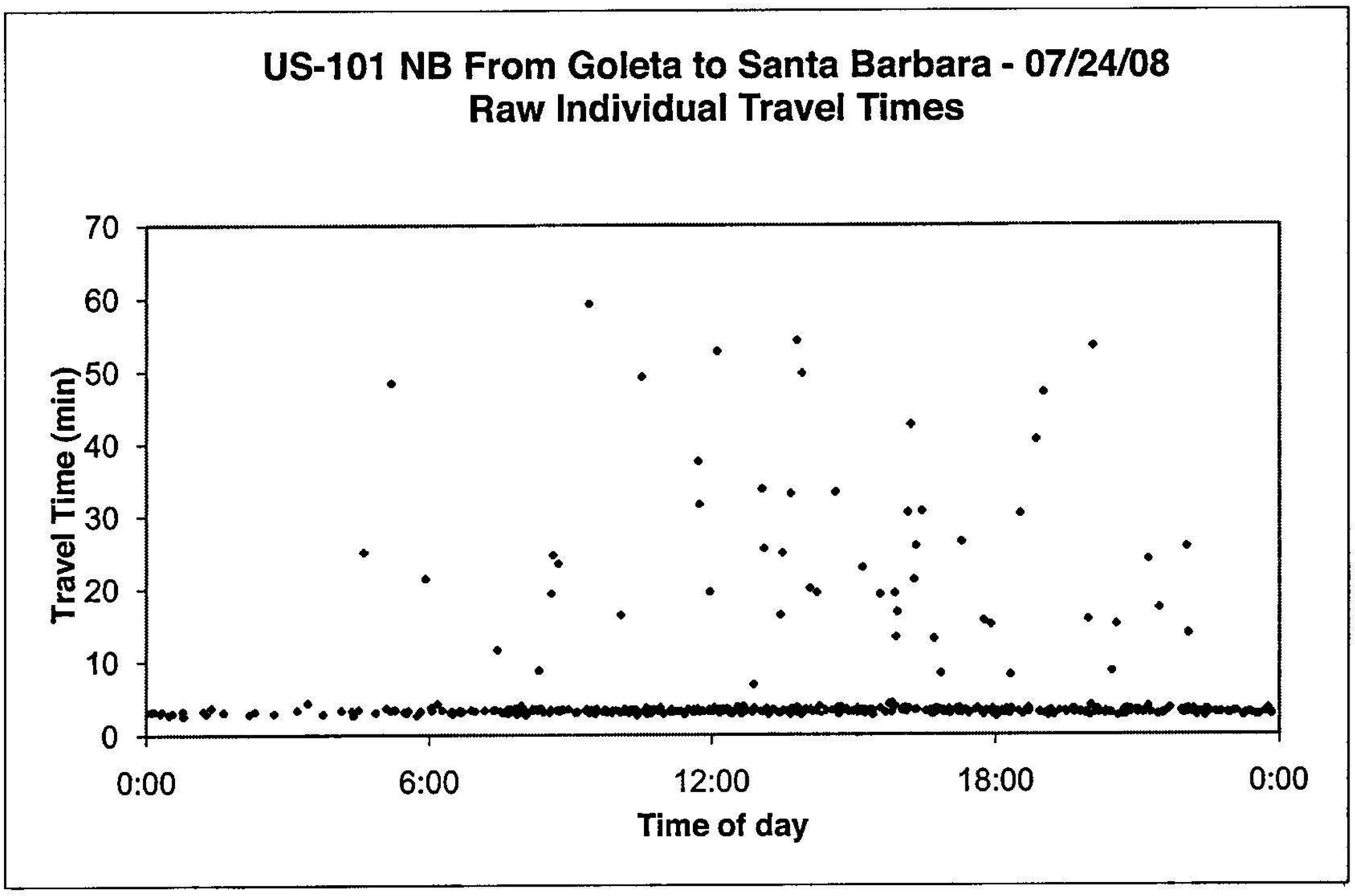

US-101 SB From Ellwood to Goleta - 07/15/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

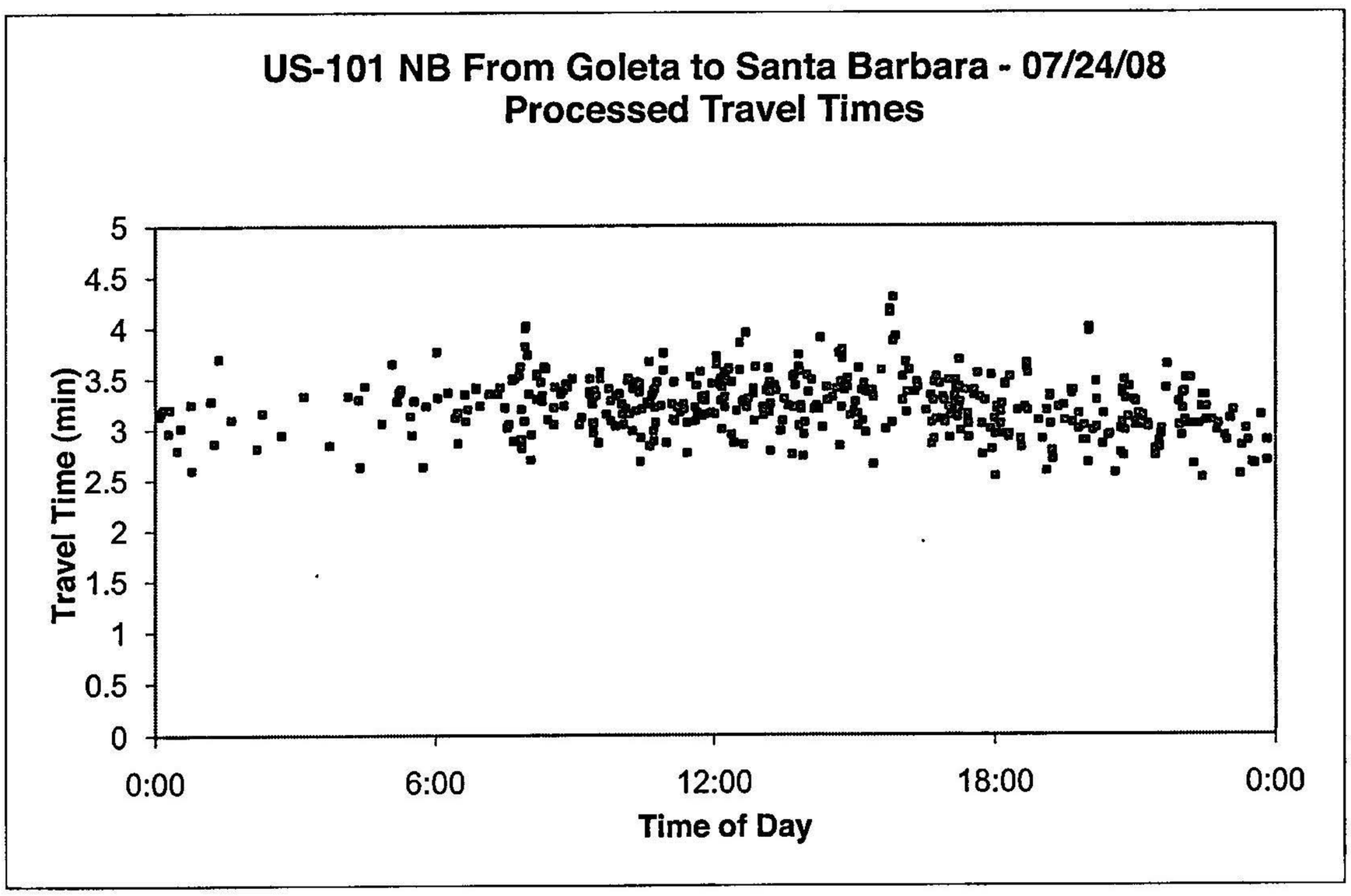

US-101 SB From Ellwood to Goleta - 07/15/08
Processed Travel Times
Travel Time (min)
5
4
3
2
0:00
6:00
12:00
18:00
0:00
Time of Day

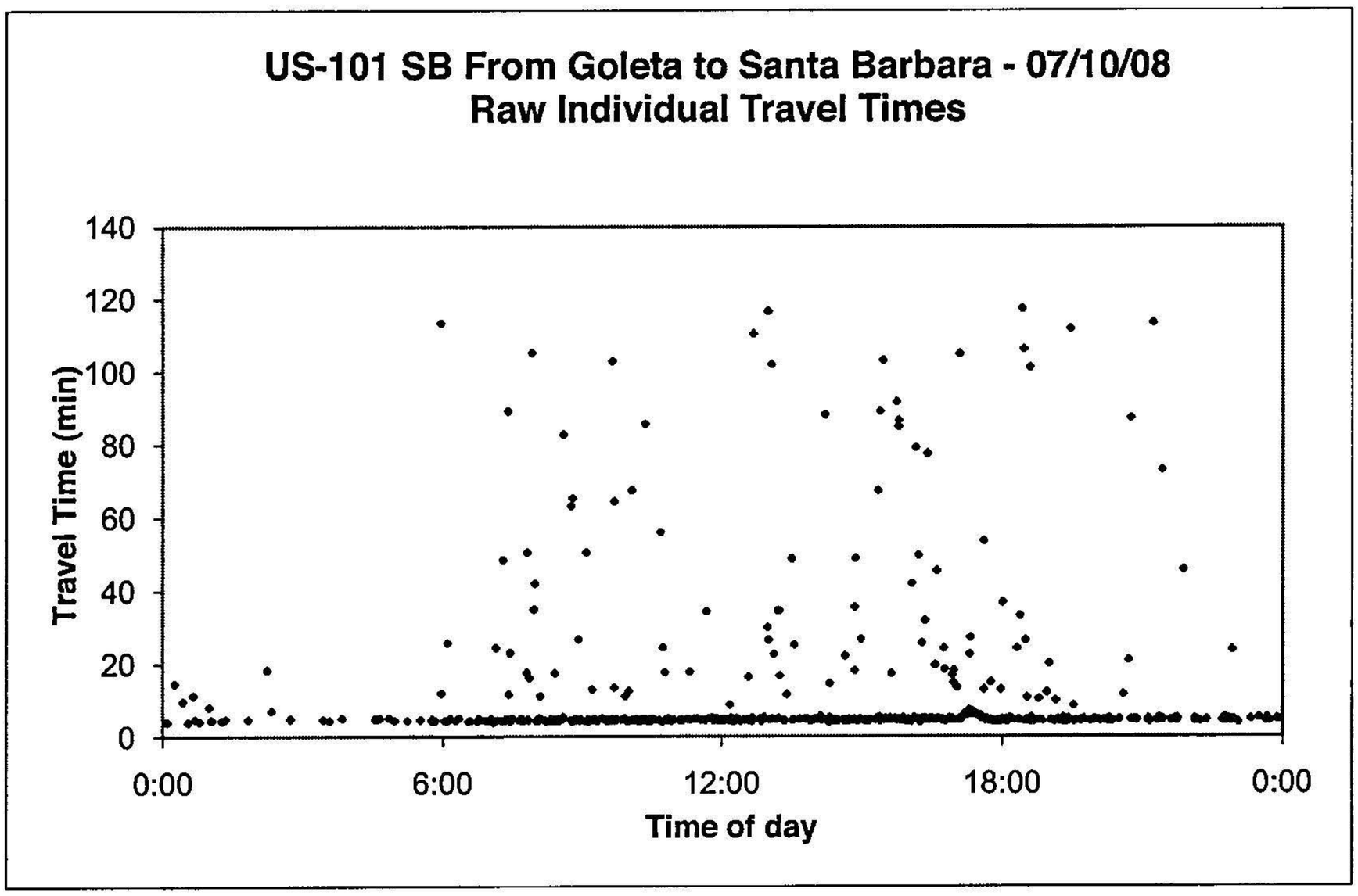

US-101 SB From Ellwood to Goleta - 07/16/08
Raw Individual Travel Times
Travel Time (min)
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120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

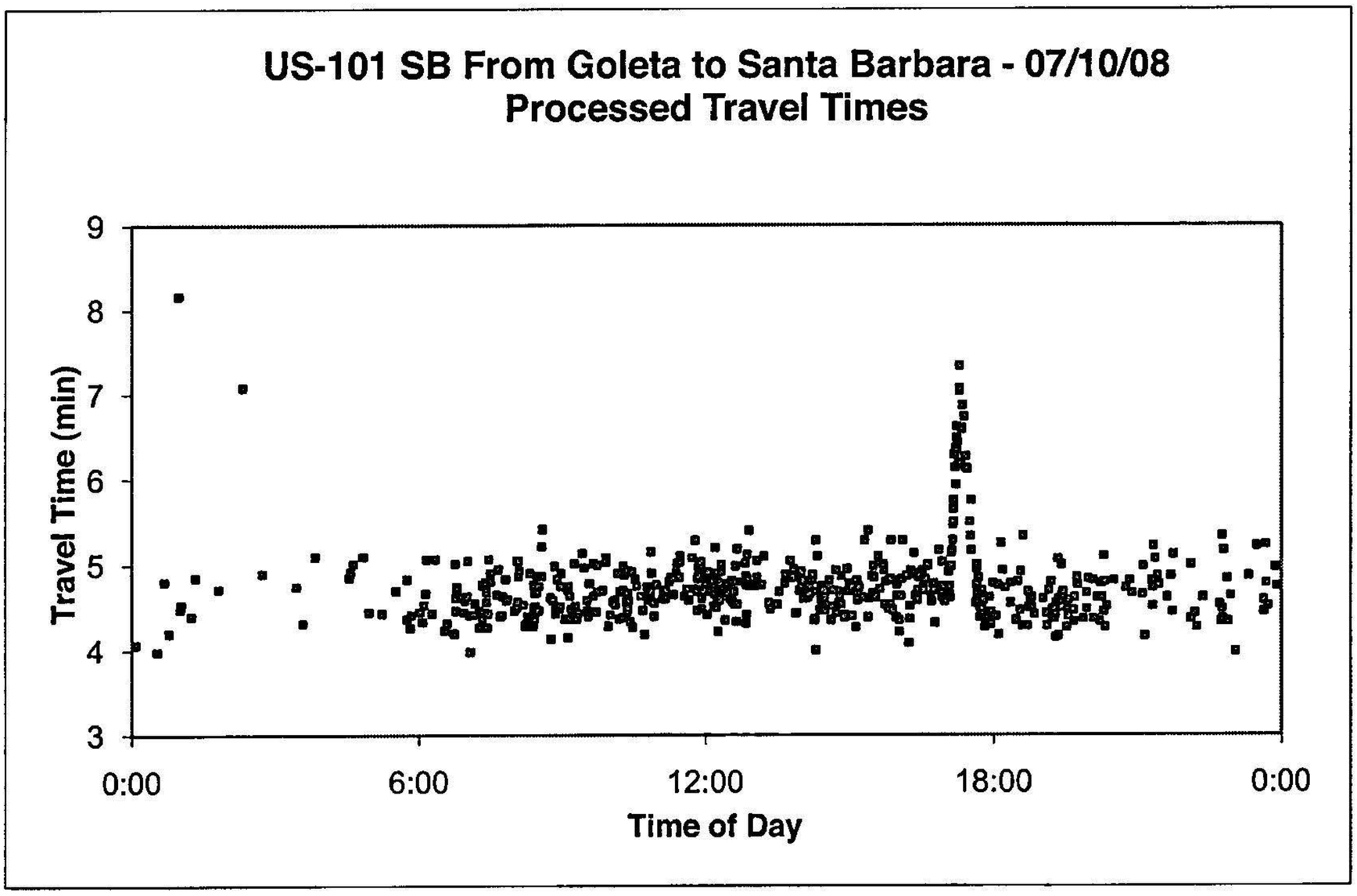

US-101 SB From Ellwood to Goleta - 07/16/08
Processed Travel Times
Travel Time (min)
5
4
3
2
0:00
6:00
12:00
18:00
0:00
Time of Day

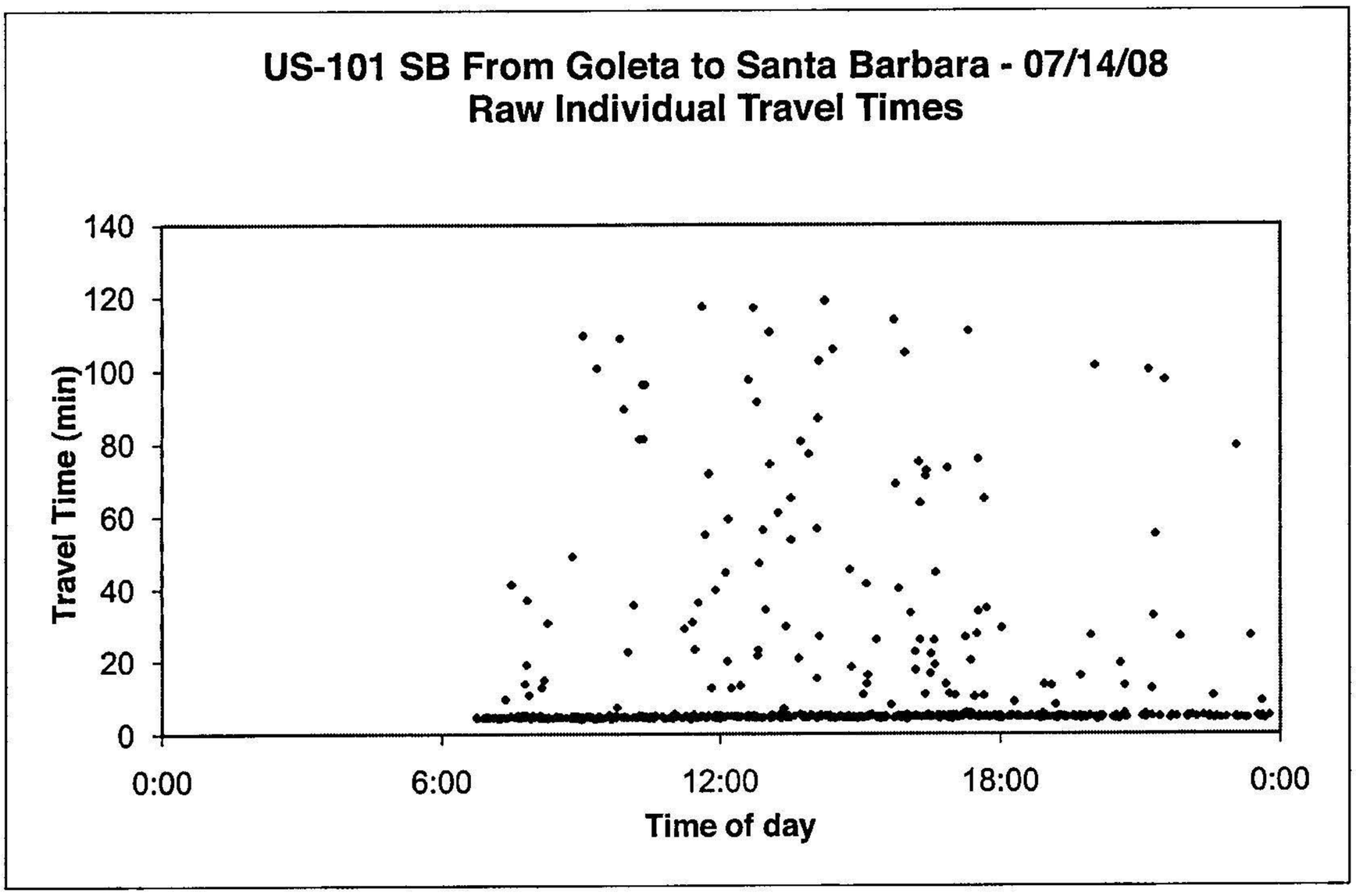
C.10 US-101 From Goleta to Santa Barbara Travel Time Distribution

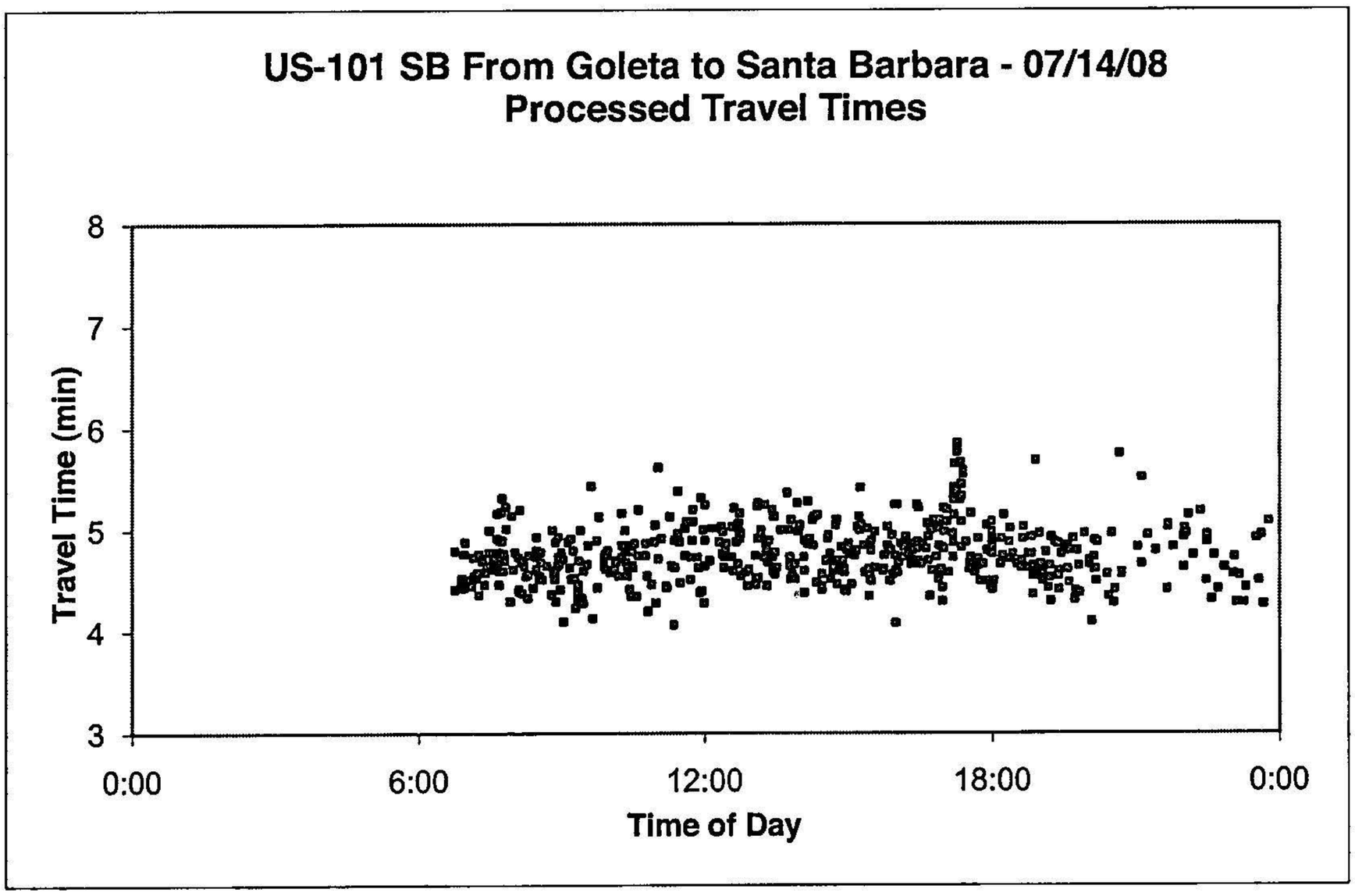


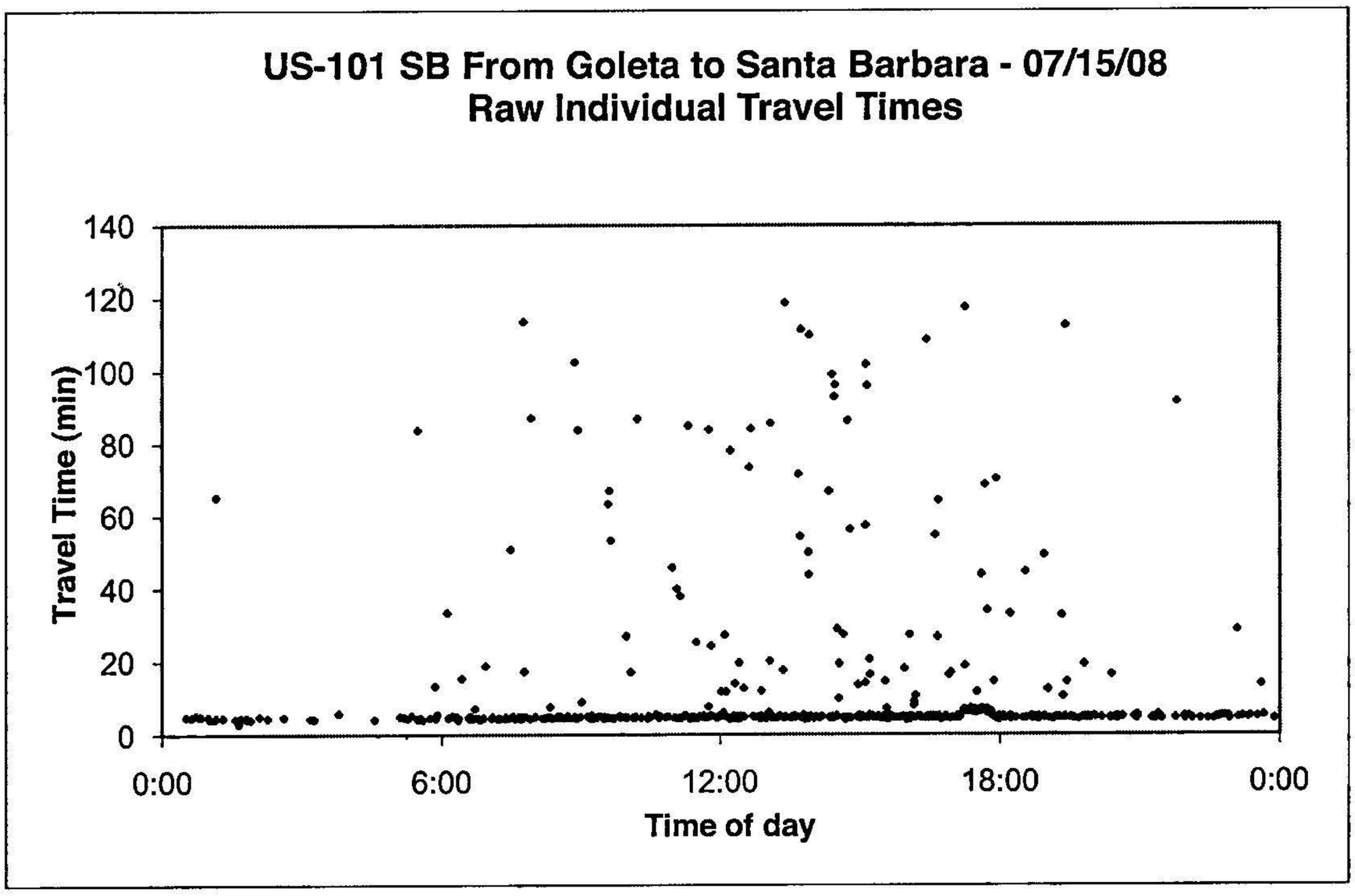


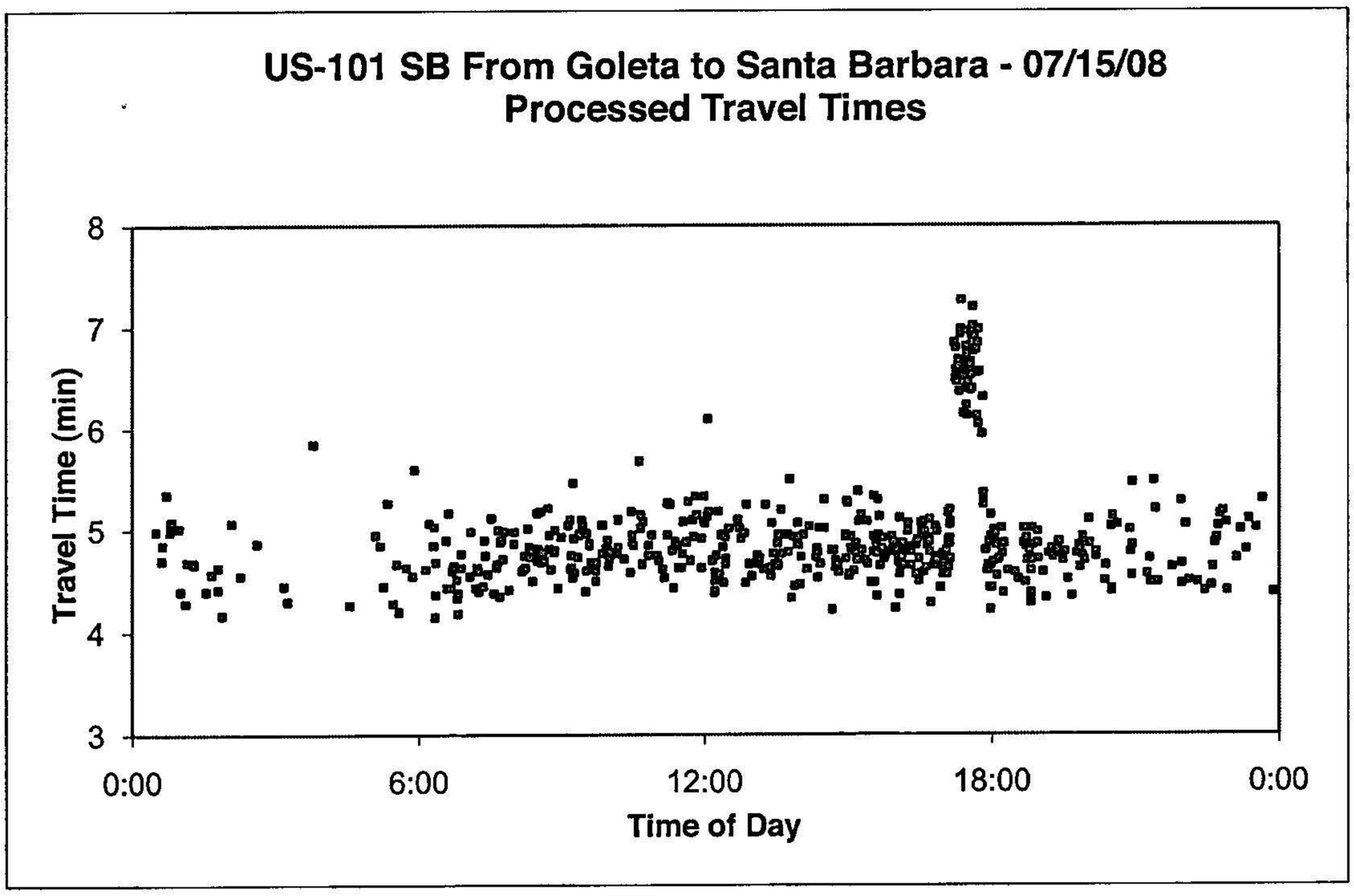

US-101 SB From Goleta to Santa Barbara - 07/10/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day

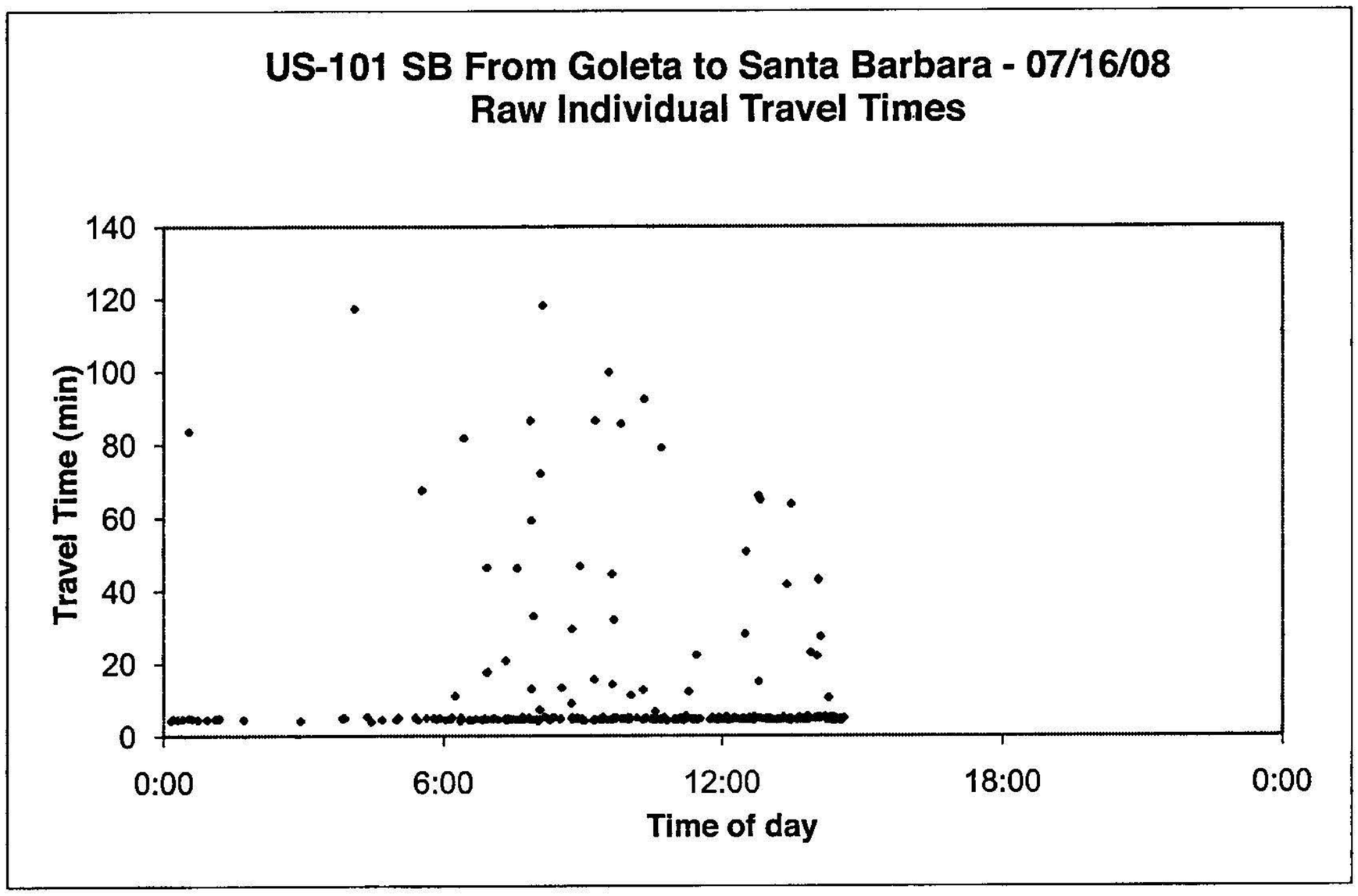

US-101 SB From Goleta to Santa Barbara - 07/10/08
Processed Travel Times
Travel Time (min)
9
8
7
6
5
4
3
0:00
6:00
12:00
18:00
0:00
Time of Day

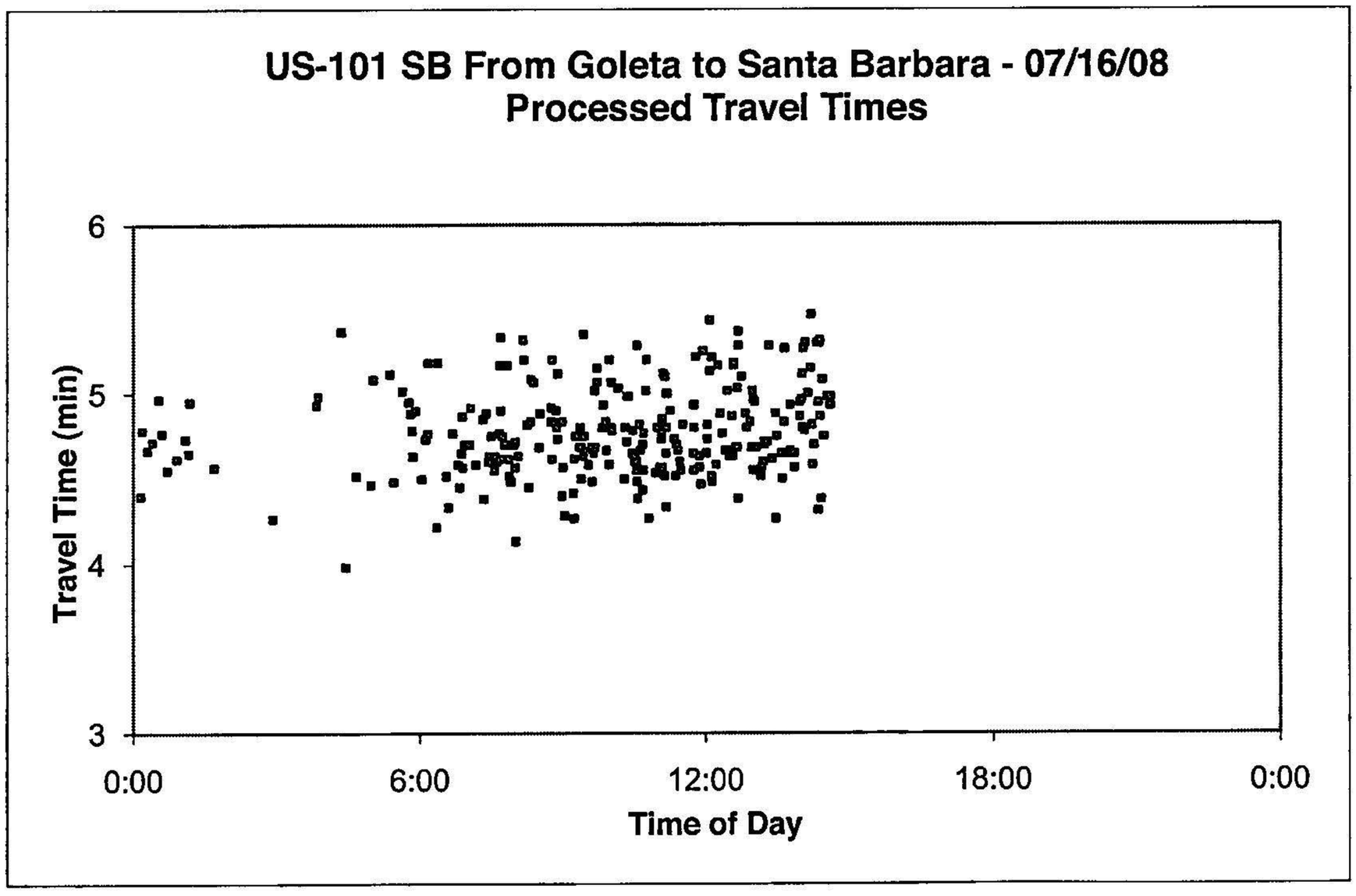

US-101 SB From Goleta to Santa Barbara - 07/14/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Goleta to Santa Barbara - 07/14/08
Processed Travel Times
Travel Time (min)
8
7
6
5
4
3
0:00
6:00
12:00
18:00
0:00
Time of Day


US-101 SB From Goleta to Santa Barbara - 07/15/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Goleta to Santa Barbara - 07/15/08
Processed Travel Times
Travel Time (min)
8
7
6
5
4
3
0:00
6:00
12:00
18:00
0:00
Time of Day


US-101 SB From Goleta to Santa Barbara - 07/16/08
Raw Individual Travel Times
Travel Time (min)
140
120
100
80
60
40
20
0
0:00
6:00
12:00
18:00
0:00
Time of day


US-101 SB From Goleta to Santa Barbara - 07/16/08
Processed Travel Times
Travel Time (min)
6
5
4
3
0:00
6:00
12:00
18:00
0:00
Time of Day

Section II

Data Analysis for Travel Time Estimation on US-50E and I-80: Sacramento-Tahoe

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Final Report – September, 2009

For:

CALIFORNIA DEPARTMENT OF TRANSPORTATION

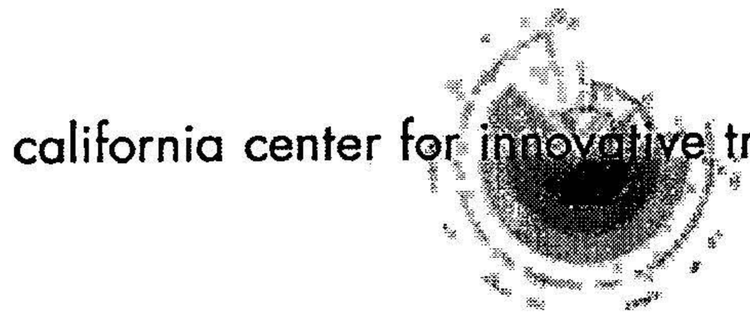


Table of Contents

1. Overview 5
2. Route description 5
3. Data collection 6
4. Sample size analysis 7
4.1. Experimental design 7
4.2. Sample size calculation 8
5. Conclusion 11

Tables and Figures

Table 1: Summary of data collected for US-50 EB 6
Table 2: Summary of data collected for I-80 7
Table 3: Distribution of samples at Harbor Blvd 8
Table 4: Distribution of samples at El Dorado Hills 9
Table 5: Distribution of samples at US-89 Interchange 9
Table 6: Distribution of samples at Horseshoe Bar Road (weekends) 9
Table 7: Distribution of samples at Horseshoe Bar Road (weekdays) 10
Table 8: Overall distributions (US-50E) 10
Table 9: Overall distributions (I-80) 10

Figure 1: US-50 EB and I-80: Sacramento-Tahoe 5

1. Overview

Caltrans District 3 is planning to deploy Electronic Toll Tag Collection (ETC) readers along US-50 and I-80 between Sacramento and Tahoe area. The goal of this project is to use the data collected with ETC readers to predict and display travel time from Sacramento to Tahoe at the benefit of commuters. Caltrans has collected a first set of data with a single ETC reader during March-April 2006. This report evaluates the volume of vehicles detected during that experiment and determines whether or not enough ETC logs are present on US-50 and I-80 for reliable travel time estimation.

2. Route description

The study routes, as shown in Figure 1, are along US-50 EB and I-80 WB between Sacramento and Tahoe. Their lengths are about 92 and 94 miles respectively. Figure 1 shows the locations of ETC readers.

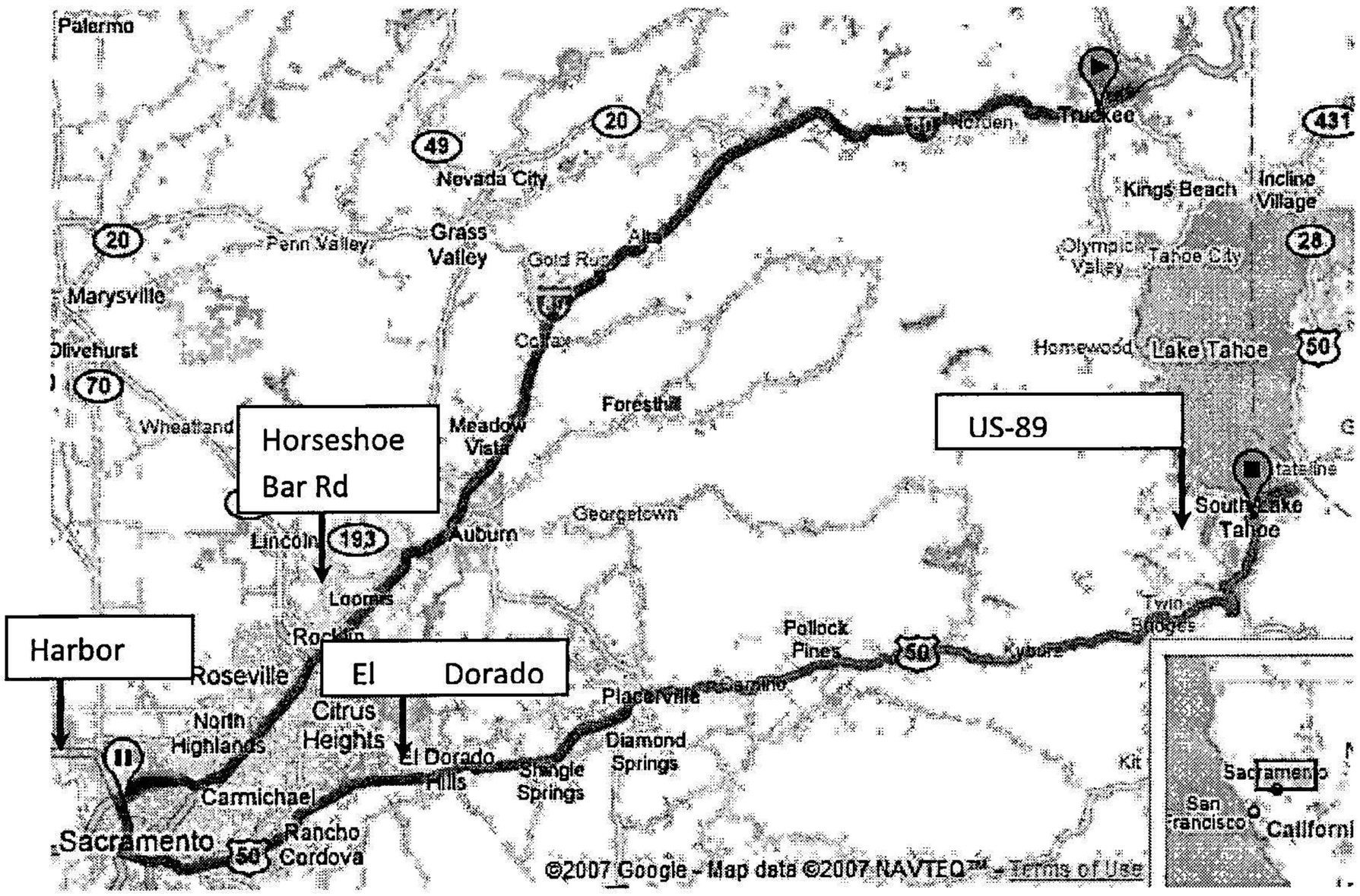


Figure 1: US-50 EB and I-80: Sacramento-Tahoe

3. Data collection

US-50 EB:

The data used for this preliminary analysis was collected with a single toll tag reader during 24 days in March and April 2006. Data was gathered alternatively in three different locations indicated by dark arrows on Figure 1. The table below shows the dates and locations where the ETC reader was deployed.

Table 1: Summary of data collected for US-50 EB

	March																				April					
Location	9	10	11	13	14	15	16	17	18	19	21	22	23	24	25	26	27	28	29	30	31	6	7	8	9	Total days	Total hours
Harbor Blvd																										11	200
El Dorado Hills																										3	46
US 89 Interchange																										10	237

I-80 WB:

The data was collected with a single toll tag reader for four days, Saturday 3rd to Tuesday 6th March 2006, in one location (Figure 1). The table below shows the dates and location of the data collected.

Table 2: Summary of data collected for I-80

	March				Total days	Total hours
Location	3	4	5	6		
Horseshoe Bar Road					4	75

4. Sample size analysis

4.1. Experimental design

We suppose that ETC readers are deployed along the study routes at 5 to 10 miles intervals. The travel time of a vehicle between two consecutive readers A and B is $(t_B - t_A)$ where t_A and t_B are respectively the time logs at A and B. Let N the number of vehicles detected at B within an hour. N can be described as sum of four components:

$$N = N_{normal} + N_{outlier} + N_{missed} + N_{notfromA}$$

Where

N_{normal} is the number of vehicles that have been detected at both of the readers and have a travel time qualified to be normal for the segment.

$N_{outlier}$ is the number of vehicles with travel times that diverge from the normal travel time.

N_{missed} is the number of vehicles that the ETC reader A has missed.

$N_{notfromA}$ is the number of vehicles that enter the highway somewhere between the two readers.

For a given segment, the minimum valid detections needed for reliable travel time estimation ranges from 30 to 60 vehicles per hour. N_{normal} and $N_{outlier}$ represent the number of matching tags for the segment A-B. N_{missed} depends on the accuracy of the toll tag reader which has an average of 85%[1]. $N_{notfromA}$ can not be estimated accurately, it is a random component. For simplicity, we will assume that all vehicles detected at B have passed trough the ETC reader A. Finally, based on previous studies[2] of

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[1]John D. Riley , (Copyright 1999), "Evaluation of Travel Time Estimates Derived From Automatic Vehicle Identification Tags in San Antonio, TX"

[2] Xuegang (Jeff) Ban et al. (2006) , "Performance Evaluation of Travel Time Methods for Real Time Traffic Applications"

travel time estimation using FasTrak data in the Bay area, the outliers for a similar segment vary between 15 and 20%. For our case, we will retain 20%.

4.2. Sample size calculation

Considering the remarks and assumptions listed above, the number of expected vehicles per hour is computed as shown in the following example:

Example: At Harbor Blvd on Friday 6:00AM -7:00AM

$N = 161$

$N_{_notfromA} = 0$

$N_{_missed} = 161*0.15 = 24$

$N_{_outlier} = 0.2*(161-24) = 27$

$N_{_normal} = 161-24-27 = 110$

The results are shown in charts 1 to 12 for US-50E and 13 to 20 for I-80W. Tables 3, 4 and 5 are summaries of the expected sample sizes during peak days for segments ending respectively at Harbor Blvd, El Dorado Hills and US-89 Interchange. Tables 6 and 7 are summaries of the expected sample sizes during weekends and weekdays respectively at Horseshoe Bar Road. Tables 8 and 9 represent the repartition of the sample sizes for the experiment period for US-50E and I-80W respectively.

Table 3: Distribution of samples at Harbor Blvd

	Friday		Saturday	
	Hours	Frequency	Hours	Frequency
Less than 30	5	21%	5	21%
30 to 60	2	8%	6	25%
More than 60	17	71%	13	54%
Total hours	24		24	

Table 4: Distribution of samples at El Dorado Hills

	Friday		Saturday	
	Hours	Frequency	Hours	Frequency
Less than 30	1	7%	16	67%
30 to 60	11	79%	8	33%
More than 60	2	14%	0	0%
Total hours	14		24	

Table 5: Distribution of samples at US-89 Interchange

	Friday		Saturday	
	Hours	Frequency	Hours	Frequency
Less than 30	24	100%	24	100%
30 to 60	0	0%	0	0%
More than 60	0	0%	0	0%
Total hours	24		24	

Table 6: Distribution of samples at Horseshoe Bar Road (weekends)

	Saturday		Sunday	
	Hours	Frequency	Hours	Frequency
Less than 30	3	23%	10	42%
30 to 60	5	38%	3	13%
More than 60	5	38%	11	46%
Total Hours	13		24	

Table 7: Distribution of samples at Horseshoe Bar Road (weekdays)

	Monday		Tuesday	
	Hours	Frequency	Hours	Frequency
Less than 30	8	33%	7	50%
30 to 60	7	29%	6	43%
More than 60	9	38%	1	7%
Total Hours	24		14	

Table 8: Overall distributions (US-50E)

	Harbor Blvd		El Dorado Hills		US 89 Interchange	
	Hours	Frequency	Hours	Frequency	Hours	Frequency
Less than 30	32	16%	24	52%	236	99.6%
30 to 60	26	13%	20	44%	1	0.4%
More than 60	142	71%	2	4%	0	0.0%
Total hours	200		46		237	

Table 9: Overall distributions (I-80)

	Horseshoe Bar Road	
	Hours	Frequency
Less than 30	28	37%
30 to 60	21	28%
More than 60	26	35%
Total Hours	75	

5. Conclusion

US-50E:

The minimum sample sizes can be collected on segments that are between Sacramento and El Dorado Hills. On the other hand, the expected rate of vehicles for reliable travel time estimation may not be obtained within ETC readers deployed from El Dorado Hill to Tahoe. In fact, the volume for this segment seems to be always below 20 vehicles per hour. For a thorough study, additional data might be needed during peak days from El Dorado Hill to Tahoe.

I-80W:

The data collection was not complete (24 hours) for Saturday and Tuesday. Analysis of the available data shows that the minimum sample sizes can be collected from the morning to the evening in Horseshoe Bar Road. However, additional data collection is required to have a thorough assessment of the traffic data.

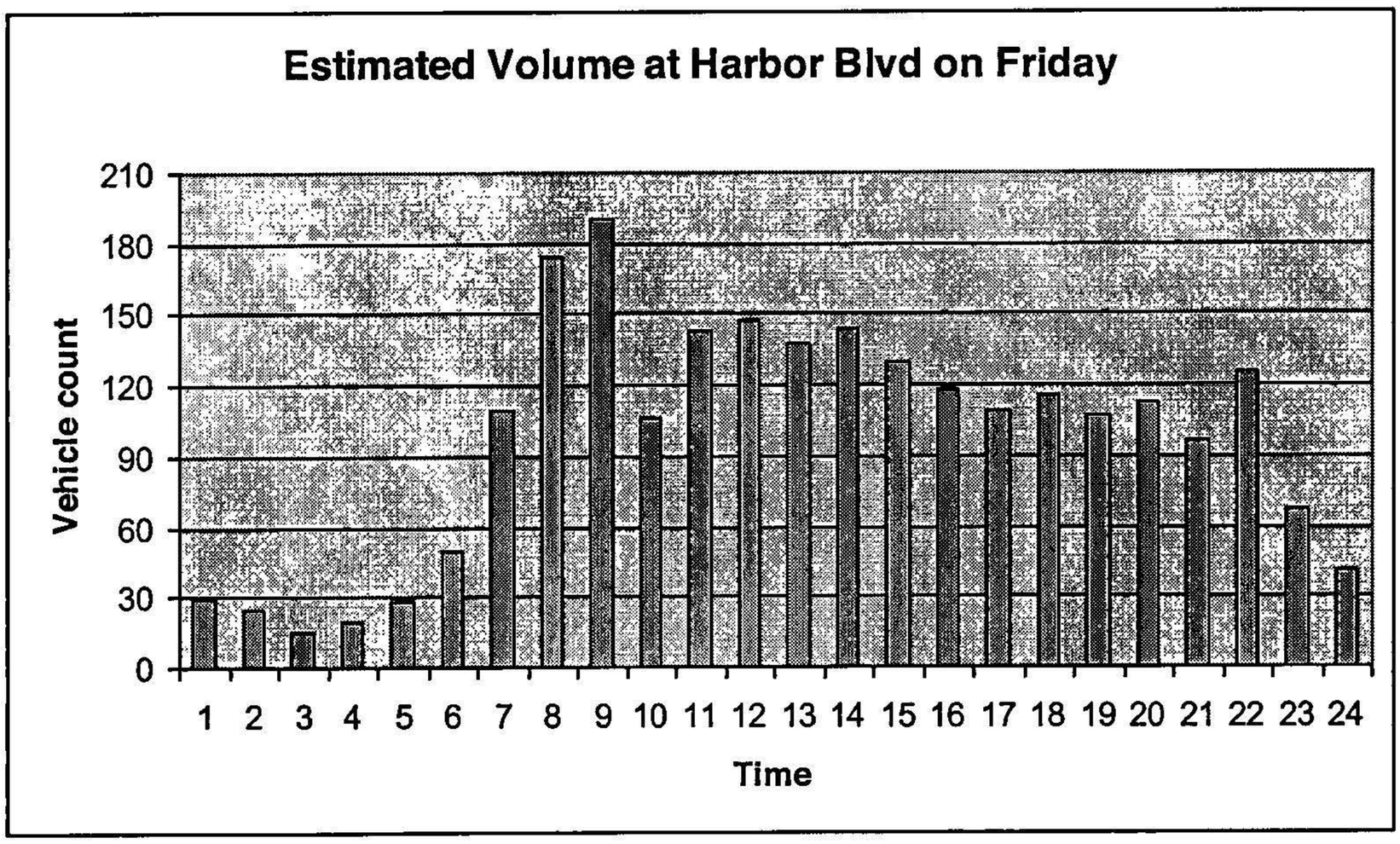


Chart 1

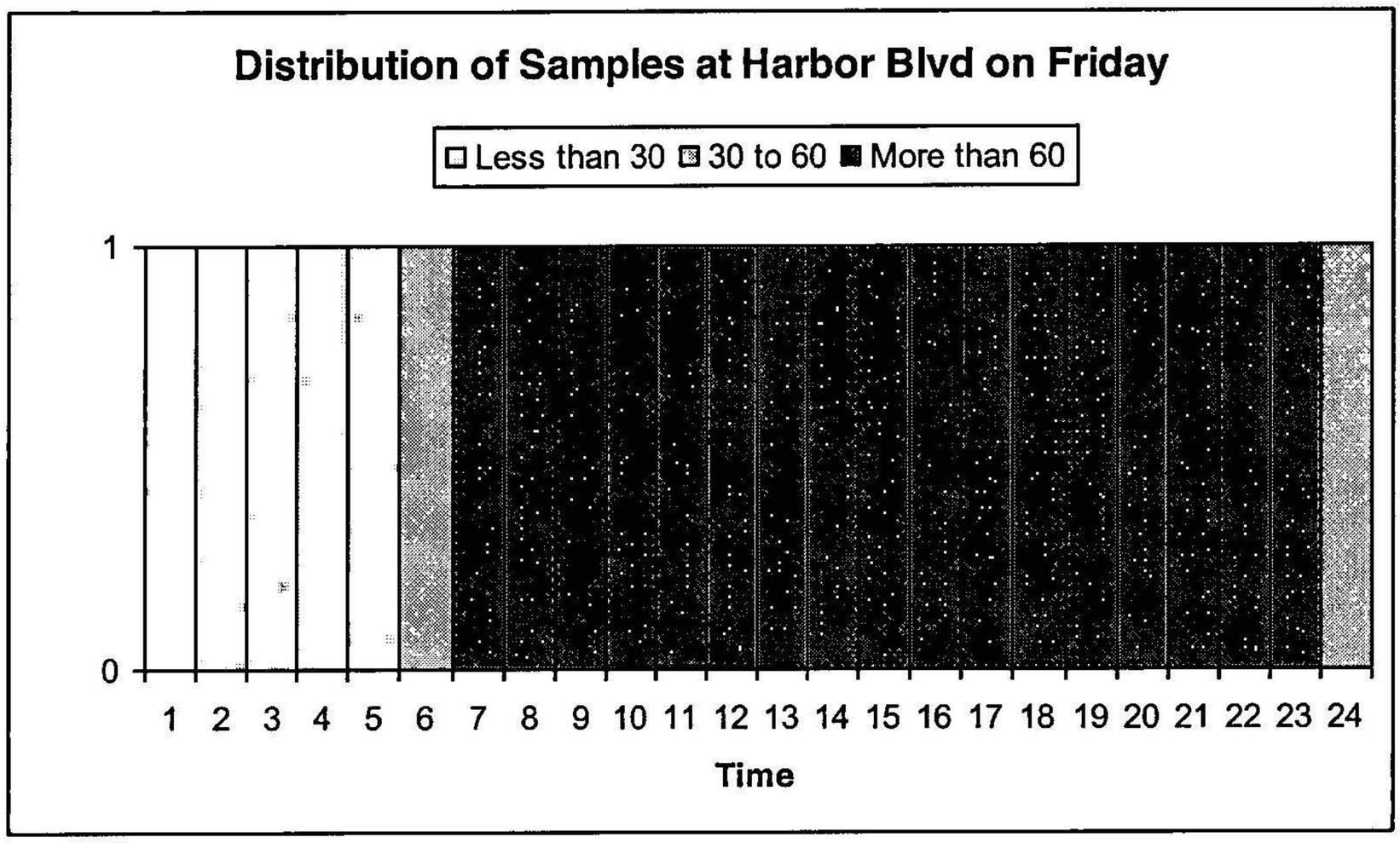


Chart 2

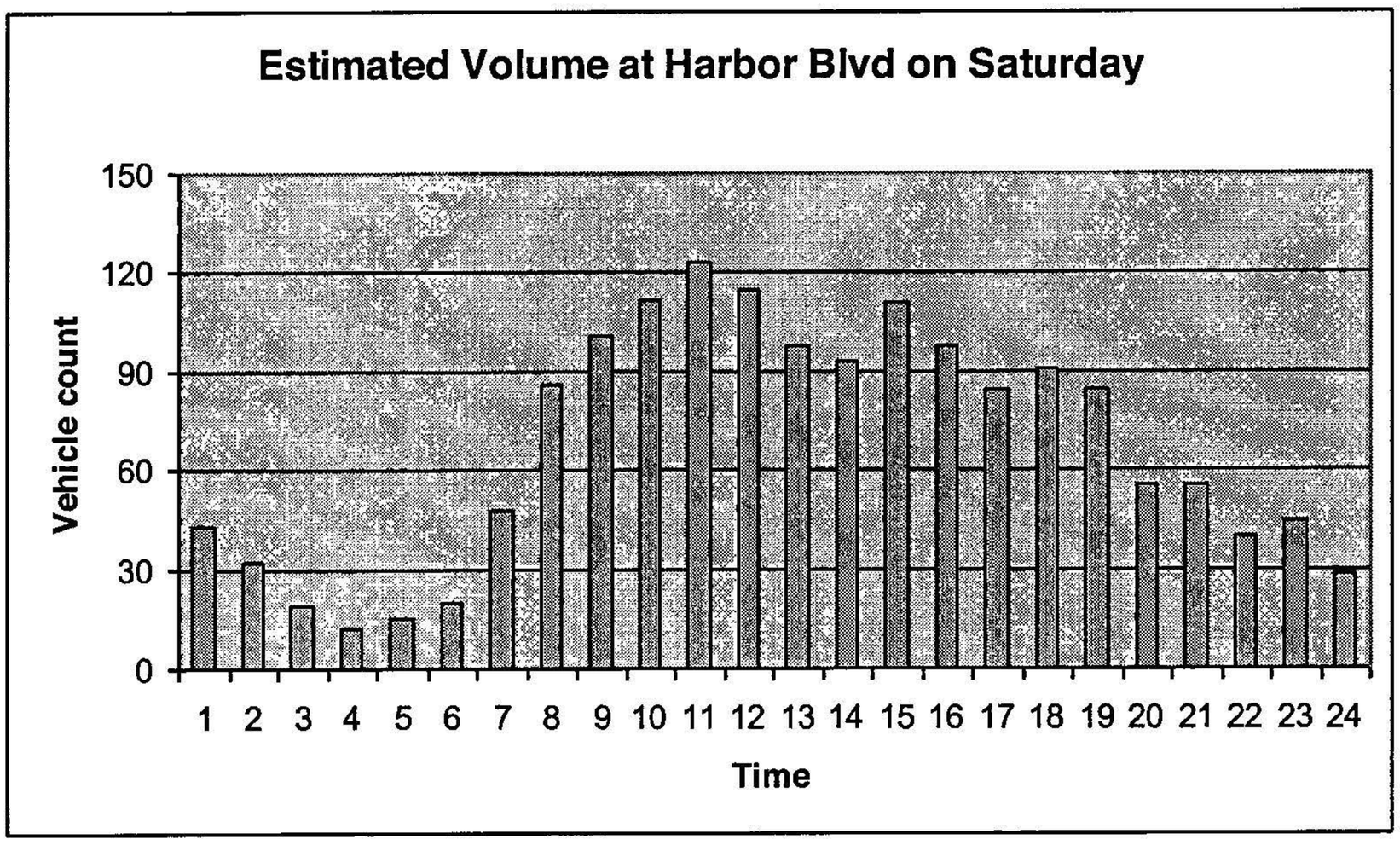


Chart 3

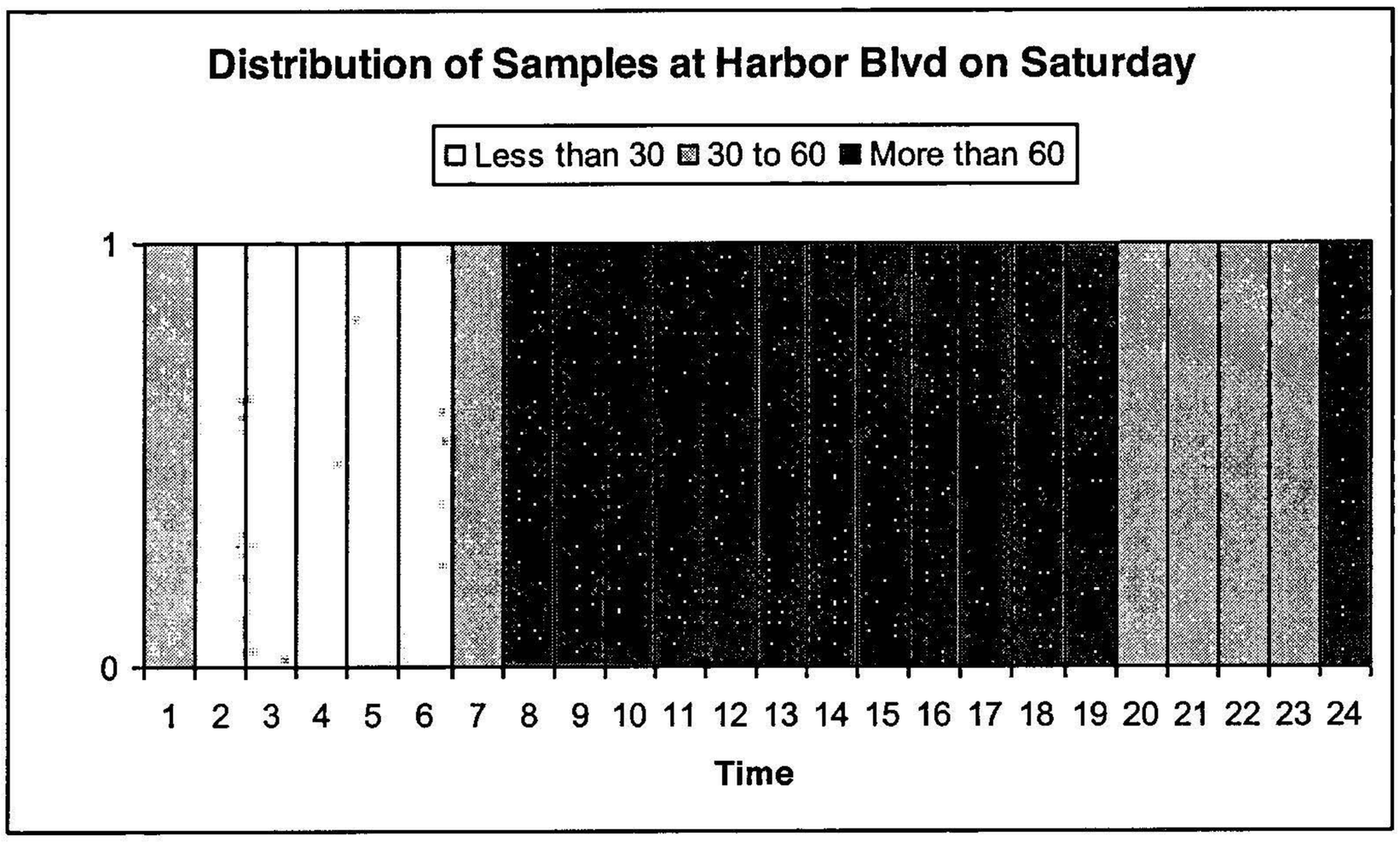


Chart 4

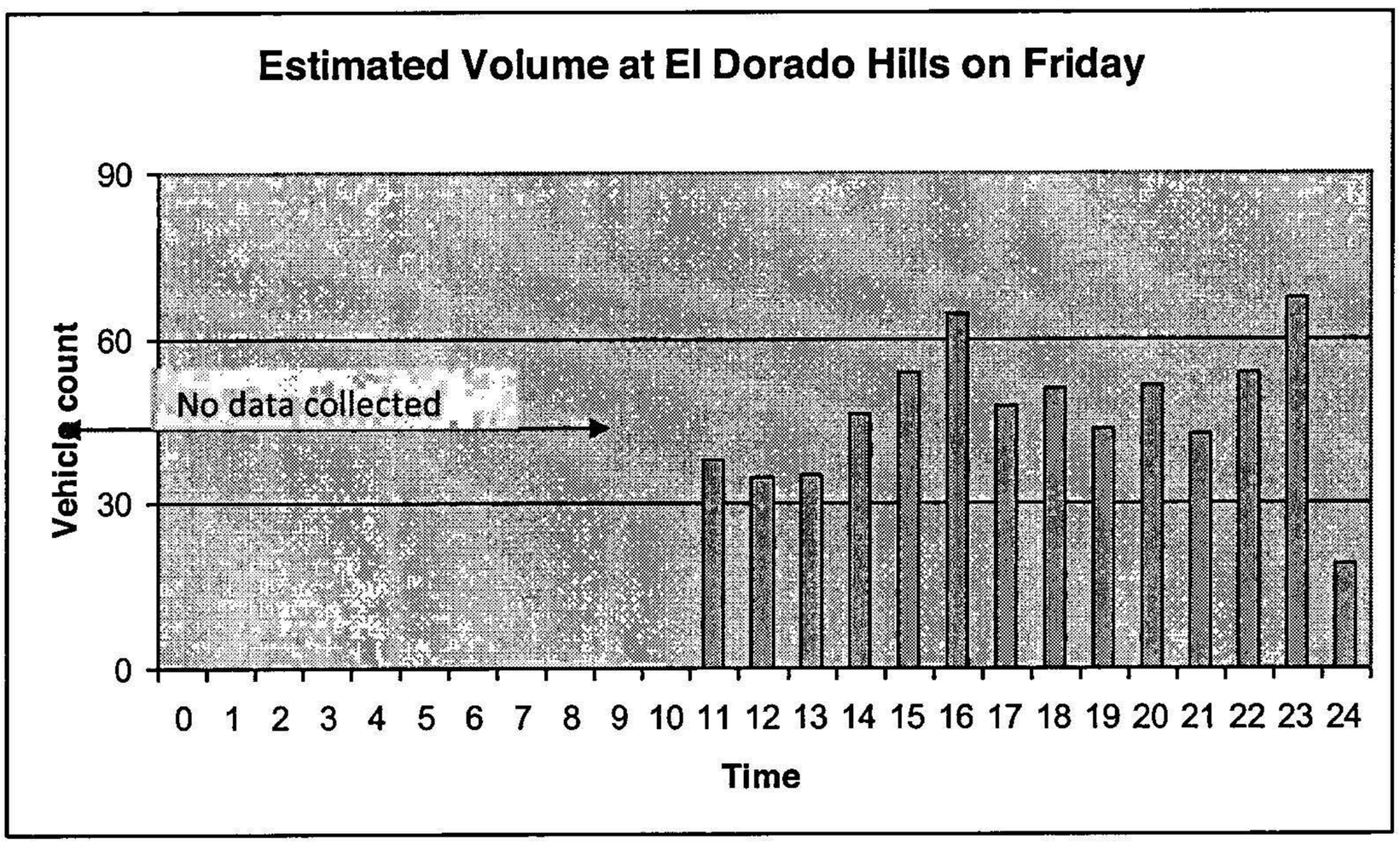


Chart 5

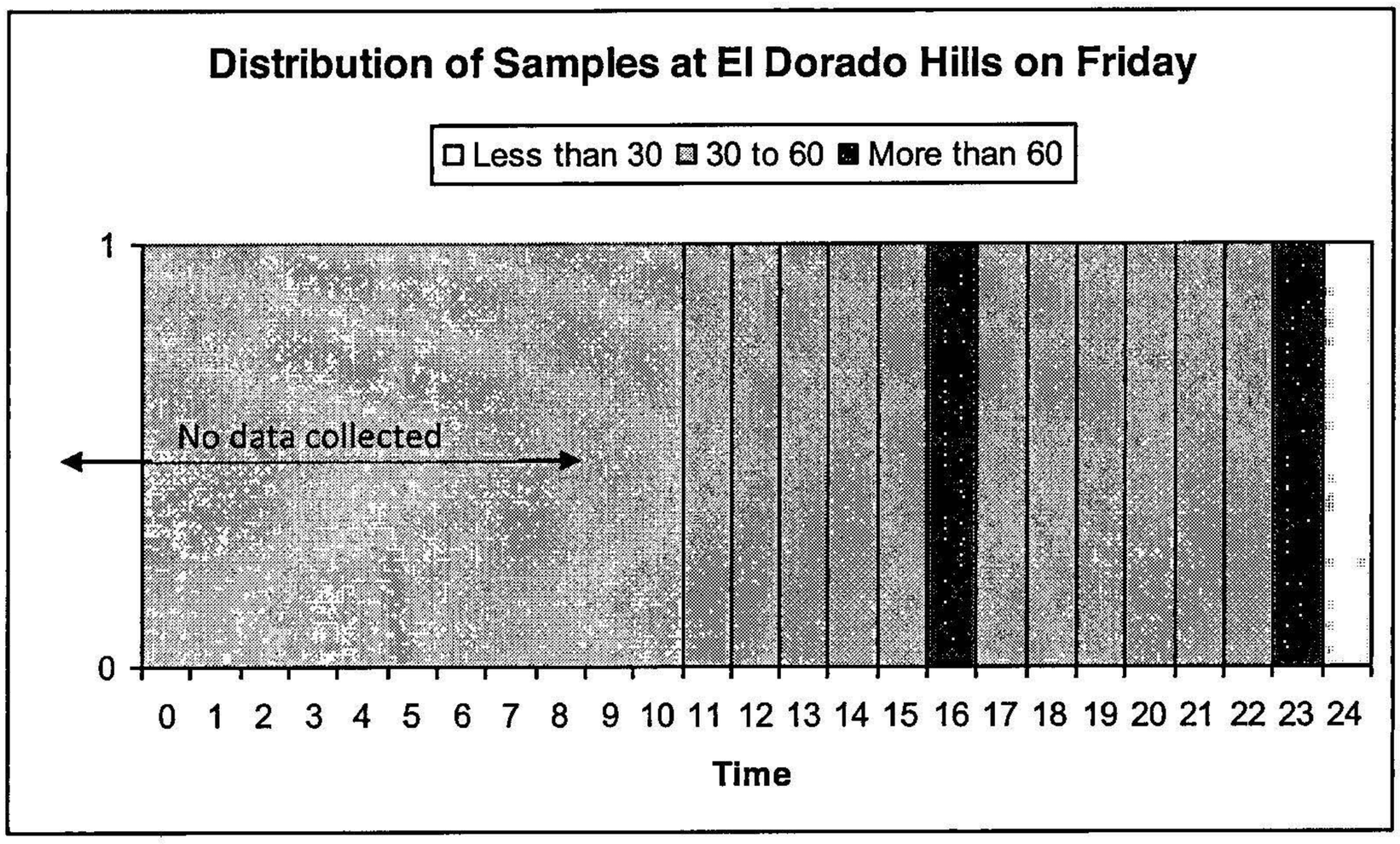

Distribution of Samples at El Dorado Hills on Friday
Less than 30
30 to 60
More than 60
1
0
No data collected
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 6

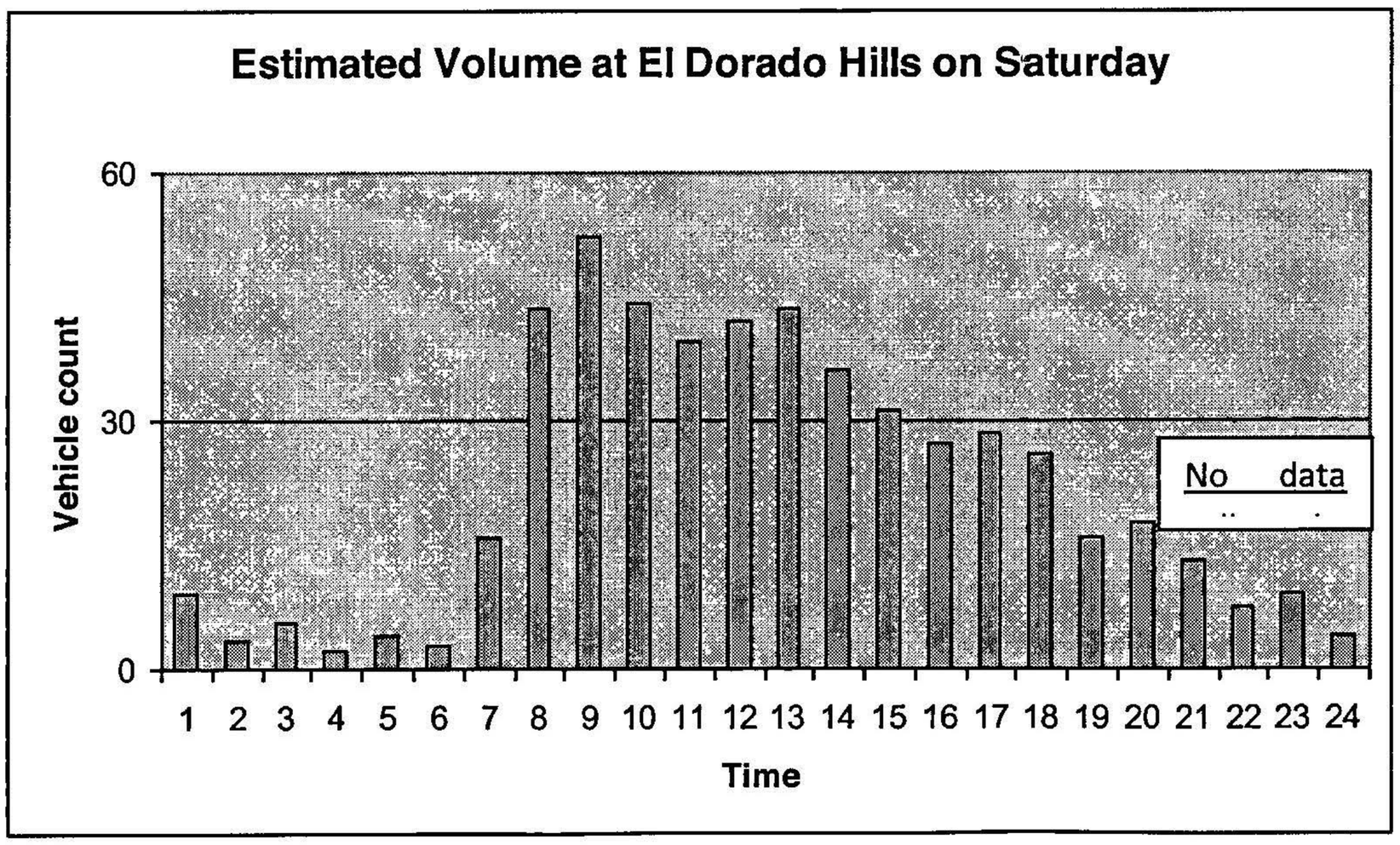

Estimated Volume at El Dorado Hills on Saturday
60
30
0
Vehicle count
No data
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 7

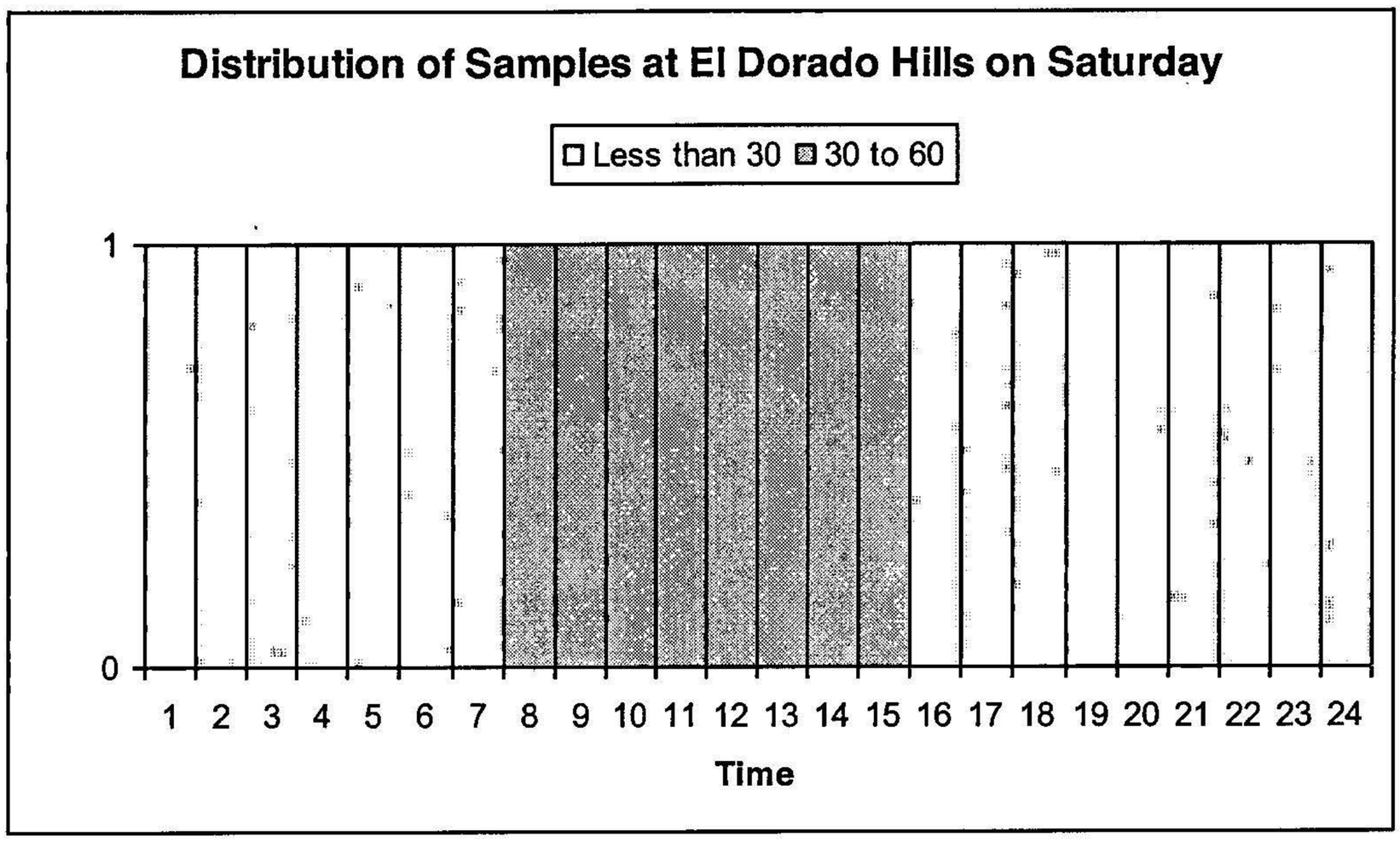


Chart 8

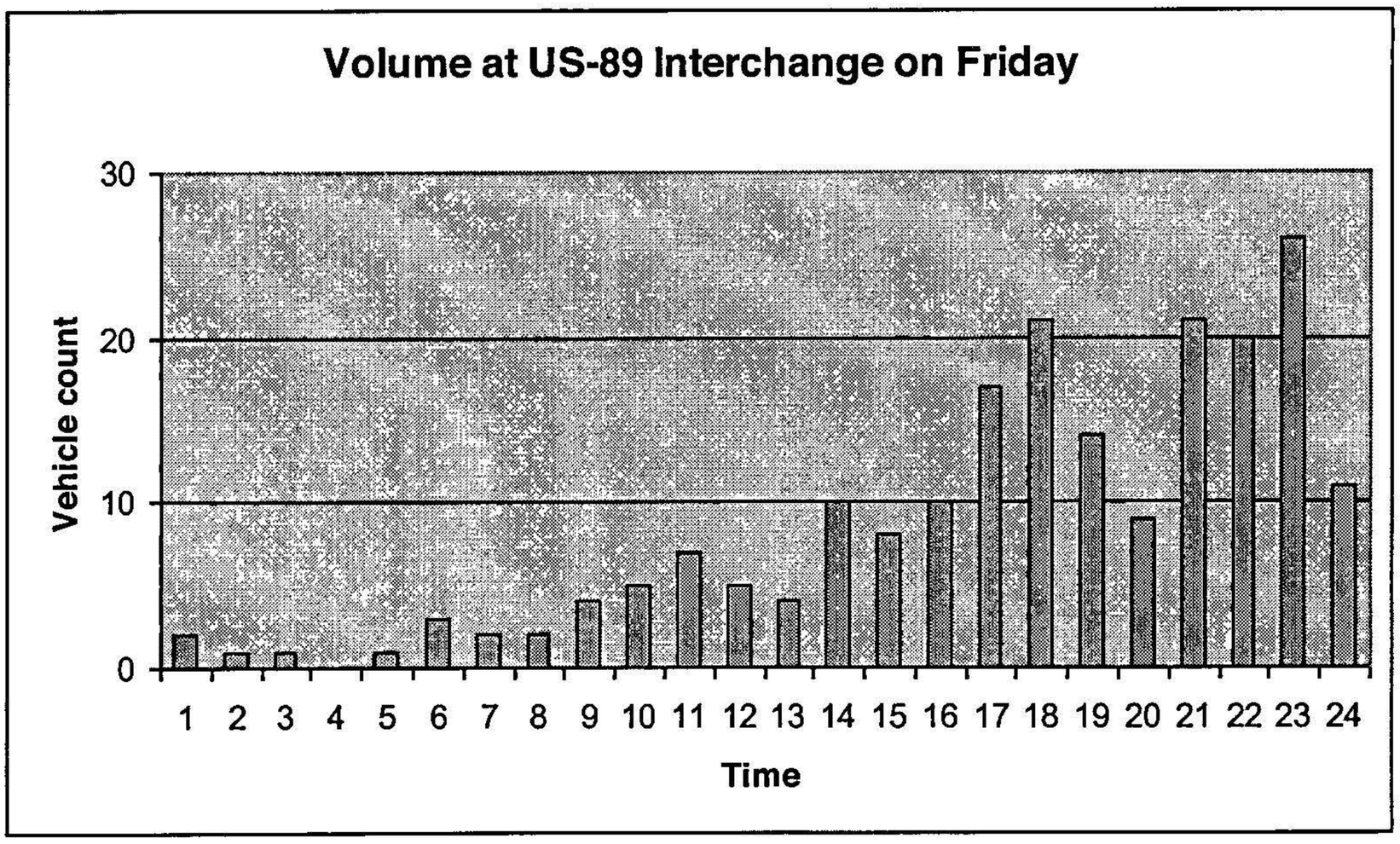


Chart 9

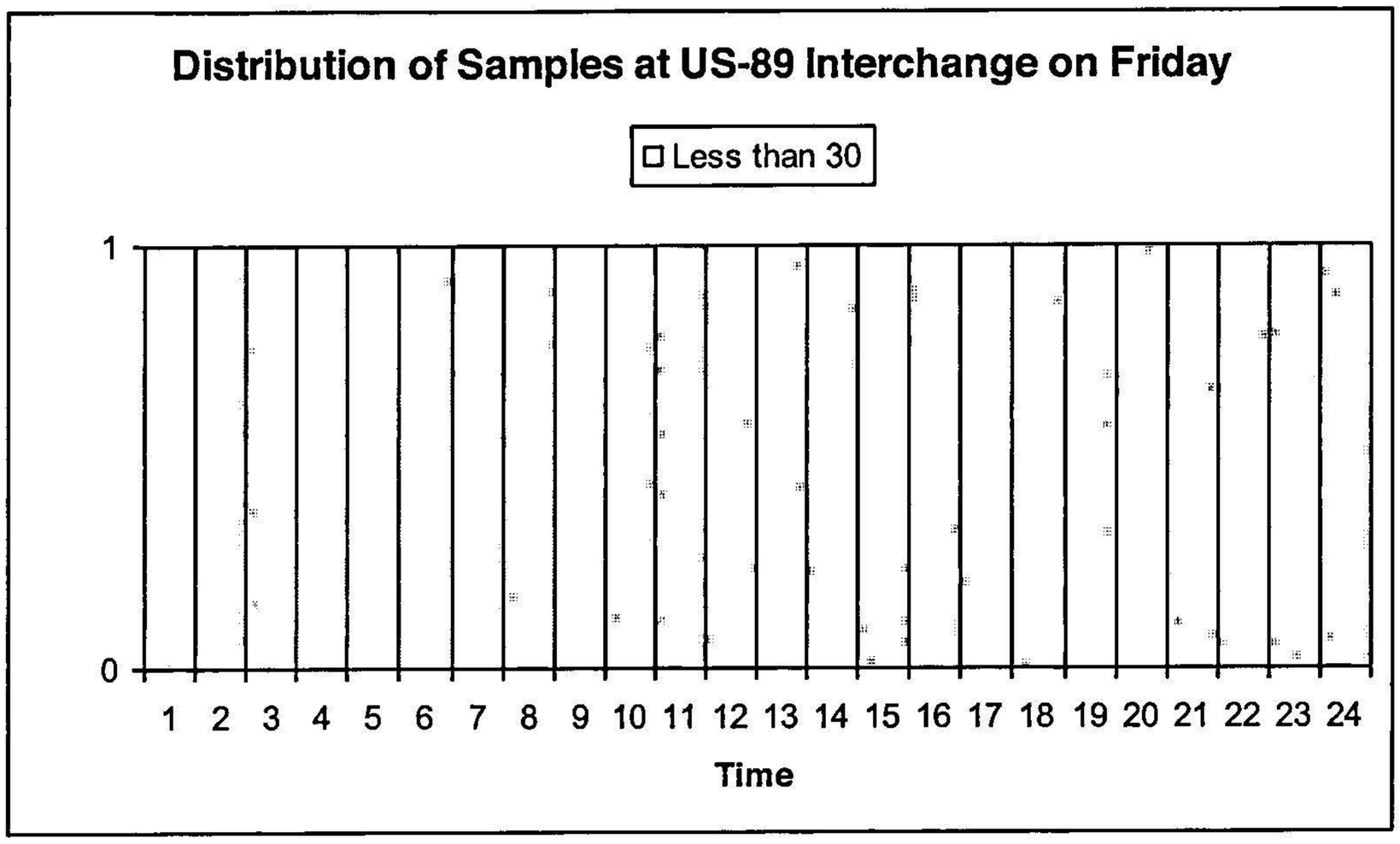


Chart 10

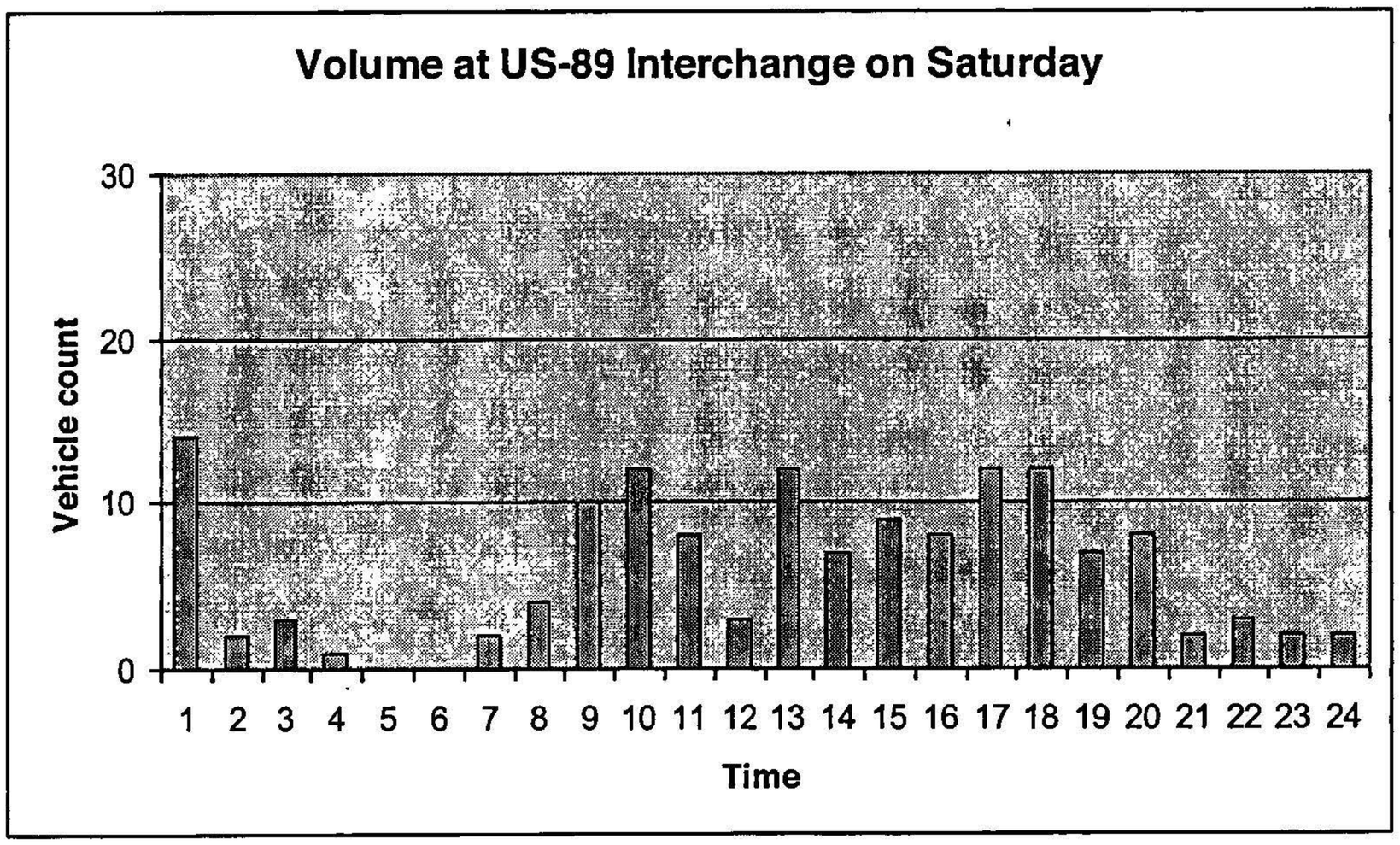


Chart 11

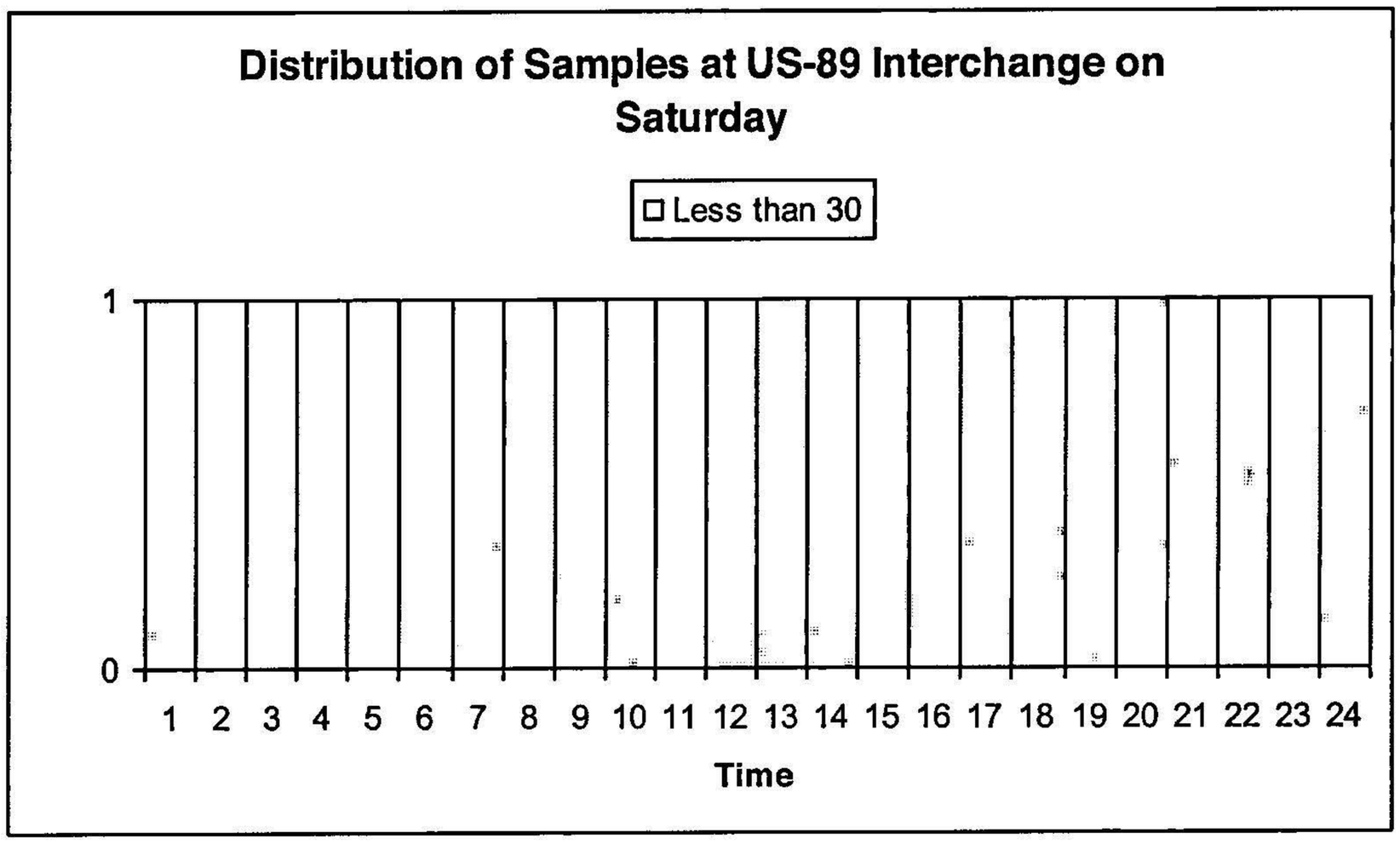


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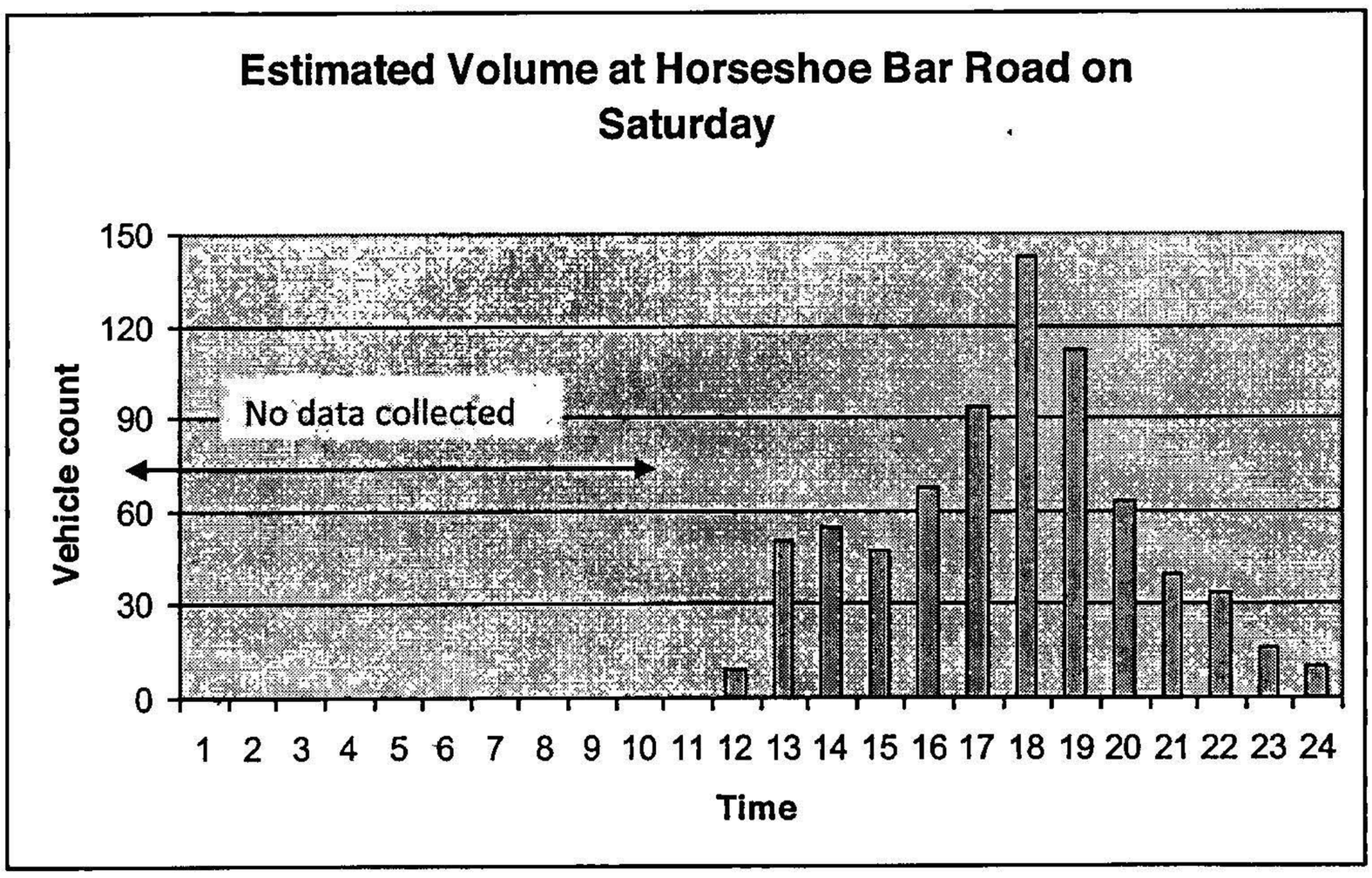


Chart 13

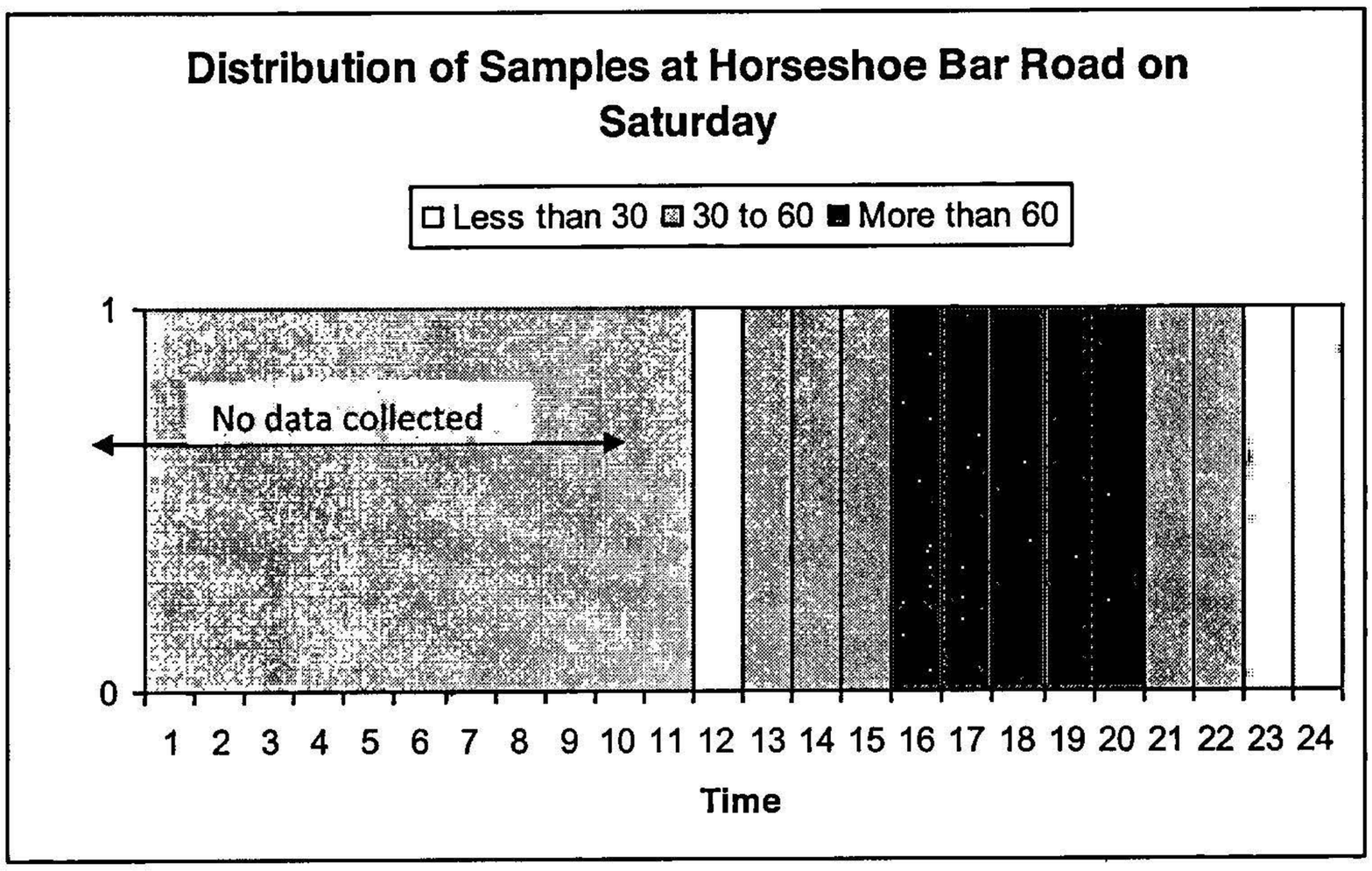


Chart 14

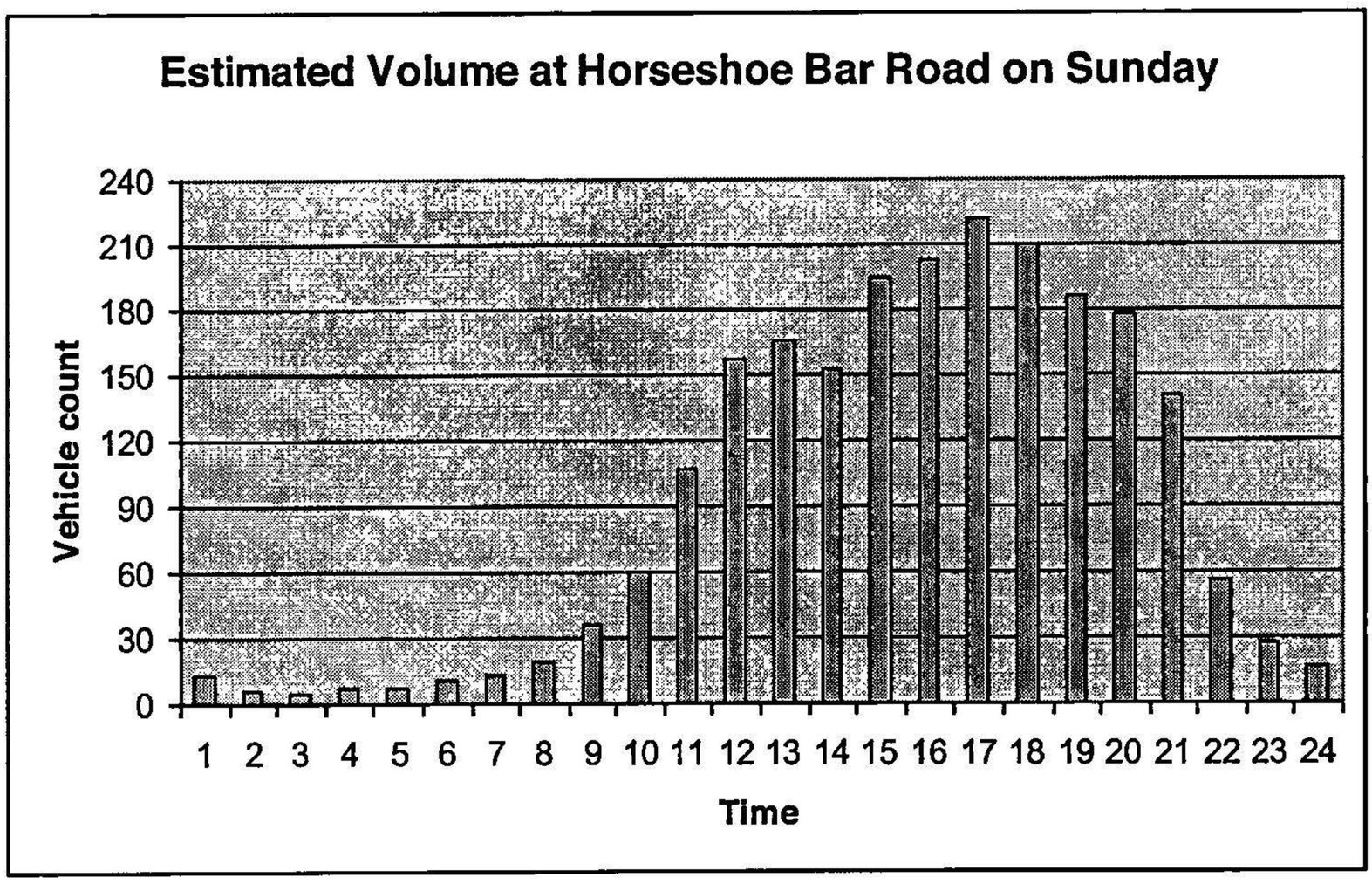


Chart 15

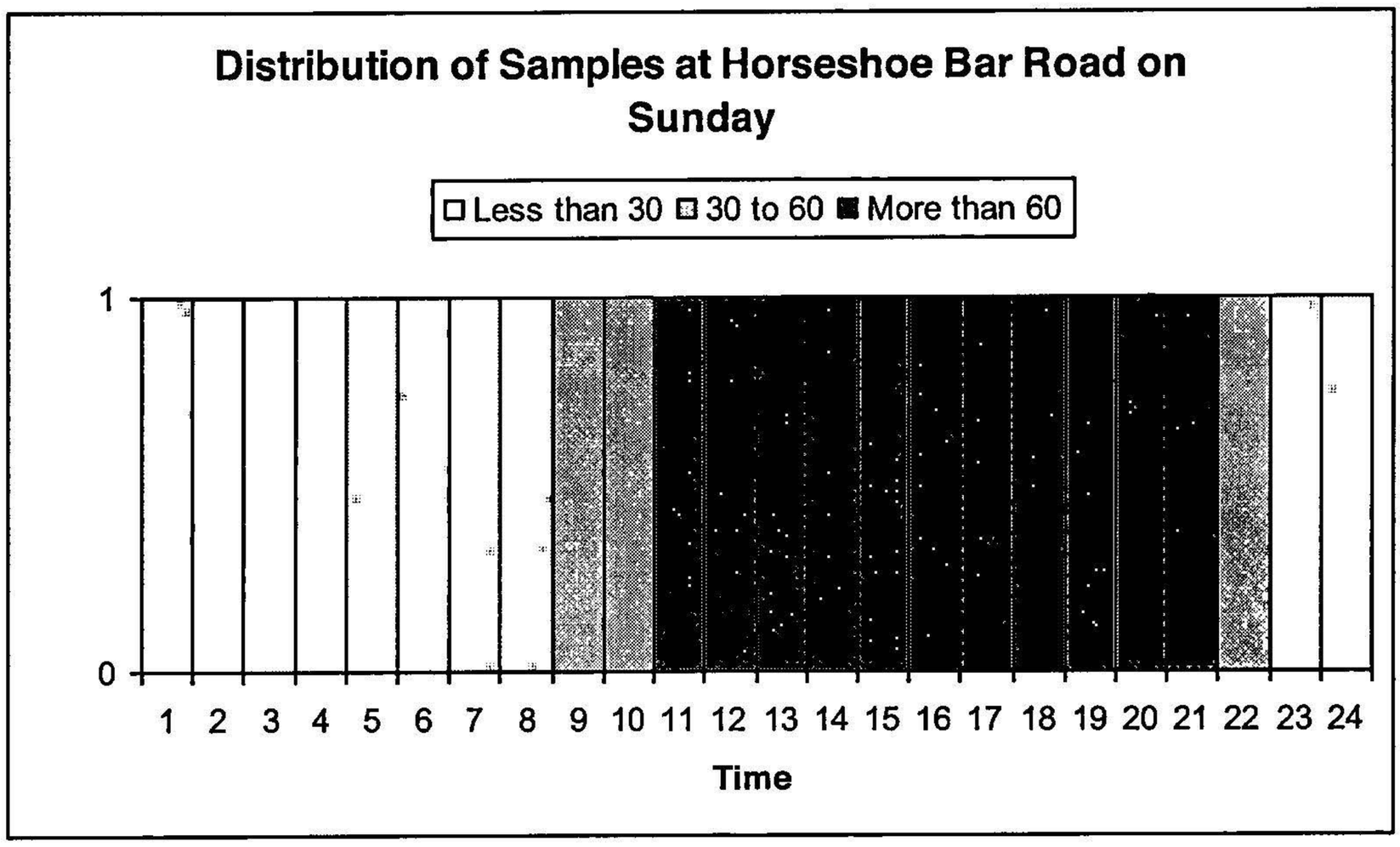

Distribution of Samples at Horseshoe Bar Road on Sunday
Less than 30
30 to 60
More than 60
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 16

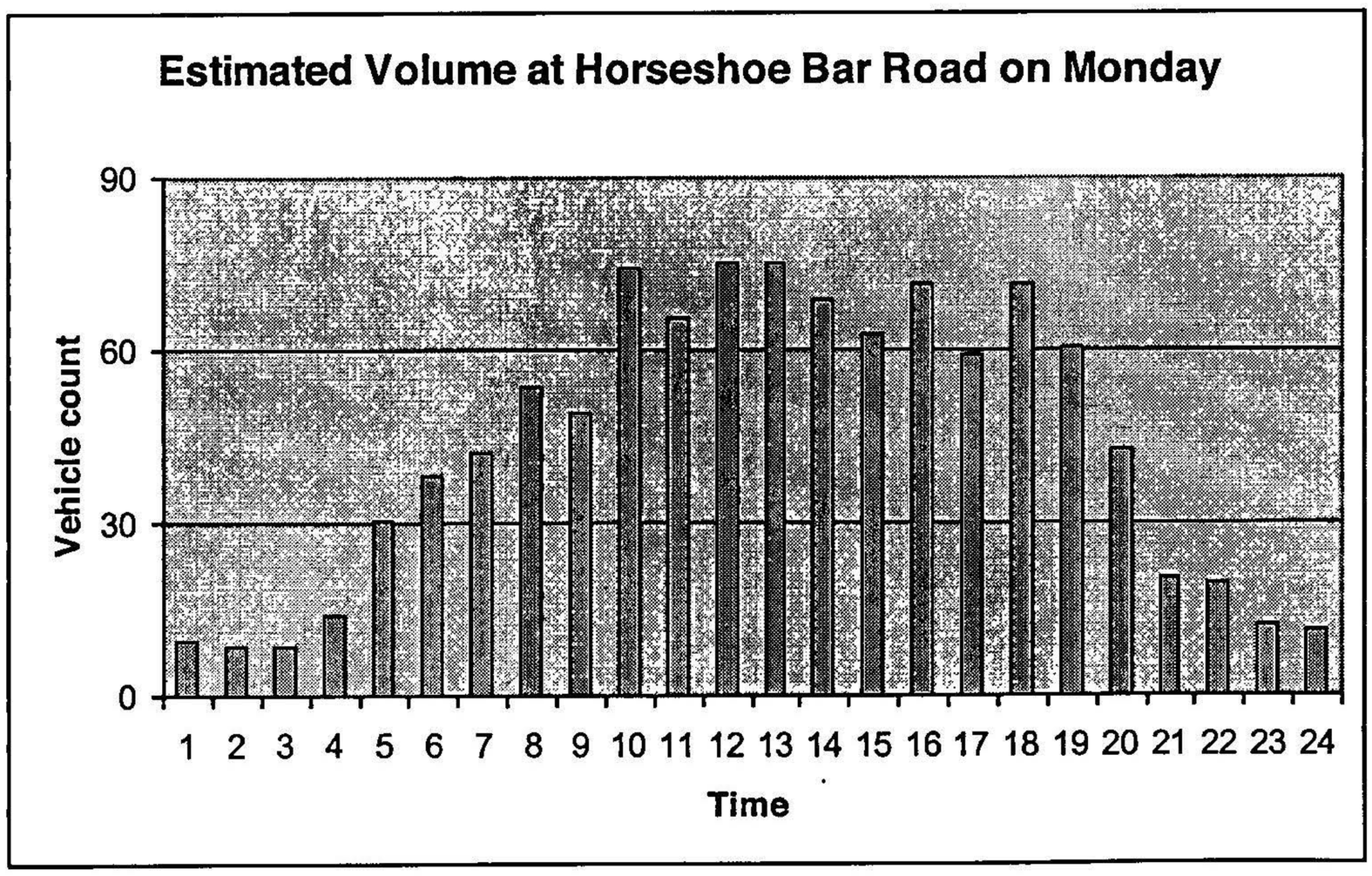

Estimated Volume at Horseshoe Bar Road on Monday
Vehicle count
90
60
30
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 17

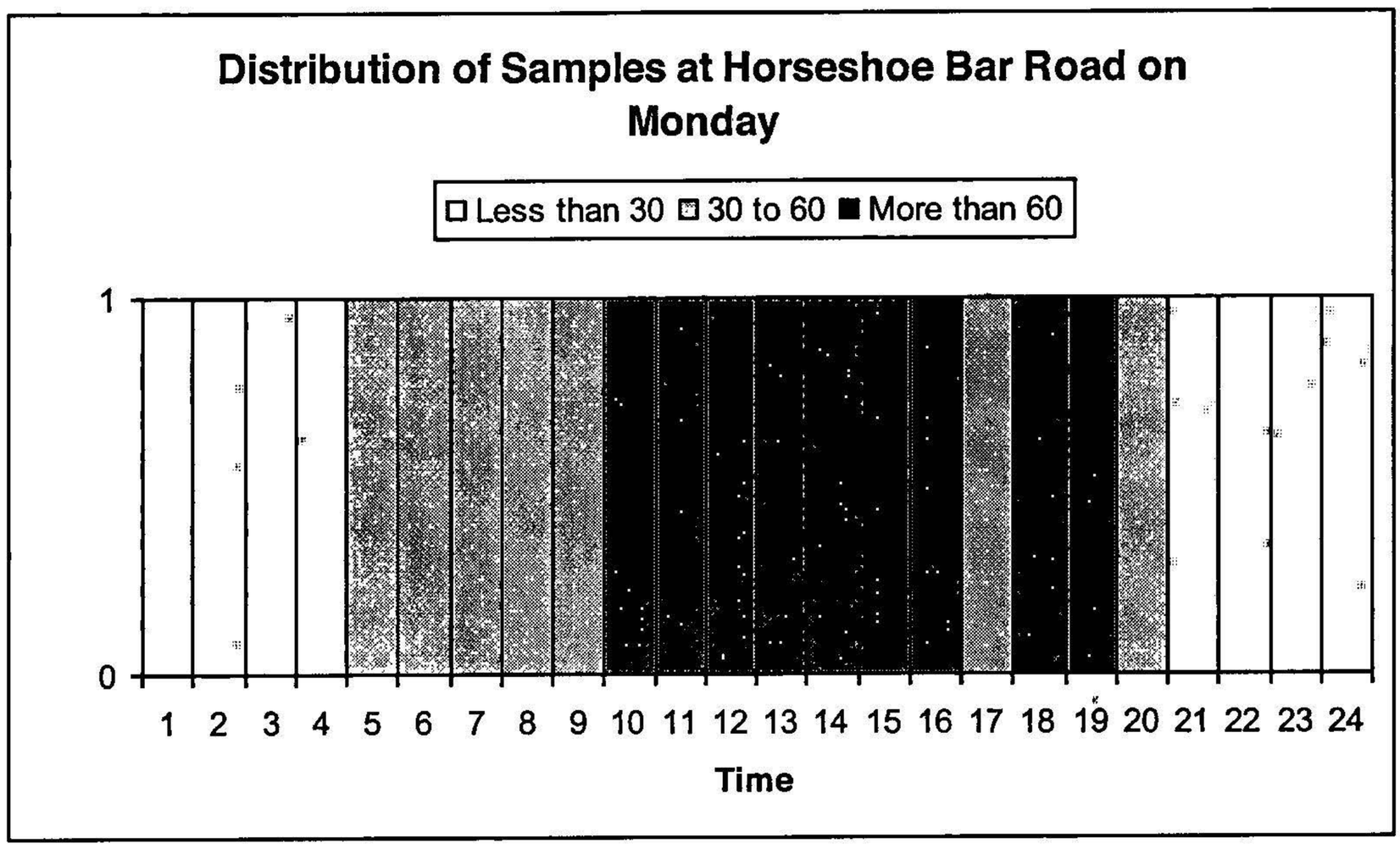
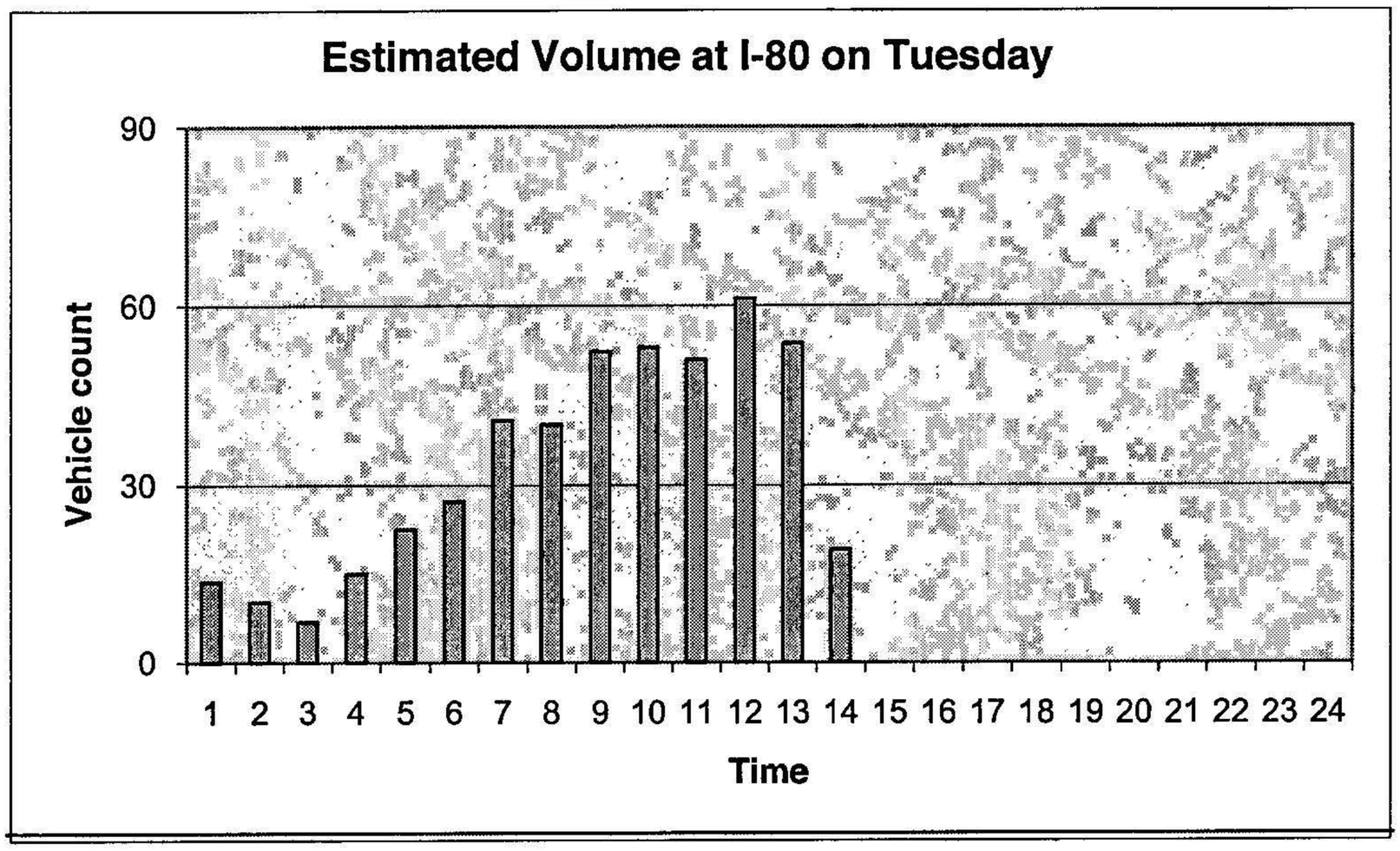


Chart 18


Estimated Volume at I-80 on Tuesday
Vehicle count
90
60
30
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

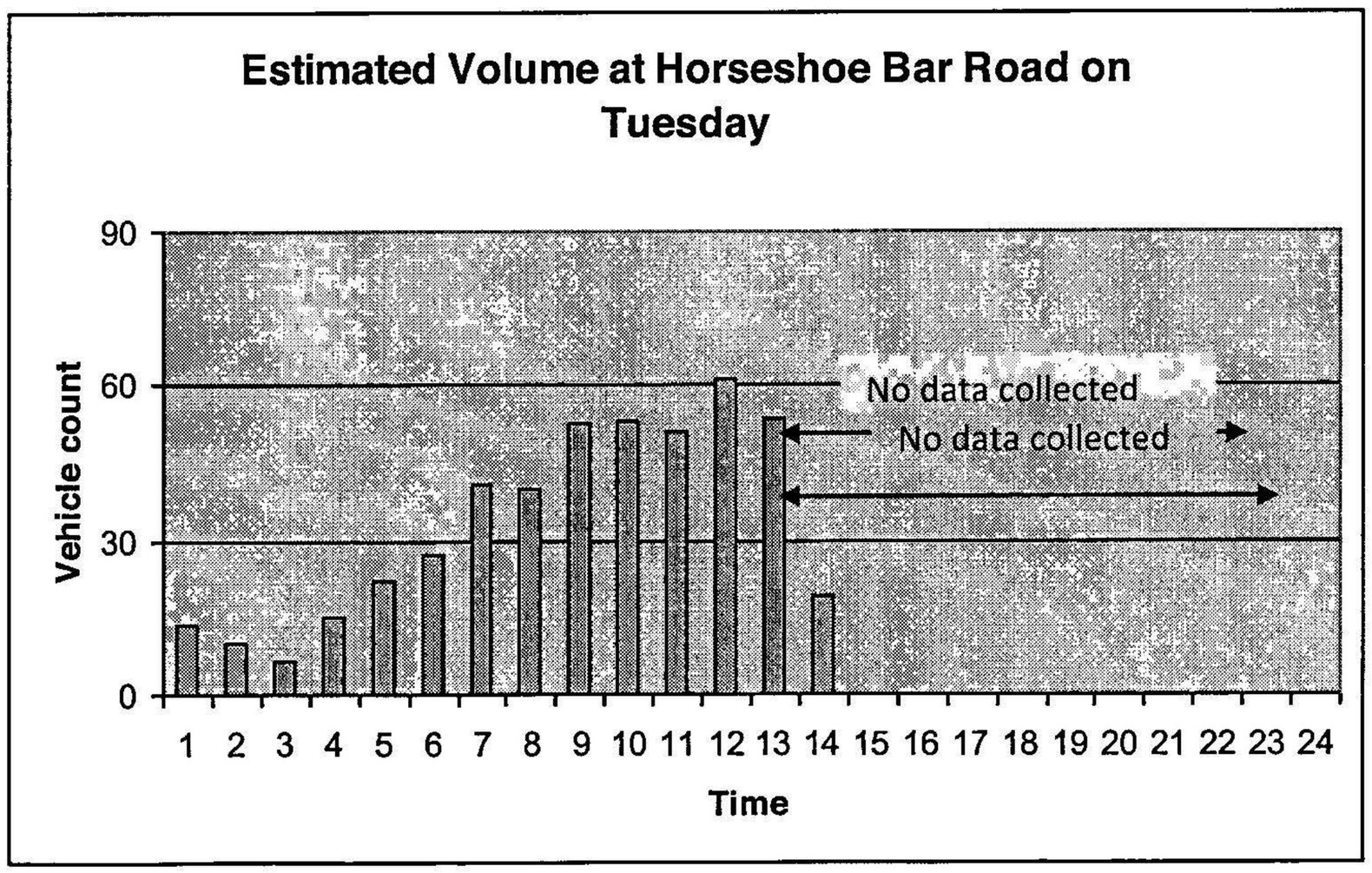

Estimated Volume at Horseshoe Bar Road on Tuesday
Vehicle count
90
60
30
0
No data collected
No data collected
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 19

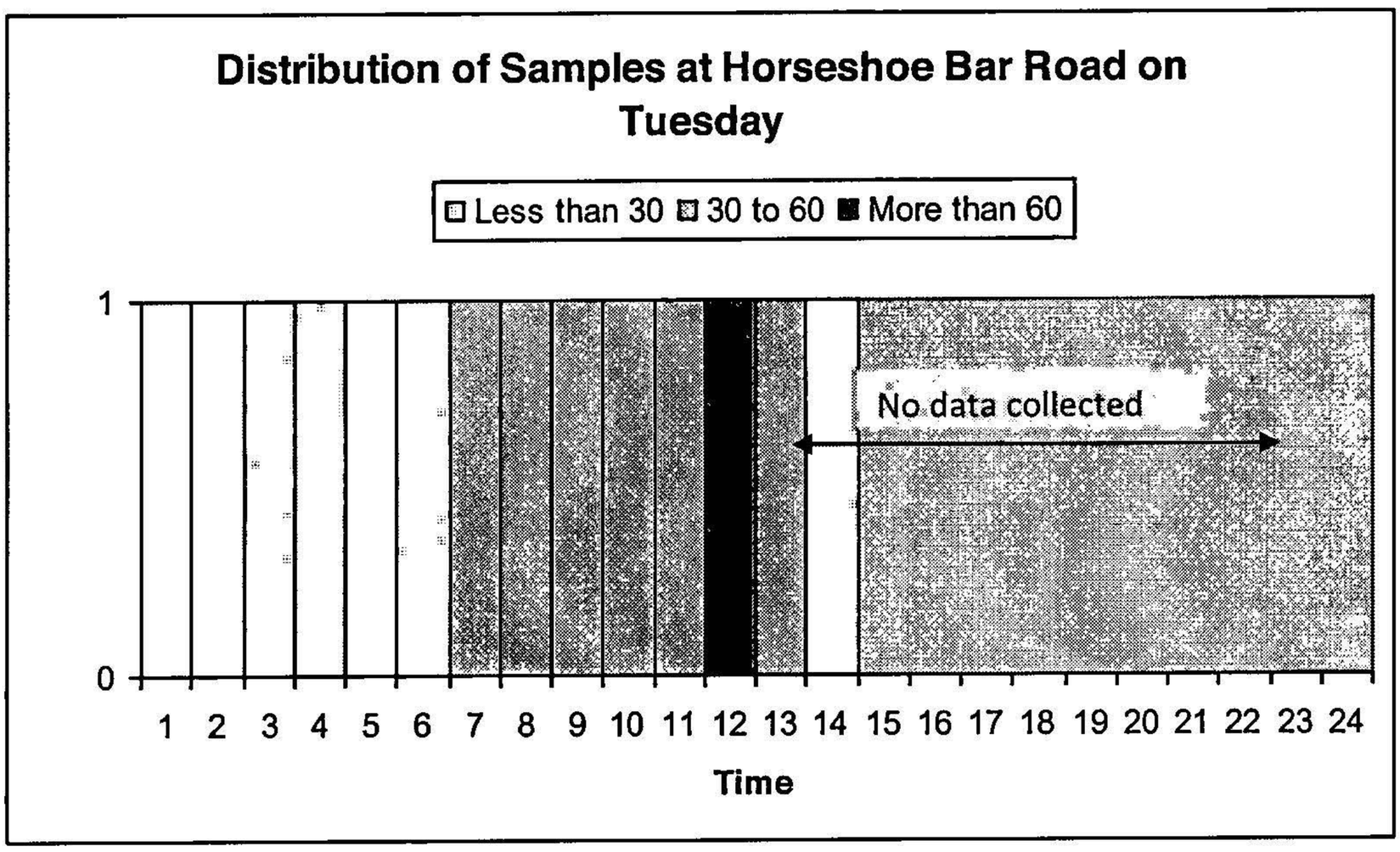

Distribution of Samples at Horseshoe Bar Road on Tuesday
Less than 30
30 to 60
More than 60
1
0
No data collected
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time

Chart 20