APPENDIX E

ADVANCE

Advanced Driver and Vehicle
Advisory Navigation Concept

Traffic Related Functions
Evaluation Report (5 of 7)
Documents # 8460.00

CONTAINS:

Base Data and Static Profile Evaluation Report	**-- Document # 8460-01.01**
Data Screening Evaluation Report	**-- Document # 8460-02.02**
Quality of Probe Reports Evaluation Report	**-- Document # 8460-03.01**
Travel Time Prediction and Performance of Probe and Detector Data Evaluation Report	**-- Document # 8460-04.01**
• Detector Travel Time Conversion and Fusion of Probe and Detector Data Evaluation Report	**-- Document # 8460-05.01**
Frequency of Probe Reports Evaluation Report	**-- Document # 8460-06.01**
Relationships Among Travel Times Evaluation Report	**-- Document # 8460-07.02**

Prepared by
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ADVANCE Evaluation

Detector Travel Time Conversion and Fusion of Probe and Detector Data

Stanislaw Berka, Helen Condie and Aaron Sheffey

URBAN TRANSPORTATION CENTER
University of Illinois at Chicago
1033 West Van Buren Street
Suite 700 South
Chicago, Illinois 60607

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Executive Summary

This report concerns the evaluation of the conversion of detector data into travel-time estimates as well as the fusion of these estimates with probe reports to obtain travel-time estimates for specific links. These processes are called Detector Travel Time Conversion (DTTC) and Data Fusion (DF) respectively, and are parts of the Traffic Related Functions (TRF) subsystem of the ADVANCE project. Data from pavement loop detectors were collected and processed on-line to create travel-time estimates. These estimates were then fused with probe-vehicle reported travel times. The fused estimates provide travel-time data which would be used for dynamic route guidance.

Detectors record two traffic measures for each link: detector occupancy and vehicular volume. While applicable to other procedures, these measurements are not directly useful for route guidance. In the DTTC process, detector data were converted into travel times which could be fused with travel times recorded by probes. These DTTC-generated travel times were computed for five-minute intervals. These data, which are used in various ADVANCE evaluations, were reprocessed off-line into configurations matching those of the memory-card data, allowing for easy comparison and contrast. DTTC uses aggregated data, which are aggregated over all detectors within a given group by averaging occupancy and summing the volume. These data include two values, average occupancy and total volume, which are derived from paired detectors at parallel locations on a given link.

Probe data were also collected and then reformatted to retain only the information needed for this evaluation and only that data from the links under consideration. In addition, information manually collected by probe drivers concerning incidents was then appended to the data set. Finally, the data were reduced into a format chosen to facilitate analysis.

Once the data from both detectors and probes were assembled into usable formats, the DTTC algorithm was run. Then average probe travel times for each interval were developed for deployment levels of one, three and five; a deployment level refers to the number of probe reports randomly selected and utilized to compute the average travel times for a given link in that five-minute interval. This average was then fused with the estimate provided by DTTC. It is important to note that even for deployment levels lower than five, only intervals with five or more reports are used in this process, keeping the same number of intervals for all deployment levels. For instance, while only three probe reports are used to compute Deployment Level 3 averages, for each interval used in the evaluation there were still at least five reports for that link available. This equivalence is helpful in comparing the results of DTTC.

Based on the results of the evaluation, the estimates of the link travel times produced by DTTC and DF appear to be accurate except when overcongested conditions exist over long periods of time. During the overcongested period, the loop detectors do not provide information on changes in traffic conditions. It is conceivable that a more advanced semi-dynamic DTTC algorithm could be developed which would yield

reasonable estimates in this case, but it would require more data to be available for the calibration process than that which was available during the development of the TRF Data Fusion subcomponent of ADVANCE.

The comparison of the quality of the DTTC/DF estimates for various deployment levels suggests that the greatest improvement in using fused data, when compared to using DTTC output only, is visible for Deployment Level 3. However, for Deployment Level 1, the estimates are much better than those derived using DTTC output only, especially for those cases where the quality of the DTTC estimate is lower (as in the case of prolonged congestion).

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1 Introduction

This report concerns the evaluation of the conversion of detector data into travel-time estimates as well as the fusion of these estimates with probe reports to obtain travel-time estimates for specific links. These processes are called Detector Travel Time Conversion (DTTC) and Data Fusion (DF) respectively, and are parts of the Traffic Related Functions (TRF) subsystem of the ADVANCE project (see Berka, et al, 1995). Data from pavement loop detectors are collected by the Traffic Information Center (TIC), and are processed on-line to create the estimates. These estimates are then fused with travel times collected by the Mobile Navigation Assistant (MNA) within each probe vehicle. The MNA transmissions provide final travel-time data which would be used by the MNAs to construct alternate route choices. Another evaluation task (see Soot and Condie, 1996) evaluates the accuracy of the probe-reported travel-time data.

For the evaluation of DTTC, we assume that the detector data are accurate. Since some errors occur, the evaluation results will account for these errors. In on-line ADVANCE operations, the data are first validated by another part of the TRF-DF module (for a description of data screening see Berka et al., 1996). For evaluation purposes, the data used are also filtered, except for the probe report data which are used as a source of the actual (average) travel times in assessing the accuracy of the estimates. These data are not filtered in order to avoid possible shortcomings of the filtering algorithm.

During the summer of 1995 approximately a dozen vehicles were driven four days a week over an eleven-week period. During this time almost 60,000 miles were driven to produce over 50,000 link reports within a confined study area. These reports provide information on at least three critical elements of travel: travel time, congested time and congested distance. Congested distance is measured in meters for each link and is the distance traversed by the probe vehicle at a speed of less than 10 meters per second (22.5mph). Congested time is measured in seconds and is the time during which the vehicle is stationary or traveling at a speed of less than two meters per second (4.4mph). This information is computed in the vehicle (also known as a probe) in its on-board MNA and is recorded in two different ways: in the vehicle (on a memory card) and in files at the Traffic Information Center (TIC) in Schaumburg, Illinois to which it is transmitted by radio frequency.

Data were collected on several study routes from June 5th to August 10th, Monday through Thursday. The original ADVANCE project design called for a massive probe deployment involving several thousand vehicles. This original vision was scaled back; this evaluation task uses data gathered from a targeted deployment of between 8 to 15 cars per day over a defined route. To simulate full deployment, the probes were sent more times over this route, thereby creating for each link a database of commensurate size to that envisioned in the original design. This data-collection exercise yielded 50,620 link travel-time reports at the TIC.

The route is located on Dundee Road and adjacent arterials, within the municipality of Wheeling, Illinois (north suburban Chicago). Dundee Road was selected because it carries a high volume of traffic and because each signalized intersection is demand-actuated by loop detectors (including turning lanes) and there are volume and occupancy detectors at several locations. Although Dundee Road extends for several miles within the ADVANCE study area, the number of potential places along Dundee Road where the necessary field tests could be performed was very limited. However, because Dundee Road is the only arterial within the ADVANCE test area with detectorized links feeding the data to TIC, these restrictions were accepted as part of the situation. The data-collection route also required a convenient location where vehicles could turn around safely and avoid being off the study route for a long period of time. As chosen, the route had a mix of link and intersection characteristics.

The first seven weeks of data collection (June 5-July 20) consisted of driving on set routes centered on Dundee Road. Data were collected, with one exception, from Monday to Thursday. For the DTTC evaluation, the data from the periods June 19–22 and July 17-20 were chosen; these two weeks contain the highest concentrations of MNA reports per link per time interval.

The report is organized as follows: the following section contains descriptions of the DTTC and DF algorithms. The next two sections are devoted to the probe and detector data, including further discussion of the data collection. The four subsequent sections describe the evaluation procedure and the results. The last section summarizes the results and draws conclusions about the DTTC and DF processes.

2 DTTC and the Data Fusion Algorithm

2.1 Data Requirements

Detectors record two traffic measures for each link: occupancy and volume. While applicable to other procedures, these measurements are not directly useful for MNA vehicle guidance. In the DTTC process, detector data are converted into travel times which can be fused with travel times recorded by probes. These DTTC travel times are computed for five-minute intervals.

The data-collection route had only three detectorized links. While detectors are also located along freeways, it was determined that arterial information would be the focus of this effort. At the vehicle density level described above, sufficient data were collected for the evaluation process. Sections 3 and 4 describe the collection of detector data and probe travel-time data, respectively.

2.2 Detector Travel Time Conversion Algorithm

The DTTC algorithm is copied here from Berka et al (1995) for completeness. The following list describes the algorithm by which link detector data are converted into travel-time estimates (t_d). In this protocol, the average loop detector occupancy (O_d)

over all available detector outputs for a given segment is converted into a travel time common to all links with that segment. The range of occupancies (0) for a detector is partitioned into intervals which are defined by parameters $O_{t,1}$ and $O_{t,2}$.

1. If the occupancy is lower than $O_{t,1}$, then $t_d = h_{11} + h_{12} \cdot O_d$, where: 0_d = average occupancy over all detector outputs available for the segment,
   $O_{t,i}$ = break points in the travel time-detector data model, and
   h_{ij} = conversion parameter values.

2. If the occupancy is between $O_{t,1}$ and $O_{t,2}$, then $t_d = h_{21} + h_{22} \cdot O_d$.

3. If the occupancy is higher than $O_{t,2}$, then $t_d = h_{31}$.

4. If the travel time $t_d < t_{min}$, where $t_{min} = l/v_{max}$, then set $t_d = t_{min}$. If $t_d > t_{max}$, where $t_{max} = l/v_{min}$, then set $t_d = t_{max}$,

where:

$O_{t,1}$	=	27% occupancy level;
$0_{t,2}$	=	42% occupancy level;
l	=	segment length (m);
v_{max} and v_{min}	=	the upper and lower limits for travel speed (35 m/sec and 1 m/sec, respectively); and,
t_{max} and t_{min}	=	the upper and lower bounds for link travel time.

Table 1 includes the parameter values required for converting arterial detector data into travel times for Links 1, 7 and 11. These values come from the calibration procedure, described in Berka and Tian (1994). An example of the conversion model can be seen in Figure 1.

Table 1: Parameter Values for Detector Data Conversion

Link ID	ADVANCE Segment ID	h_{11}	h_{12}	h_{21}	h_{22}	h_{31}	σ_d
1	88cb2b	59.73	2.53	136.10	0.00	123.56	39.99
7	88c9a8	70.49	1.62	110.58	0.13	116.09	38.42
11	8cae7	38.35	0.40	23.95	0.93	63.22	21.09
[where σ_d = standard deviation of detector travel time (sec)]							

[Note: the Link and ADVANCE Segment IDs are merely two systems used to designate identical links, and both are included for completeness.]

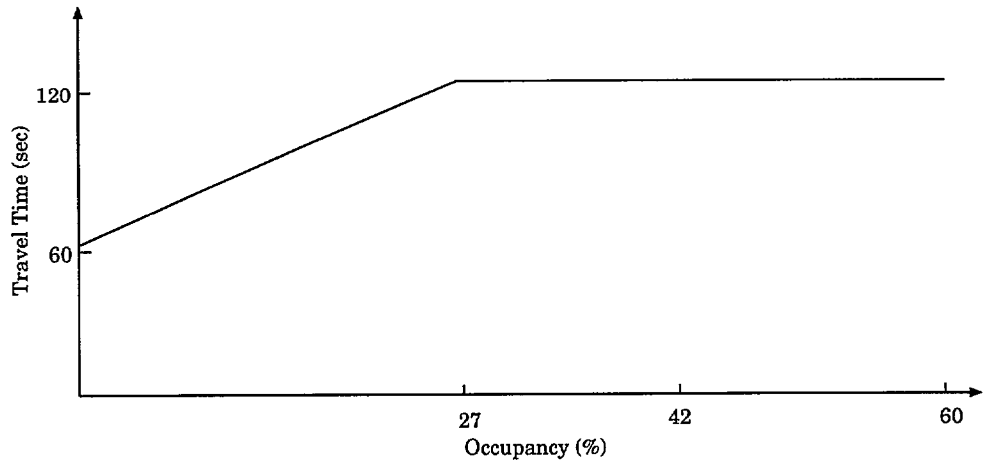


Figure 1: DTTC Conversion Model: Link 1

2.3 Data-Fusion Algorithm

Like the DTTC algorithm, the Data-Fusion Algorithm is copied here from Berka et al (1995) for completeness. Detector travel time t_d (converted from detector data) and mean probe travel time t_{pm} are fused together by the method of weighted averaging:

$$t_f = \frac{f_p \cdot \frac{N_p}{\sigma_p^2} \cdot t_{pm} + f_d \cdot \frac{W_d}{\sigma_d^2} \cdot t_d}{f_p \cdot \frac{N_p}{\sigma_p^2} + f_d \cdot \frac{W_d}{\sigma_d^2}}$$

where:

t_f	=	fused travel time (sec);
N_p	=	sum of weights of reasonable probe reports (-);
t_{pm}	=	mean probe travel time (sec);
σ_p	=	standard deviation of probe travel time (sec);
W_d	=	weight assigned to detector travel time in data screening;
t_d	=	travel time estimated from detector data (sec);
σ_d	=	standard deviation of detector travel time (sec);
f_d, f_p	=	fusion adjustment factors to control the contribution of each travel time source to the fused value.

3 Probe Data Collection

3.1 Study Routes

Two route configurations were used for the field data collection. The long route (Figure 2) consists of twelve links. The route was selected to be completed during a fifteen-minute period to provide the desired frequency of probe reports. During the off-peak period the majority of the drivers completed this twelve-link route in ten to fourteen minutes.

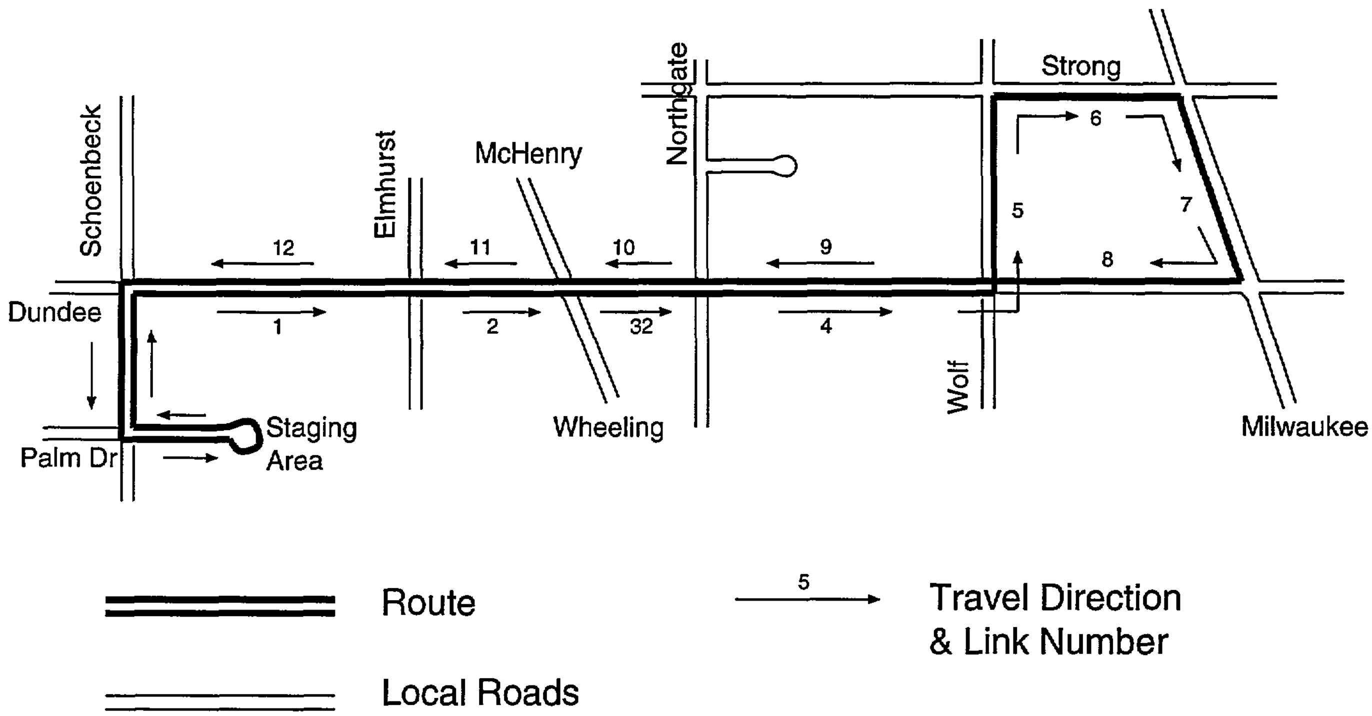


Figure 2: Probe Data Collection: Long Route

During the peak period this route proved to be too long to complete in fifteen minutes and a shorter alternative was used. This is shown in Figure 3. Even the short route could not always be completed in fifteen minutes but this happened infrequently.

The number of probe reports from each link on the two study routes is given in Table 2. In this evaluation of DTTC and DF we are concerned with Links 1, 7 and 11; it may be seen that Links 1 and 11, which feature in both the short and long routes, provide us with a greater number of probe reports than Link 7, which features in the long route only.

During the last three weeks of data-collection in the Dundee Road study area, the vehicles were used to test turning relationships. Unlike the earlier driving, in this case each driver was given a set of randomly drawn routes to be driven in sequence. Since the data-collection in the earlier part of the summer had gathered sufficient data, the turning data are not used in this evaluation of DTTC.

3.2 Data-Collection Schedule

At the beginning of each day of data collection, a twelve-noon briefing was held at the ADVANCE office in Schaumburg. At this time, the drivers were assigned vehicles and they left the office at approximately 12:30pm. Each driver used a designated

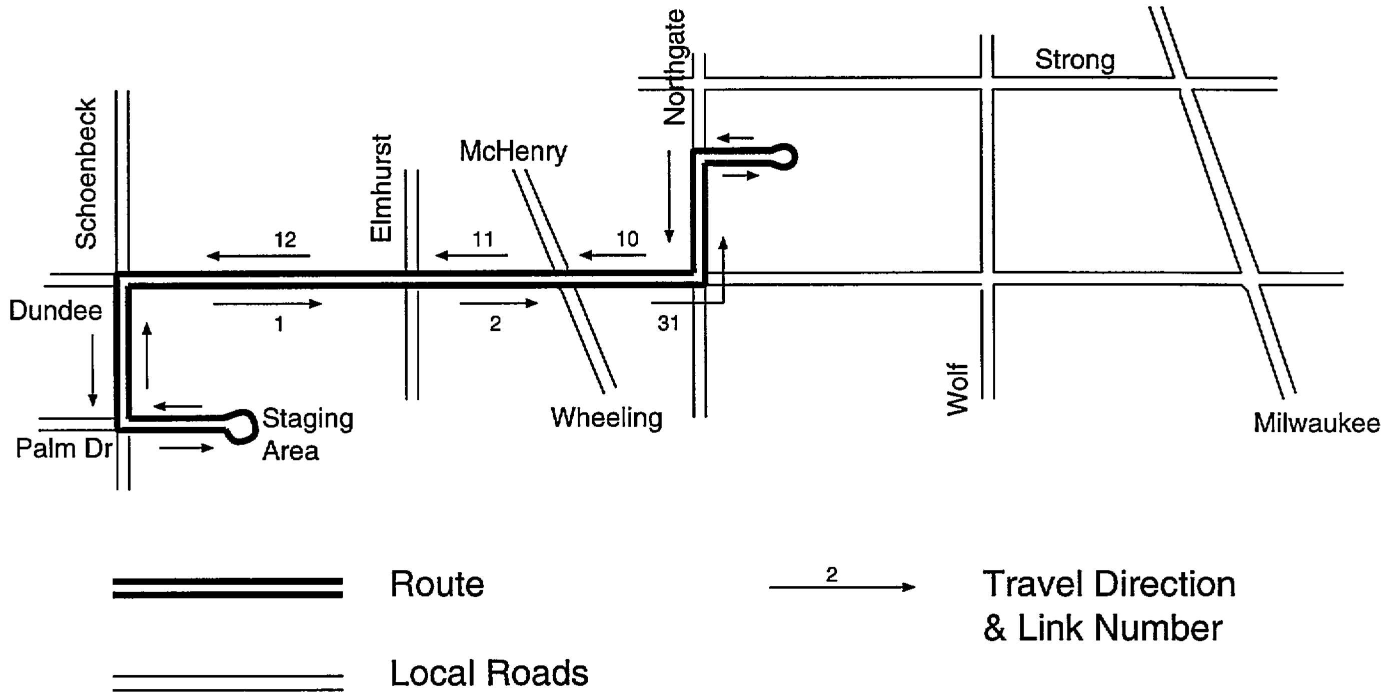


Figure 3: Probe Data Collection: Short Route

Table 2: MNA Reports by Link

Link	Frequency	Percent	Link	Frequency	Percent
1	5481	10.8	7	2323	4.6
2	6298	12.4	8	2172	4.3
3*	5886	11.6 *	9	2462	4.9
4	2313	4.6	10	6066	12.0
5	2294	4.5	11	7826	15.5
6	2293	4.5	12	5206	10.3
31*	3555	7.0 *			
32*	2331	4.6 *			
			Total	50,620	100.0

* Link 3 consists of two links, 31 and 32. Link 31 is on the short route and includes a left turn at the end of the link. Link 32 is on the long route and has a through movement at the end of the link (no turn). For DTTC we are concerned with Links 1, 7 and 11.

route to drive to the study area. There were several different routes; this report is not concerned with the routes to and from the study area. Data were collected by probe vehicles driven in the study area between lpm and 7pm, with breaks as described below.

On each day of data collection, a field manager was present at the staging area. The field manager ensured that vehicles were driving the study route at satisfactory headways and instructed drivers when to, take breaks. The field manager also assisted with other problems which routinely occurred.

The drivers were given a ten-minute break from approximately 2:00pm to 2:l0pm and another one from approximately 6:00pm to 6:l0pm. Since each driver was dispatched by the field manager to the break area as they arrived at the staging area, each took his or her break at a slightly different time. During breaks each probe vehicle was inactive for more than ten minutes because time was lost both off-route and while the MNA warmed up. The longest break occurred from 3:30pm to 4:00pm. During the two-hour peak period from 4:00pm to 6:00pm, the drivers operated their vehicles without scheduled breaks.

3.3 Data Processing and Reduction

Data received from probe MNA reports were reformatted to retain only the information needed for this evaluation and only that data from those links on the routes shown in Figures 2 and 3. Information manually collected by probe-vehicle drivers concerning incidents was then appended to the data set. Finally, the data were reduced into a format chosen to facilitate analysis.

4 Detector Data Collection

4.1 Loop-Detector Location

Two types of in-ground loop detectors are present on selected intersection approaches on the Dundee Road study routes. Their locations are shown in Figure 4. These are parts of two Closed Loop Systems. System detectors (detectors A and B in Figure 5) are located 250-300 feet upstream of the intersection; approach detectors (C, D and E in Figure 5) are located just upstream of the stop line. While both types of detector measure traffic volume and occupancy, DTTC only uses information from the system detectors, A and B. The two detector groups are used to actuate traffic signals, allowing for coordinated green times and continuous traffic flows along Dundee Road. Because of the presence of other arterials leading into Dundee Road, detector data also help coordinate traffic flows among these other roads. Detectors are generally placed in parallel positions along a link, as seen in Figure 5.

Information is collected from system loop detectors for each Closed Loop System (type Econolite KMC-1000 controllers), which begin data transmission back to the

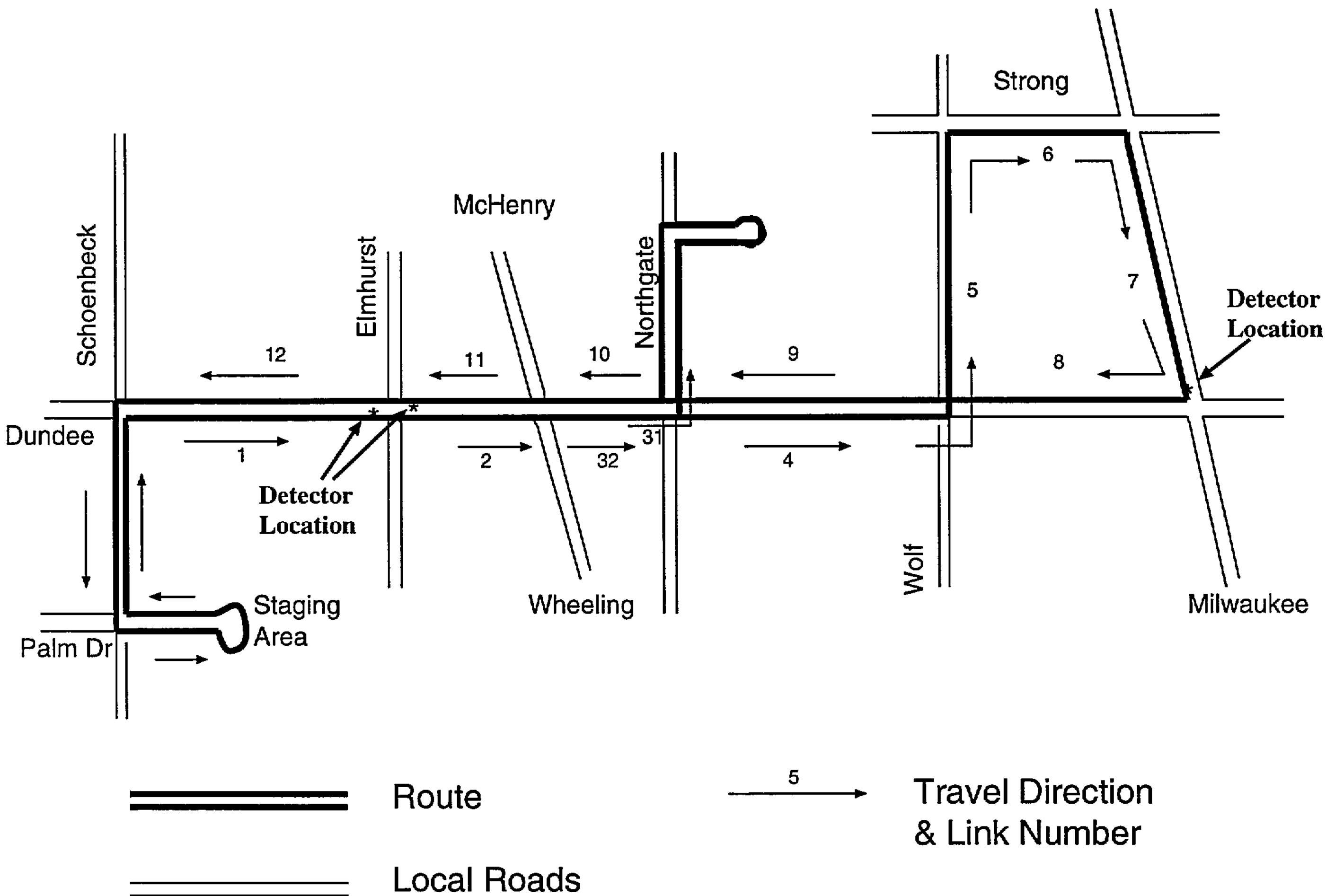


Figure 4: Probe-Data Collection Route showing Detector Locations

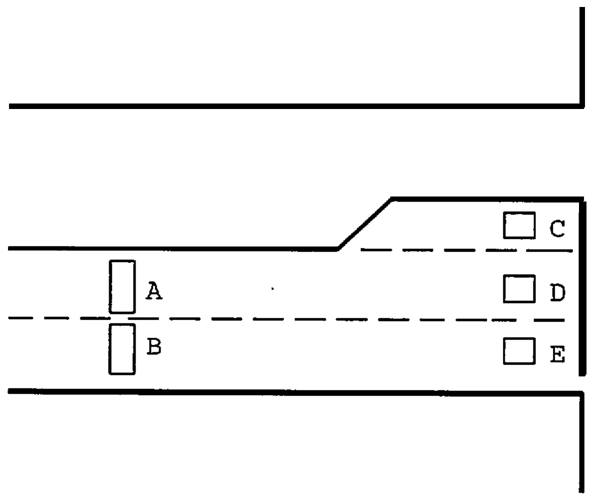


Figure 5: Location of Loop Detectors Used in Data Collection

Note: A through E represent in-ground detector locations, detectors A and B are used for DTTC

TIC. These data, along with information sent in from the MNAs in the probe vehicles [transmitted to the TIC using radio frequency (RF)], constitute part of the TIC's communications subsystem. These data are sent through the Illinois Department of Transportation' s (IDOT) standard menu interface for loop-detector data and are transmitted by IDOT's Traffic Systems Center (TSC) communications software via modem to the TIC. Detector data are sent at five-minute intervals, containing the information which is discussed in Section 4.2. TSC has multiple data configurations, which can be varied depending on what types of data are being collected. As recorded by the TIC, these data have a dual nature, and are stored in both statically and dynamically-generated formats. Data collected in this fashion are used on-line for ADVANCE project tasks and are then archived.

4.2 Data Processing and Data Reduction

Unlike other types of data collection in the ADVANCE Project, detector data collection was completely dependent on an outside source: IDOT. Detector data collection is wholly conducted by IDOT, with information only sent to the TIC after collection and assimilation by a third party.

Detector data are sent in five-minute intervals to the TIC. These data are then processed on-line into usable configurations. Data for use in ADVANCE evaluations are then reprocessed off-line into configurations matching those of the MNA and memory-card data, which allows for easy comparison and contrast. There are two basic forms for detector data, detector-by-detector and aggregated. Detector-by-detector data contain separate reports, each containing volume and occupancy, for each detector. Aggregated data are detector data aggregated over all detectors within a given group by averaging occupancy and summing the volume; this process creates a data set providing one report per five-minute interval. DTTC uses aggregated data, which includes two values [average occupancy (occ_{ag}) and total volume (vol_{ag})] derived from both detectors at parallel locations on a given link.

The data are first organized into a database. As part of this process, the data are reduced, eliminating links not within the route area under consideration. Data reduced in this fashion produce a data set similar in format to that shown in Table 3, taken from the output for August 1, 1995. Detector data are reduced to only include those detectorized links (1, 7 and 11) within the routes shown in Figure 4.

Table 3: Sample of Reduced Data Output

Date m/d/yr	Time	Traffic Volume	Occupancy (%)	Link ID (hex)	Link ID	Detector Station Name
8 1 95	13 2 27	72	16	" 8cae7"	11	"DU_W_83"
8 1 95	13 2 27	60	9	"88c9a8"	7	"DU_S_MILWK"
8 1 95	13 2 27	91	25	"88cb2b"	1	"DU_E_83"
8 1 95	13 2 27	64	25	"88c9a8"	7	"DU_S_MILWK"
8 1 95	13 2 27	83	19	"88cb2b"	1	"DU_E_83"
8 1 95	13 2 27	67	6	" 8cae7"	11	"DU_W_83"

5 Evaluation Procedure

There are two distinct data assembly procedures for our analysis: that using detector data only and that using detector data and probe data. We compare both detector travel time conversions (the output of DTTC, using detector data only) and fused travel times (the output of the fusion of probe data and DTTC) with average probe travel times.

The evaluation procedure for analysis using fused detector data and probe data is depicted in full in Figure 6. For analysis using detector data only the output of DTTC (Step 5 on Figure 6) is compared with mean probe travel time; data fusion is not, performed.

Data for DTTC (i.e., detector data) are divided into five-minute intervals so that there is exactly one detector report per interval. Five-minute intervals are used because detectors only transmit data in five-minute intervals. Data for use in analysis using both detector and probe data are also assembled into five-minute intervals; in this case, an interval is only created when at least five probe reports for the same interval are available for the same link (see following).

Data Used for Evaluation of DTTC and DF

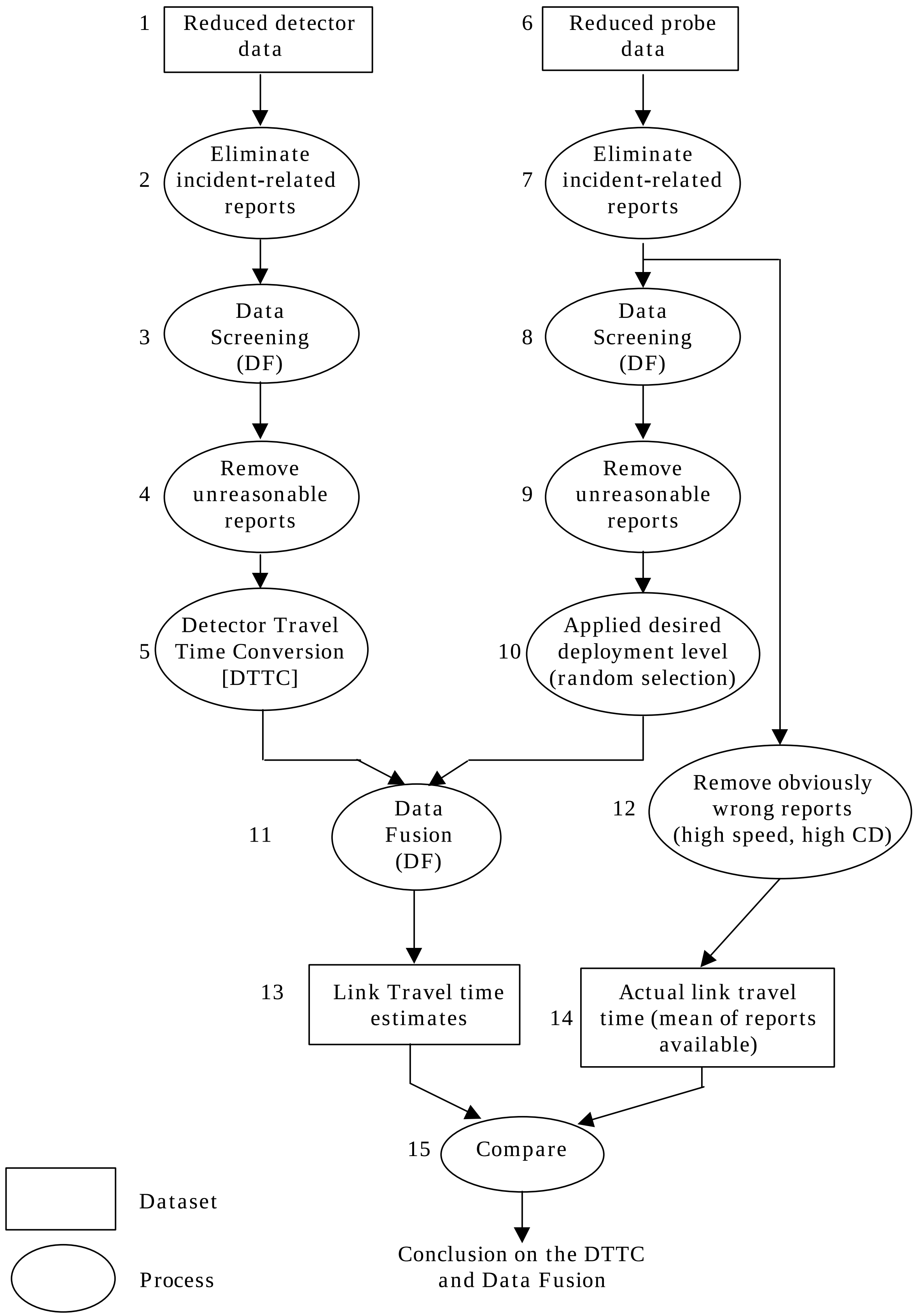


Figure 6: Flow Diagram of DTTC and DF Evaluation Procedures

Three steps are performed in parallel for both detector and probe data, including the elimination of incident-related reports, data screening as developed for the TRF Data Fusion (DF) subcomponent, and the elimination of reports determined by the data-screening algorithm to be unreasonable. These three steps describe the two threads in Figure 6 (2-3-4 and 7-8-9).

In the DTTC procedure, average volume and occupancy are computed using detector data as assigned to each interval. For analysis using fused detector and probe data, an additional step (Step 10 on the flow chart) is performed on probe data. Average probe travel times for each interval are developed for deployment levels of 1, 3 and 5; a deployment level refers to the number of probe reports randomly selected and utilized to compute the average values for a given link in that five-minute interval (see Section 6). It is important to note that even for deployment levels lower than 5, only intervals with five or more reports are used in this process, keeping the number of intervals the same for all deployment levels. For instance, while only three probe reports are used to compute Deployment Level 3 averages, there are still at least five reports available for that link for that time period. This equivalence is helpful in comparing the results for different deployment levels. These interval data are then used as the inputs for the data fusion procedure.

Seven deployment levels are suggested by the Evaluation Test Plan (ETP), as specified by Table 4; deployment levels used in our analysis are described in detail in the next section. While the ETP suggests analyses for the evening period (6pm-8pm) and for those links controlled by stop signs and for approaches to major-minor priority links, no data are available for these conditions (marked with square braces in Table 4). Evaluation is therefore not possible for these additional cases.

Table 4: Input Conditions for DTTC and DF Simulation, as Specified in the Evaluation Test Plan

Probe Deployment Level (observ/inter)	Time Period	Link Class
0	1pm-4pm	unopposed, signal
1	4pm-6pm	[opposed, stop sign]
2	[6pm-8pm]	[unopposed, priority]
3		
4		
5		
+5		

The detector data are converted into link travel-time estimates using the TRF-DTTC algorithm (see Section 2.2). For analysis using probe and detector data, the travel-time estimates which are the output of the DTTC procedure are fused with probe reports, simulating the desired levels of probe deployment by randomly filtering the probe reports for the interval considered, as noted above. The data fusion algorithm is described in Section 2.3. Standard deviations used in the fusion process are presented in Tables 1 and 5 for detector-based, travel-time estimates and probe reports, respectively. Values in Table 5 are obtained from the output of the Static Profile Update (Sen et al., 1996).

Table 5: Standard Deviations of Probe Reports

	Link	Data from Period: June 19-22	Data from Period: July 17-20
Off-Peak	1	41.00	24.93
	7	79.18	46.92
	11	48.45	83.11
Peak	1	38.74	26.34
	7	447.25	133.41
	11	54.24	21.31

Using all available probe reports for the same time interval as a reference point, the estimates are assessed for accuracy (Step 14 in Figure 6). Probe reports used in this step were processed to eliminate incorrect reports. The deleted reports included those which had excessively high or low travel times which could not be correct.

6 Evaluation Results

The following sections present the results of the evaluation obtained using the procedures described in the previous section. The results for different time-of-day periods, various probe-deployment levels (including deployment level 0, i.e., detector data only) and links are presented graphically in Figures 7 through 24 and 26 through 31. The results of the analysis are presented for two cases; the moderately-congested case refers to Links 1 and 11 and the congested case refers to Link 7. Each of the twenty-four figures follows the same format, with a scattergram at the top of the page and a histogram below. The scattergrams reflect the five-minute data, representing five-minute intervals. The mean probe travel times for the five-minute intervals are on the y-axis and the travel time estimates generated by the DTTC and DF are on the x-axis. The line reflecting equal values of x and y is drawn to help assess how closely the estimates mimic the average travel time. Ideally, all circles would be concentrated along this line.

The histogram in each figure shows the frequency distribution of the difference between the estimated travel time and the probe reported travel time for each five-minute interval. The height of one bar represents the number of reports for which the difference between the probe and estimated travel time is within a narrow range as defined by the x-axis. An ideal procedure would be represented by a few high bars concentrated around zero.

Out of all the possible simulations of the DTTC and DF defined by the selection of one entry from each input condition in Table 4, only the scenarios presented in Table 6 are analyzed. Used throughout the report, the term *vehicle deployment level* can be explained as follows: Deployment Level N means that for each five-minute interval analyzed, exactly N probe reports are used as input to the DF process. Deployment Level 0 is used to denote the case when the travel-time estimates are based on the DTTC output only, that is, no probe reports are fused with DTTC output. A desired deployment level is obtained within the evaluation procedure by selecting all intervals with at least five (5) probe reports, out of which *n* reports are *randomly selected.* The exception is Deployment Level 0 where all intervals with any number of probe reports are used for the analysis (although the probe reports themselves are not used in the process).

Table 6: Combination Inputs for DTTC and DF Simulations Selected for Evaluation

Time Period	Deployment Level*	Corresponding Figure # (for Links 1, 11 and 7)
Off-Peak (1-4pm)	0 (detector only)	7, 9, 11
	1	13,15,26
	3	17,19,28
	5	21,23,30
Peak (4-6pm)	0 (detector only)	8, 10,12,
	1	14,16,27
	3	18,20,29
	5	22,24,31

7 Results for DTTC: Detector Data Only

The evaluation results presented in this section are divided into two groups, moderately-congested links (Links 1 and 11) and congested links (Link 7). Data analyzed in this section were assembled using the procedure described above; that is, there is only one detector report per five-minute interval. Travel-time estimates based on these detector data are compared with probe data travel time averages for accuracy.

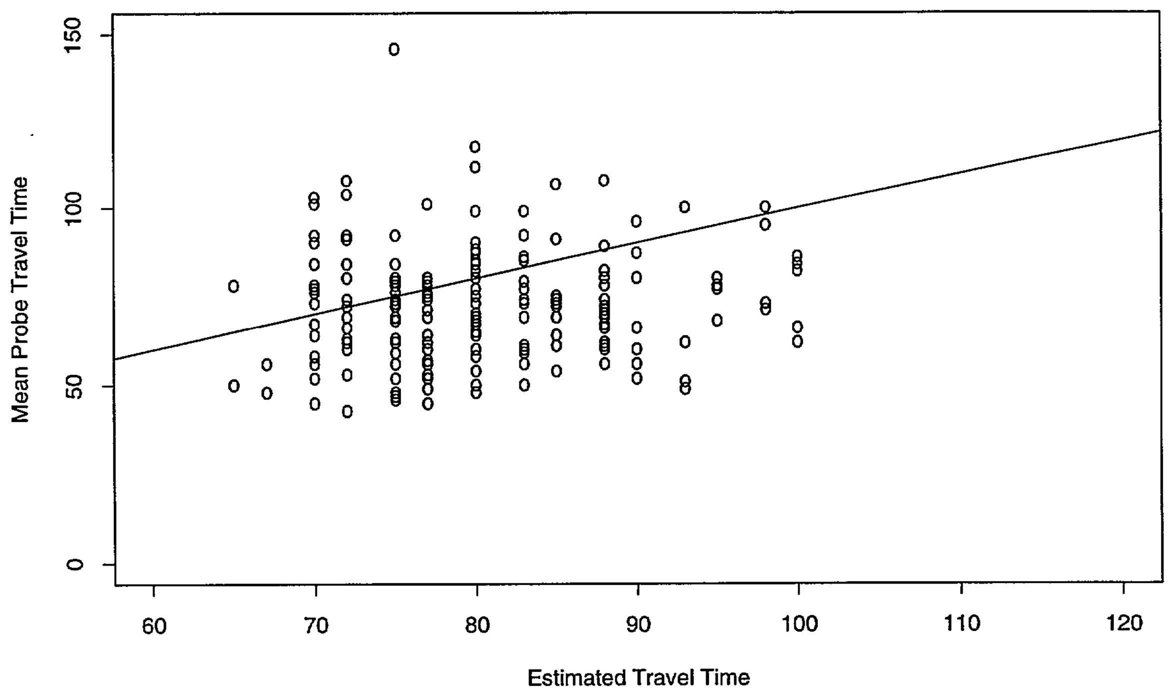
7.1 Moderately-Congested Case

Results for this case (Links 1 and 11) are presented in Figures 7 through 10. The detector occupancy used to estimate the travel times are rounded in the detector controller to the nearest integer number and are then transferred in this form to TIC. Integer values converted by a conversion model like the one in Figure 1 give discrete values as shown in Figures 7 through 10. Generally, the scattergrams in these four figures are similar. A visual analysis of the quality of the DTTC estimates, based on the histograms in Figures 7 through 10, shows that the estimate typically differs from the actual probe travel time by less than 50 seconds.

While Link 1 during the off-peak and peak periods (scattergrams on the upper half of Figures 7 and 8) has the same range of mean travel times, the estimated travel times for the peak period are lower. Several of the estimates reach 100 seconds for the off-peak period but only one estimate exceeds 85 seconds for the peak period. This fact, while counterintuitive, can be explained. Link 1 is not saturated, either during the peak or off-peak periods, so the travel time is about the same for both cases. However, during the off-peak period (l-4pm) there is more east-bound traffic (Link 1 is east-bound) than during the peak period, when the majority of the traffic is west-bound, outward from Chicago. As a result, Link l's occupancy and the resulting travel-time estimate for the off-peak period are higher than those for the peak period.

The explanation given above can be verified by using a west-bound example of Link 11. If the explanation is true, we would expect the opposite situation than for Link 1; that is, we would expect the estimated travel time to be higher for the peak period. Indeed, the mean travel times for Link 11 for both off-peak and peak periods lie in approximately the same range, but now the peak estimated travel time is slightly higher. Several of the peak estimates exceed 50 seconds (top half of Figure 10) while only one off-peak estimate exceeds 50 seconds (top half of Figure 9). The higher range of travel-time estimates for Link 11 in the peak period follows the more intuitive pattern of higher travel times during the peak period, the principal reason being that Link 11 is west-bound and carries the afternoon peak traffic from Chicago and its inner suburbs to the outlying suburbs.

The lower occupancy and corresponding travel-time estimates for the peak period on Link 1 (compared to the off-peak estimates) have a further explanation. The traffic signal at the downstream end of Link 1, like most signals in this area, is demand-actuated (dynamically adjusted to adapt to the changing traffic conditions). Roughly speaking, the street with the heavier traffic gets the longer green time. Because the traffic on Dundee Road (and Elmhurst, its cross-street) is heavier during the peak period than during the off-peak period, it gets more green time during the former than the latter. The occupancy depends not so much on the traffic volumes themselves as on the ratio of volume to capacity of the approach, this capacity being an increasing function of green time. For this reason, even if the volume on Link 1 is slightly higher during the peak period than off-peak, the volume-to-capacity ratio will be lower. Therefore, the travel-time estimate based on the corresponding occupancy figure derived from the detectors will also be lower, as seen on upper parts of Figures 7 and 8. This relationship points to the quality of the DTTC estimates. On Link 11, the green time is higher during the peak period (for the same reason as for Link l), but the volume is significantly higher during the peak period.



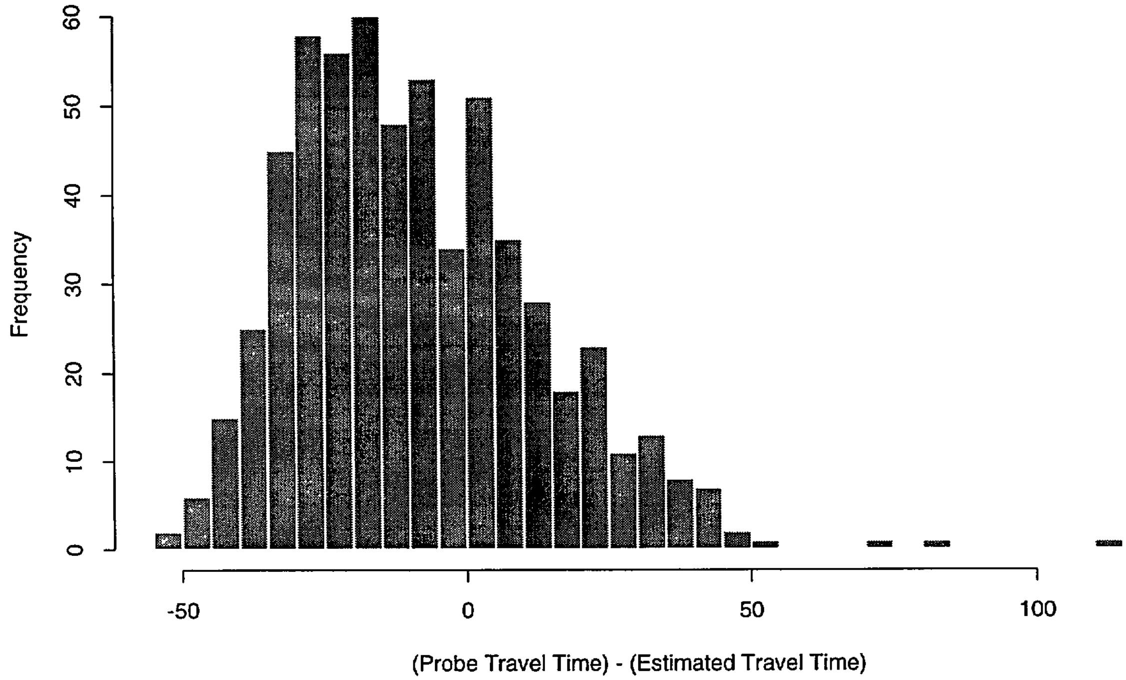
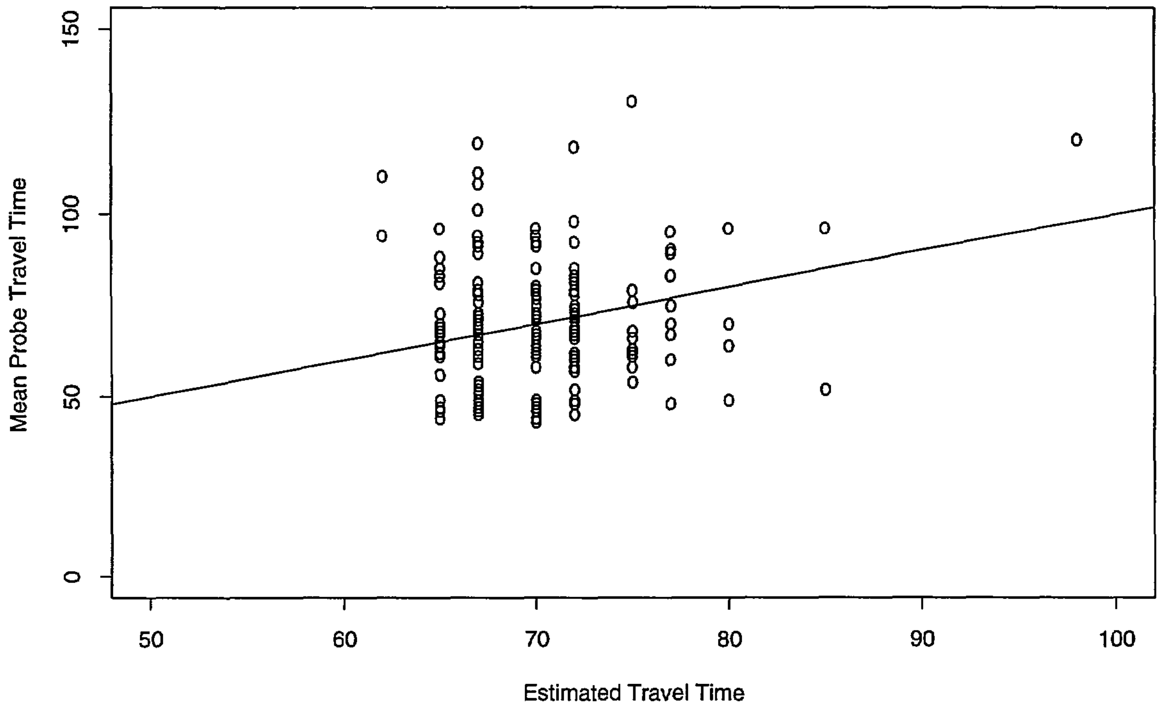


Figure 7: Difference between Probe and Estimated Travel Time: Link 1, Off-Peak, Detector Data Only



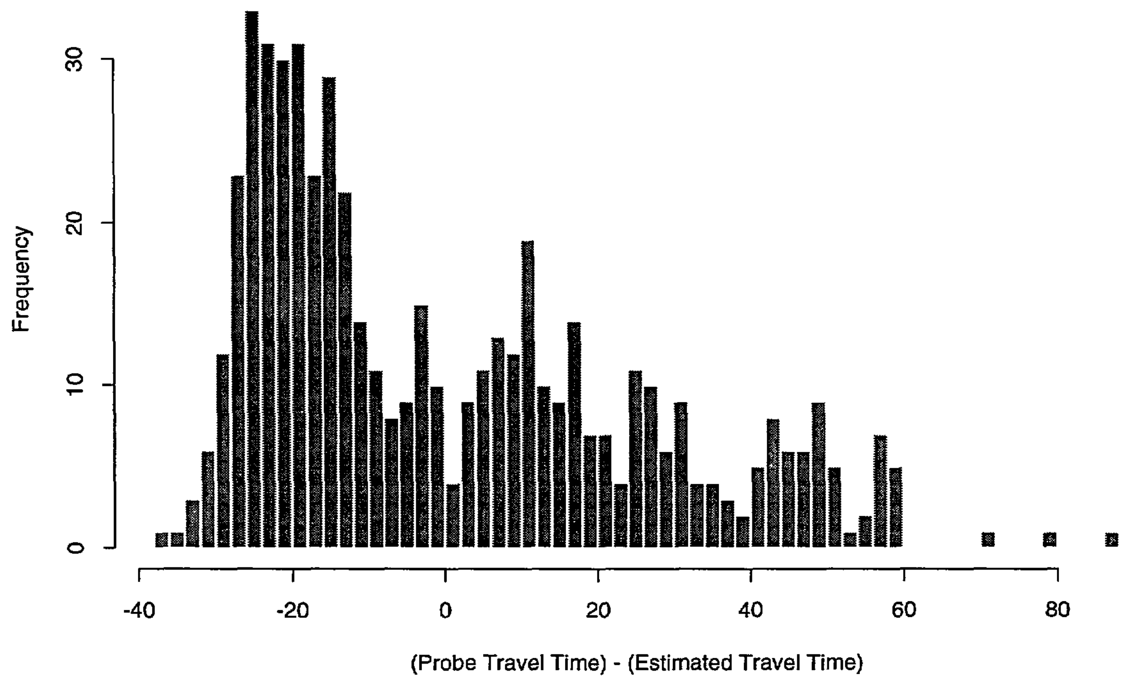


Figure 8: Difference between Probe and Estimated Travel Time: Link 1, Peak, Detector Data Only

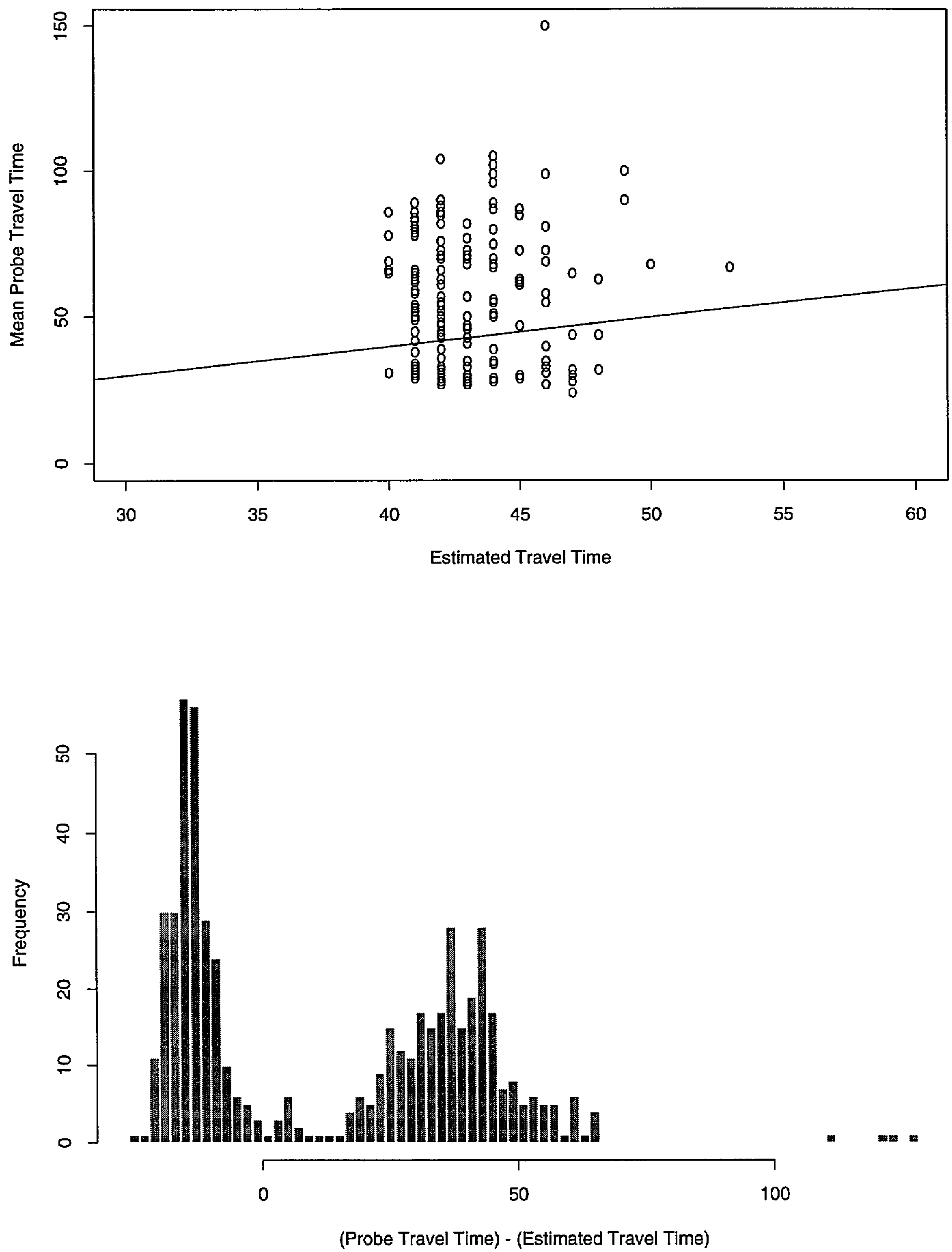


Figure 9: Difference between Probe and Estimated Travel Time: Link 11, Off-Peak, Detector Data Only

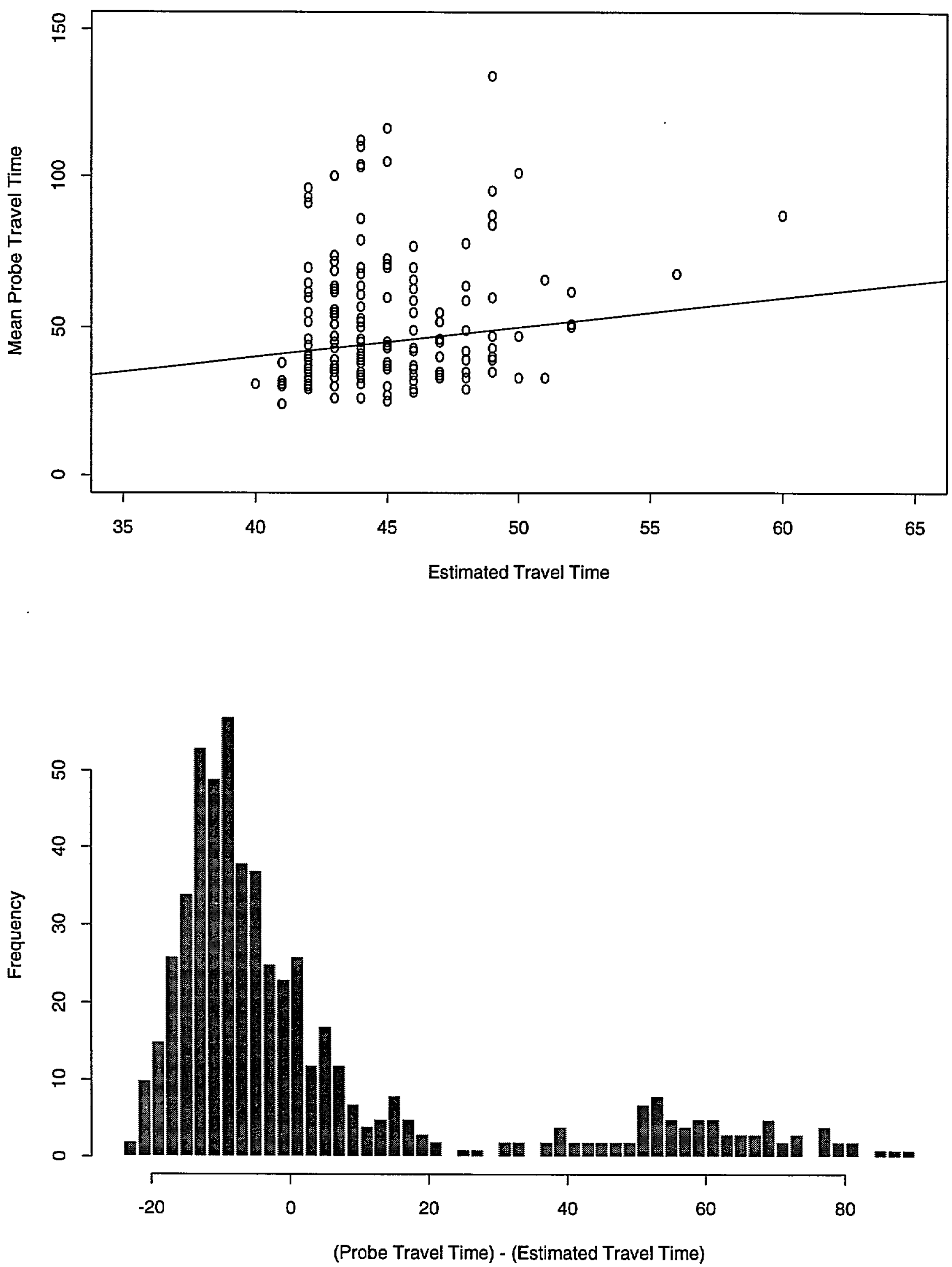


Figure 10: Difference between Probe and Estimated Travel Time: Link 11, Peak, Detector Data Only

7.2 Congested Case

This section discusses the results for the congested case (Link 7), for both the off-peak (Figure 11) and peak periods (Figure 12).

On both scattergrams we observe two distinct groups of points. The first group consists of observations located along the line x = y, which for the off-peak period includes the majority of the observations. For the first group of points actual and estimated travel times roughly correspond. The second group of points is substantially different: the mean travel times are much higher then the corresponding estimates; these points ar grouped together in a vertical line. Overall, while evidencing less correspondence between the probe averages and the DTTC estimates than those in the off-peak scattergram, the points plotted in the peak scattergram still show correspondence between the averages and the estimates. Therefore, the quality of estimates from the first group of points for both periods is still quite good even though its quality is slightly lower than that of the off-peak estimates for Link 1.

The peak-period case for Link 7 can be explained by the fact that during the peak period the approach of Link 7 is highly congested with the queue frequently spilling back into the upstream link. Importantly, the queue for most of the 4-6pm period is much longer than the loop-detector setback (about 300 feet). Thus, the occupancy measured by the detector is more or less constant as long as over-congestion persists. This deduction is valid assuming that the green and red times do not change, a condition satisfied by Link 7 during the peak period. Therefore, the travel time estimated by DTTC based on the detector occupancy is the same during most of the peak period (the vertical line of points in Figure 12), while the queue and the corresponding mean probe travel times first increase as a result of extreme congestion (where demand volume is higher than the capacity of the approach), and then decrease at the end of the peak period.

A conclusion drawn from this discussion is that the DTTC algorithm functions well if the queue length on a link does not significantly exceed the loop-detector setback for long periods of time. In other words, as long as the loop detector provides actual information on traffic conditions, DTTC provides accurate travel-time estimates. Except for the case when the queue length on a link significantly exceeds the setback of the loop detector for a long period, the range of differences between the probe and estimated travel times described in the previous two sections is actually not as great as the range of actual individual link travel times. These times may differ among themselves by the same range due to the vehicle arriving during a red or green light, with the variation reaching as much as 60 seconds. Assuming a signal cycle length of 120-150 seconds where the red time equals 50% of the cycle length, the difference in travel time between the vehicle that passed through the intersection just before the signal turned red and the travel time for the first vehicle which stopped on red may be up to 60 seconds.

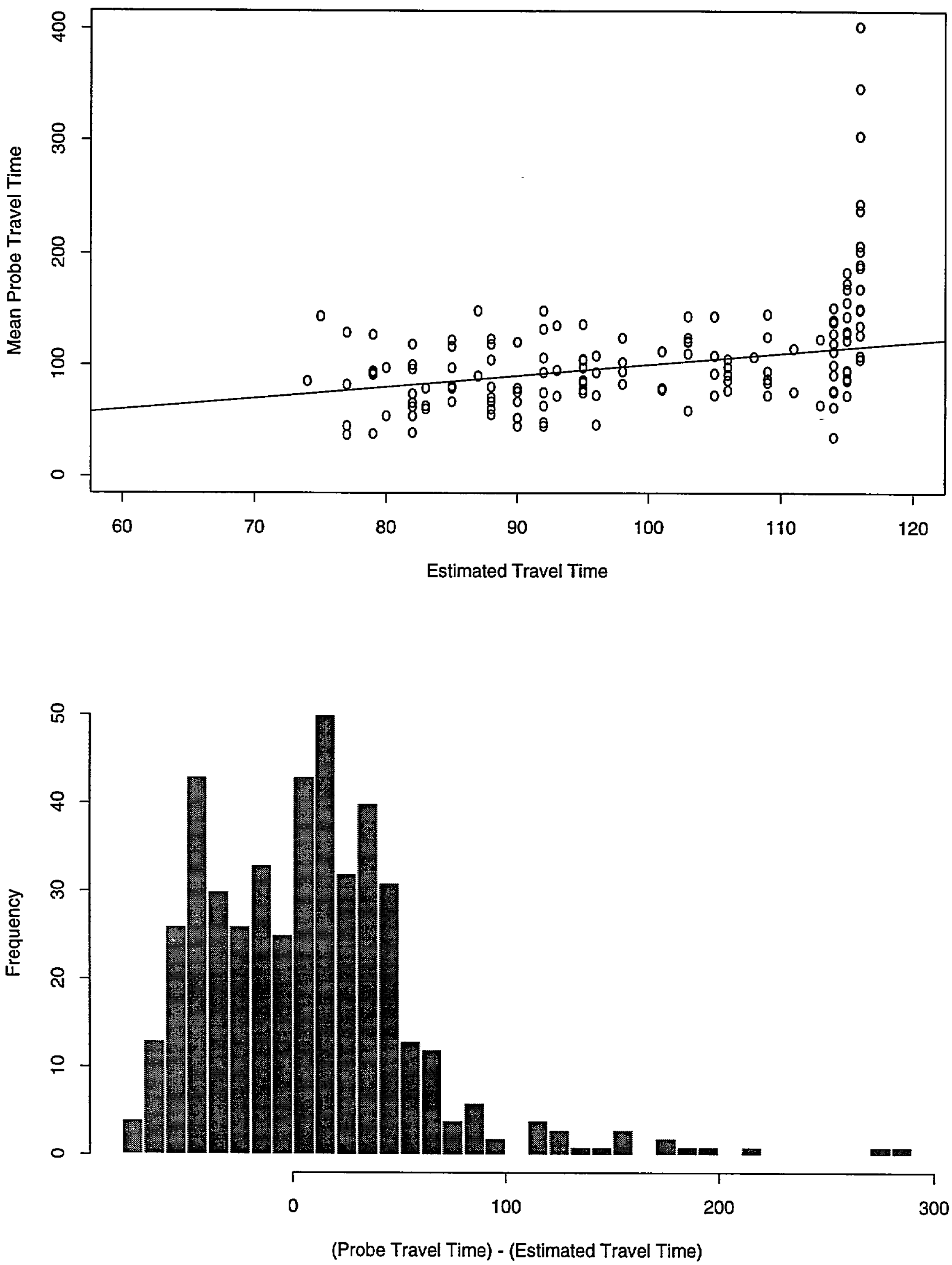
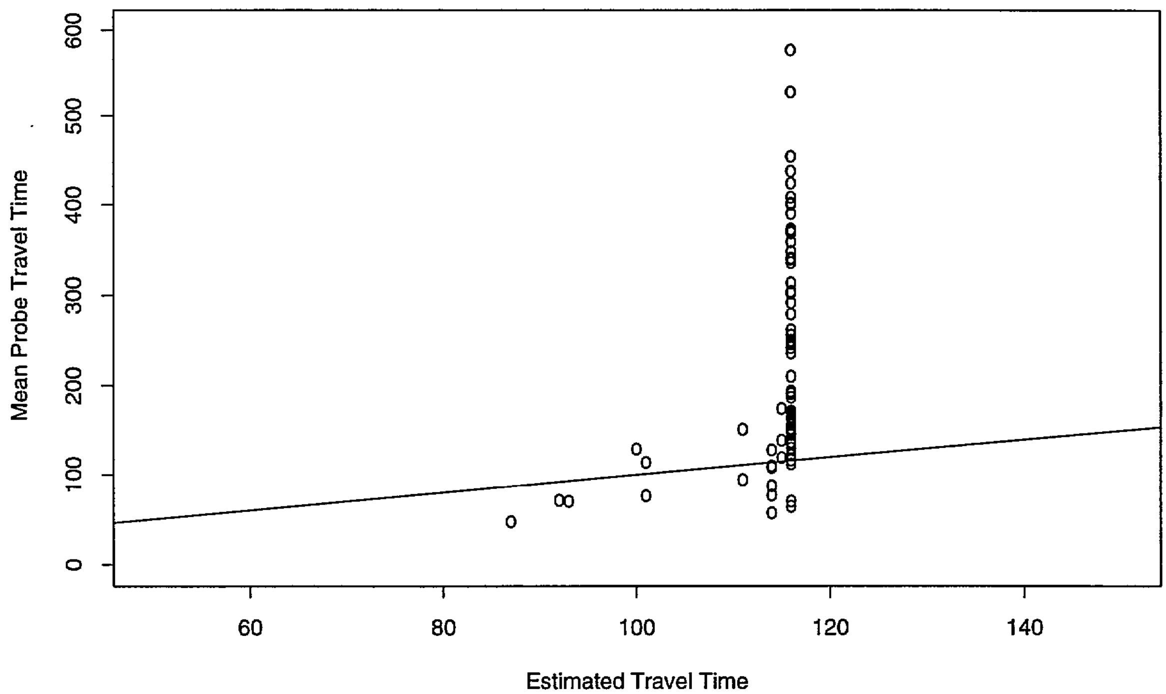


Figure 11: Difference between Probe and Estimated Travel Time: Link 7, Off-Peak, Detector Data Only



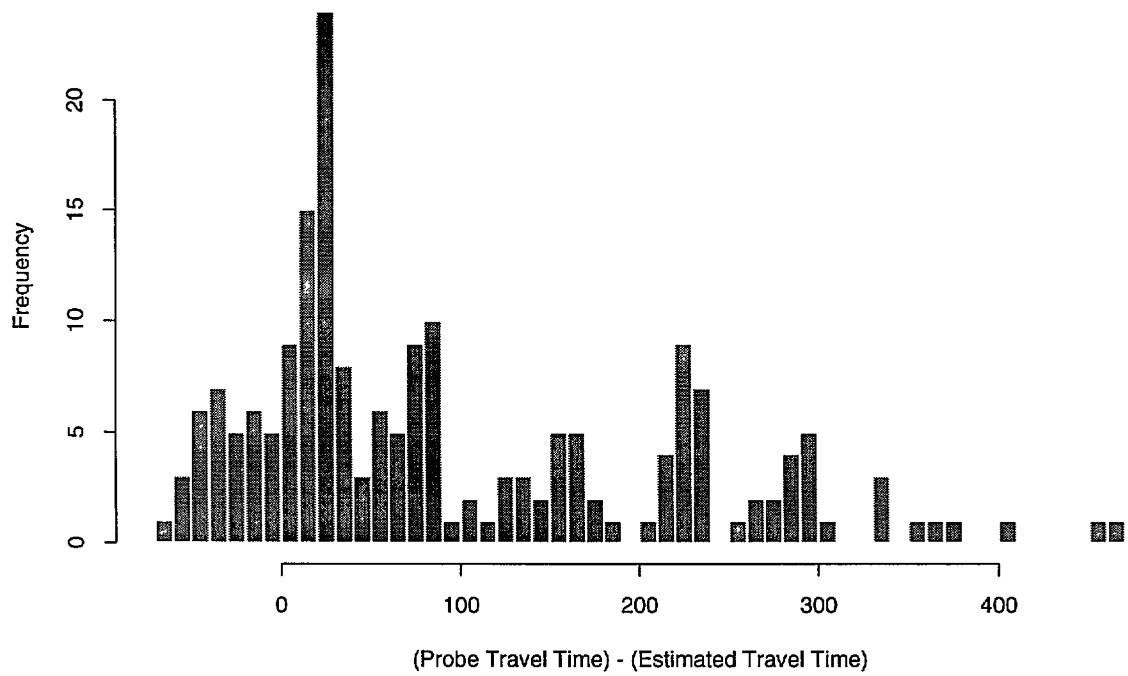


Figure 12: Difference between Probe and Estimated Travel Time: Link 7, Peak, Detector Data Only

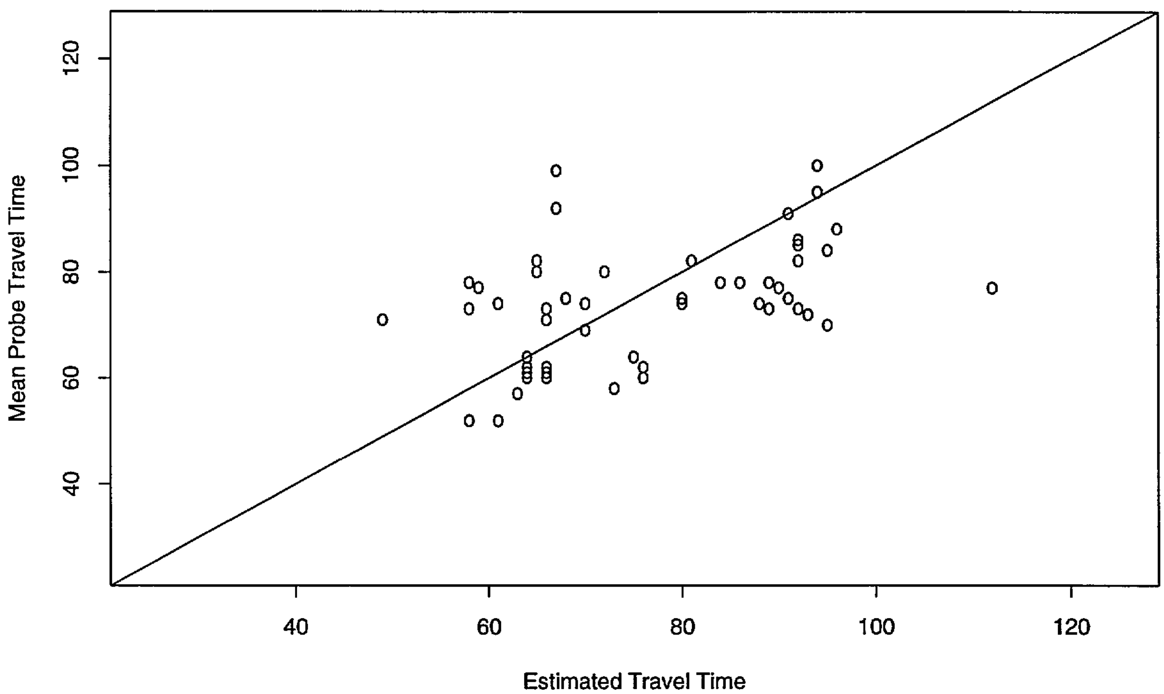
8 Results for DTTC Fused with Probe Data

As before, these results are presented separately for the moderately-congested links, Links 1 and 11 and for the congested conditions of Link 7. While in the previous section all intervals with any number of reports were used for the analysis, in this and the following sections only those intervals with at least five reports per five-minute interval are analyzed. As noted earlier, this restriction is applied to facilitate comparisons among different deployment levels when probe data are used. Because not all possible five-minute intervals contain the minimum number (five) of probe reports to fulfill this requirement, the total number of intervals under consideration is decreased and is therefore substantially lower than in those cases using detector data only. The probe reported travel-time averages used for comparison with the DTTC travel-time estimates are always based on all probe reports available for the considered time interval. Therefore, while analysis using fused detector and probe-report data may examine fewer intervals, the probe report means to which they are compared always contain all probe reports for that time interval.

8.1 Moderately-Congested Case

8.1.1 Deployment Level 1

This discussion is based on Figures 13 and 14 for Link 1 and Figures 15 and 16 for Link 11. For Link 1 the difference between the probe and estimated travel times is typically less than 50 seconds, as in the case of DTTC without probe reports (Figures 7 and 9). The scattergrams for both cases (detector data only and fused probe and detector data) look similar. However, the histograms suggest that in some five-minute intervals the estimate derived without using probe data is better than that which includes probe data. For example, in the case using detector data only in the off-peak period, there are only four estimated travel times which differ from the probe travel time by more than 50 seconds (lower half of Figure 7), while there are seven such reports for the off-peak period using DTTC fused with probe data (lower half of Figure 13). While this observation is counterintuitive, it is not surprising. Consider the following example of the data for Link 1: the detector-based estimate is 82 seconds. For the same interval, there are five reports available (118, 63, 76, 72 and 56 seconds), and the mean travel time of these reports is 77 seconds. Assume that the one probe report that we randomly selected for the fusion process is the 11%second report. When this report is fused with the DTTC estimate of 82 seconds using weights appropriate for Link 1, we get a fused estimate of 112 seconds. This estimate is 35 seconds away from the probe mean travel time, compared to the DTTC estimate using detector data only which is only five seconds off the probe mean travel time. As this example shows, due to the random selection of probe reports for the fusion procedure, the addition of probe data to the DTTC estimate might not necessarily increase accuracy.



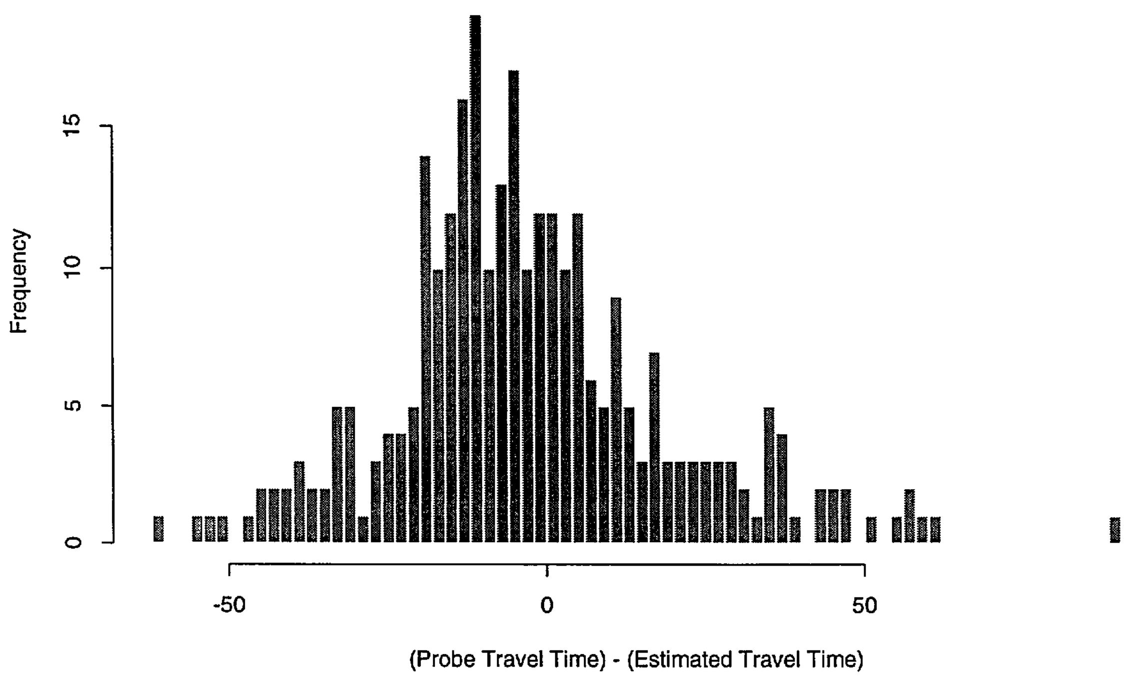


Figure 13: Difference between Probe and Estimated Travel Time: Link 1, Off-Peak, Deployment Level 1

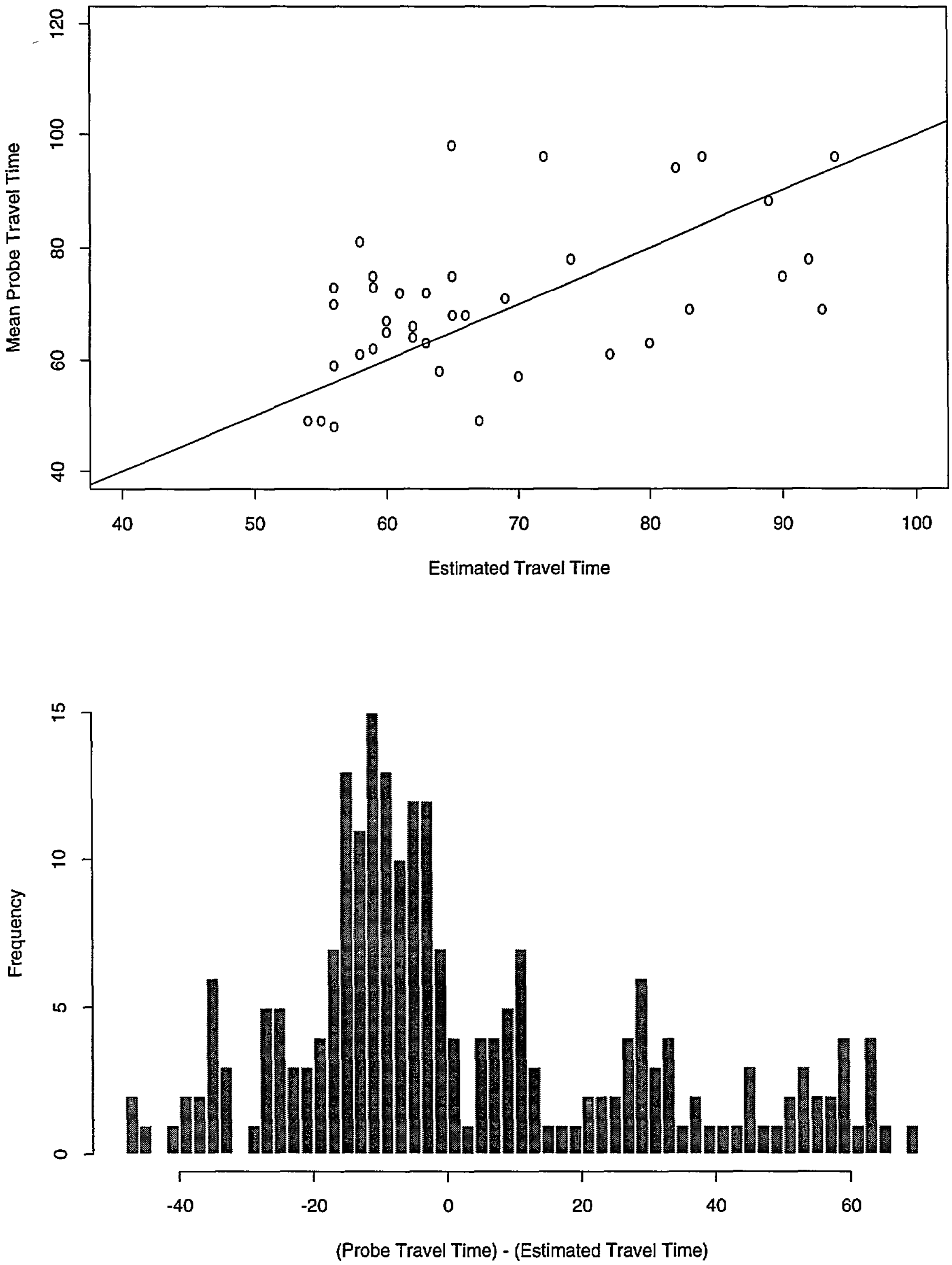
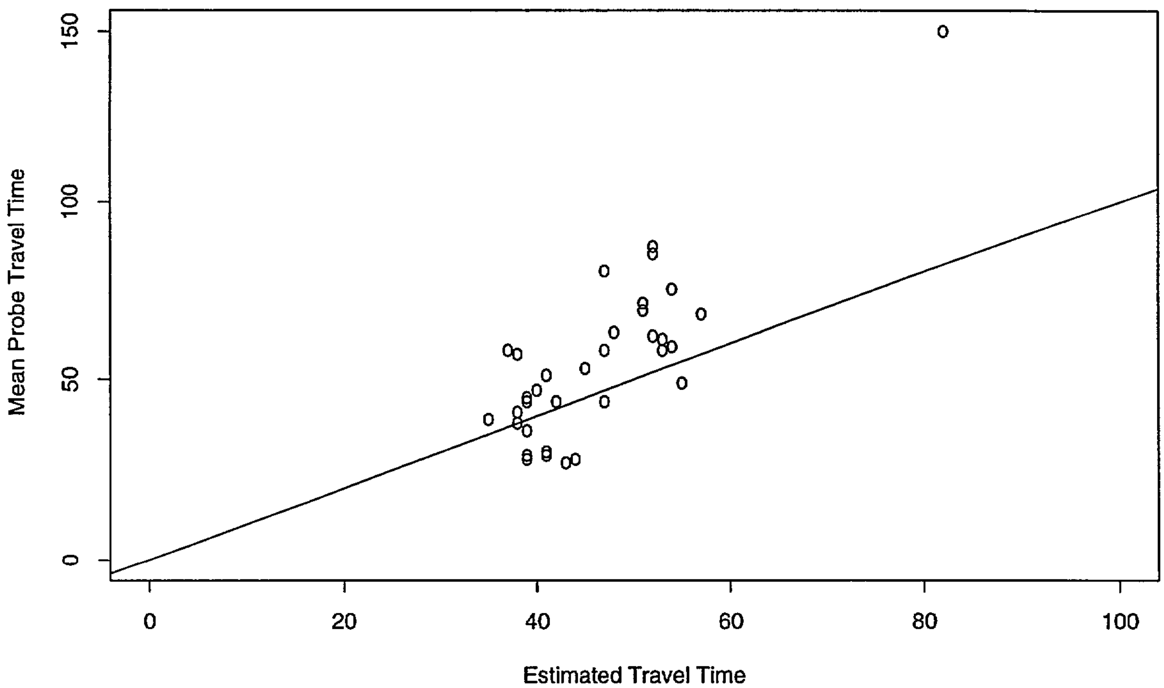


Figure 14: Difference between Probe and Estimated Travel Time: Link 1, Peak, Deployment Level 1



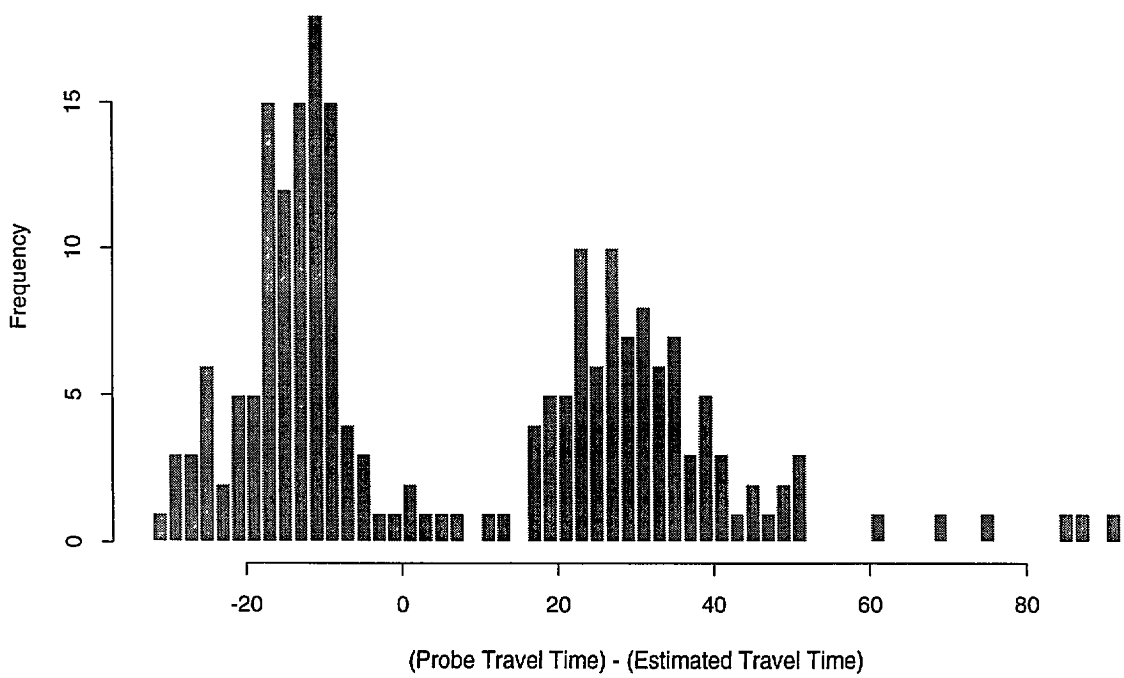
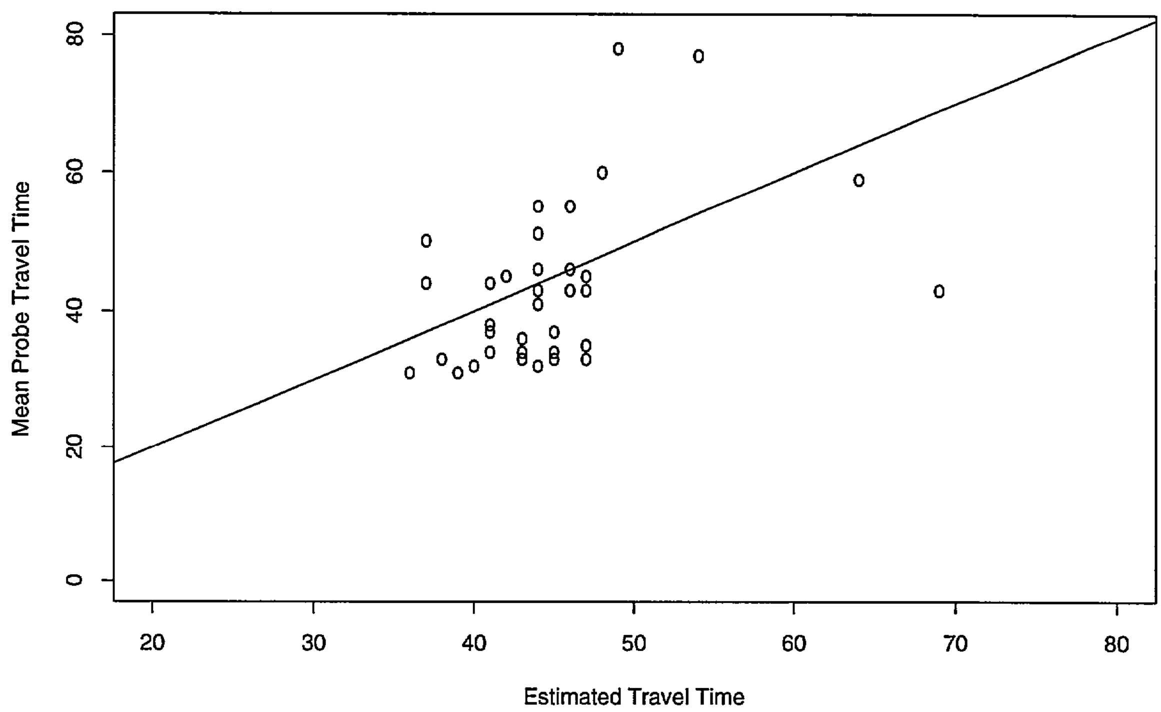


Figure 15: Difference between Probe and Estimated Travel Time: Link 11, Off-Peak, Deployment Level 1



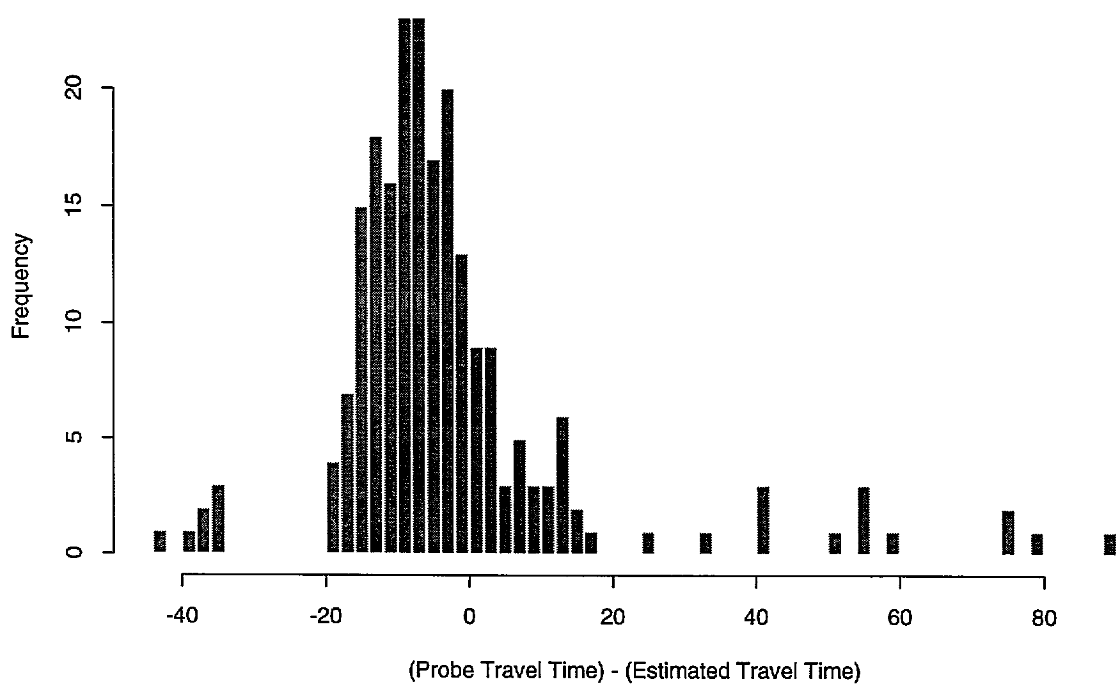


Figure 16: Difference between Probe and Estimated Travel Time: Link 11, Peak, Deployment Level 1

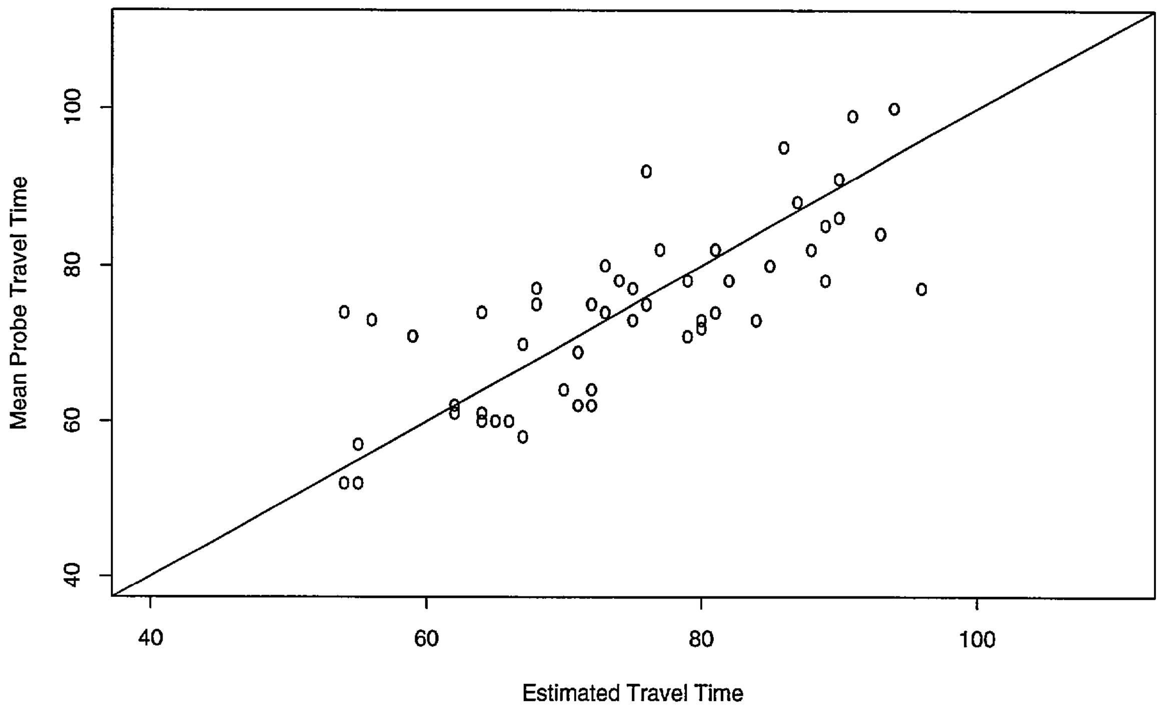
This discussion suggests that a single probe report may not be enough to improve the quality of the estimate: when only one report is used, it could be an outlier like the above 118-second report. Therefore, using more than one report would reduce the inaccuracies caused by the randomly-selected outliers. This observation is important, as the average number of probe reports per interval, even with the full deployment of 5000 probe vehicles traveling over the ADVANCE test area, was estimated to be 1.4 reports per 5-minute interval (see Hicks et al, 1992). However, it can be shown that fusing probe and detector data will, on average, yield more accurate reports. The above example is included merely to point out the possibility for inaccuracies; it is not to be taken as the predominant result of data fusion.

8.1.2 Deployment Level 3

Results for Deployment Level 3 are depicted in Figures 17, 18, 19 and 20. Several observations can be made based on these figures. First, the quality of the estimates is superior to those produced at Deployment Level 1. From the visual comparison of scattergrams in Figures 13, 14, 15 and 16 (Deployment Level 1) with 17, 18, 19 and 20 (Deployment Level 3), it can be seen that the plotted points are grouped more closely around the line of equal x and y values in the group of figures for the Deployment Level 3 case. The x = y line itself represents the optimal relationship, where the mean probe and estimated travel times are identical. The second observation is that the difference between probe mean travel times and estimated travel times at this deployment level is generally less than 40 seconds (lower half of Figures 17, 18, 19 and 20); at lower deployment levels the difference often exceeds 50 seconds. The lower differences between travel time estimates and actual travel times indicate that as the number of probe reports increases, the travel-time estimates become more accurate. This observation also indicates that the increased correspondence is not compromised by whether the period being studied is peak or off-peak.

8.1.3 Deployment Level 5

While Figures 21, 22, 23, and 24 for Deployment Level 5 indicate a marginal increase in the quality of estimates in relation to probe reports, this marginal improvement is much smaller than the improvement between Deployment Levels 1 and 3. Where the upper range of the value of (probe travel time) - (estimated travel time) between Deployment Levels 1 and 3 dropped by 10 seconds to a level of about 40 seconds, the value of (probe travel time) - (estimated travel time) between Levels 3 and 5 only decreases by 5 seconds, to a level of about 35 seconds. These changes can be seen in Figures 21 and 22 for Link 1, and Figures 23 and 24 for Link 11. At this deployment level, an increase in deployment still appears to improve the overall estimate quality.



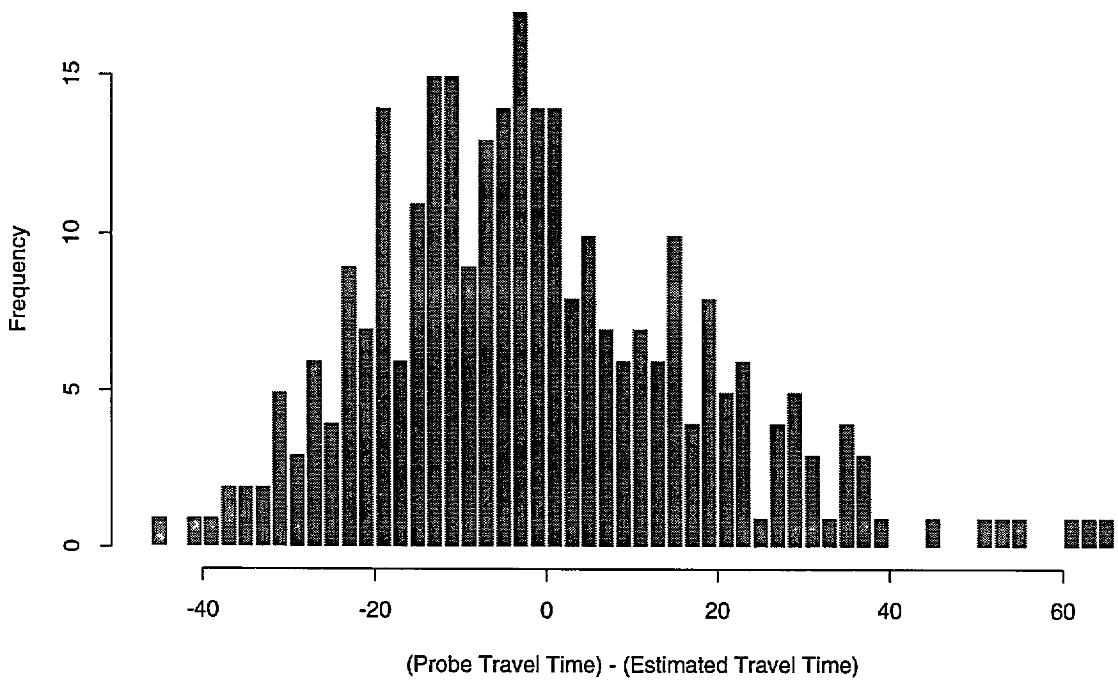


Figure 17: Difference between Probe and Estimated Travel Time: Link 1, Off-Peak, Deployment Level 3

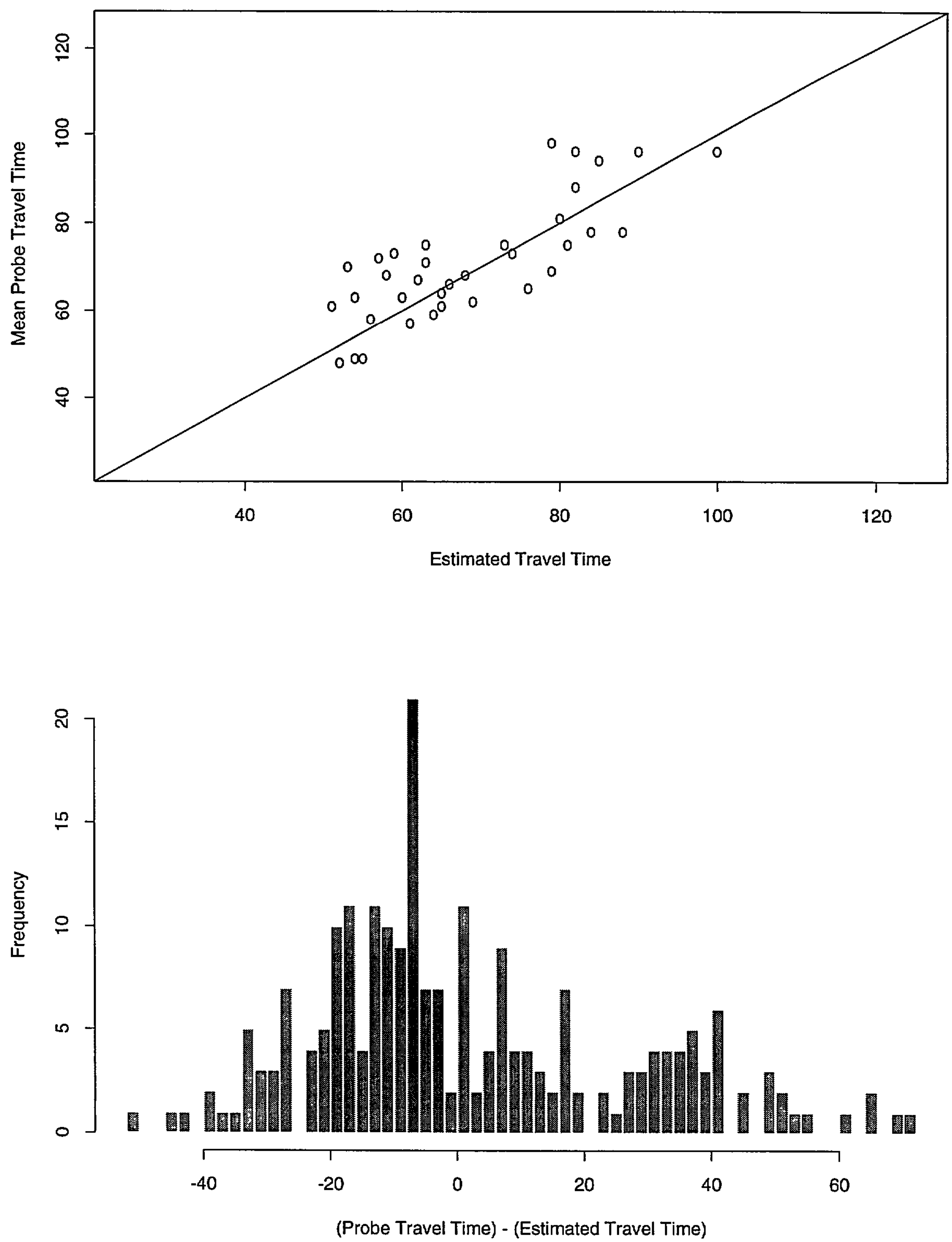


Figure 18: Difference between Probe and Estimated Travel Time: Link 1, Peak, Deployment Level 3

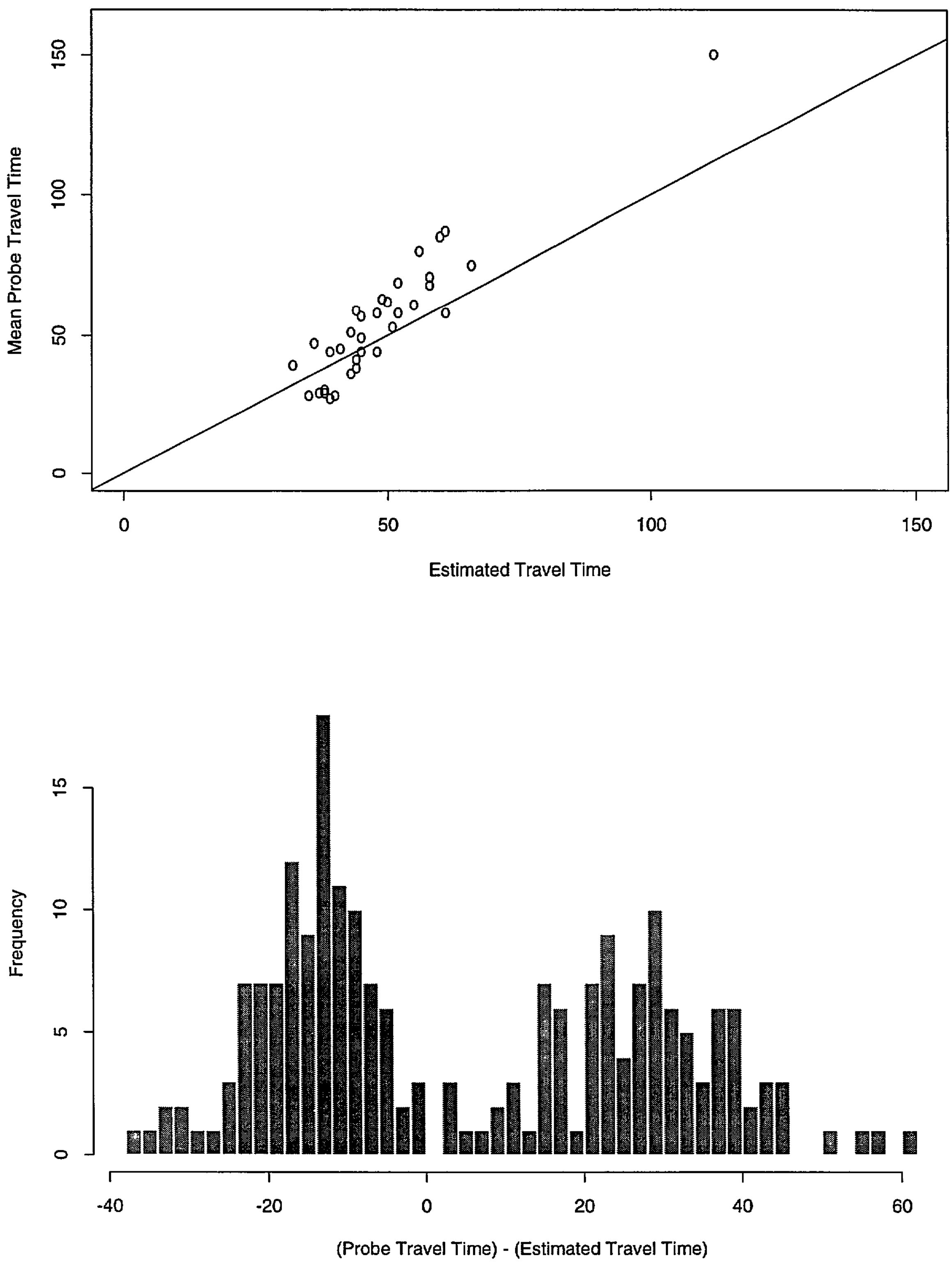
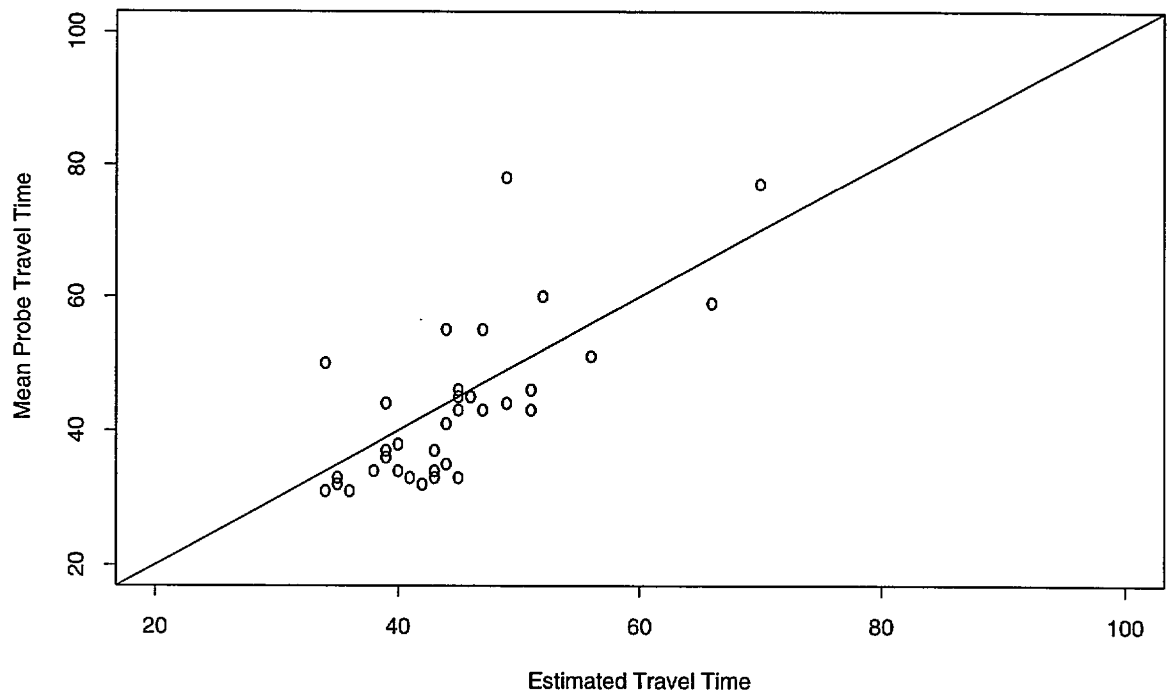


Figure 19: Difference between Probe and Estimated Travel Time: Link 11, Off-Peak, Deployment Level 3



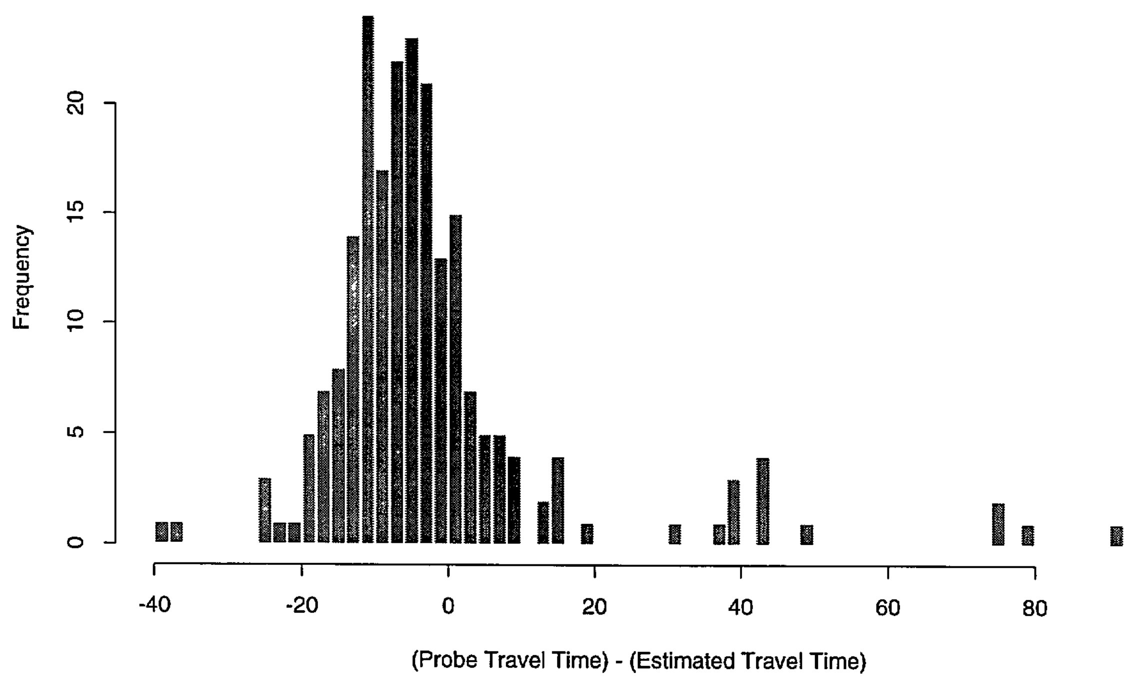
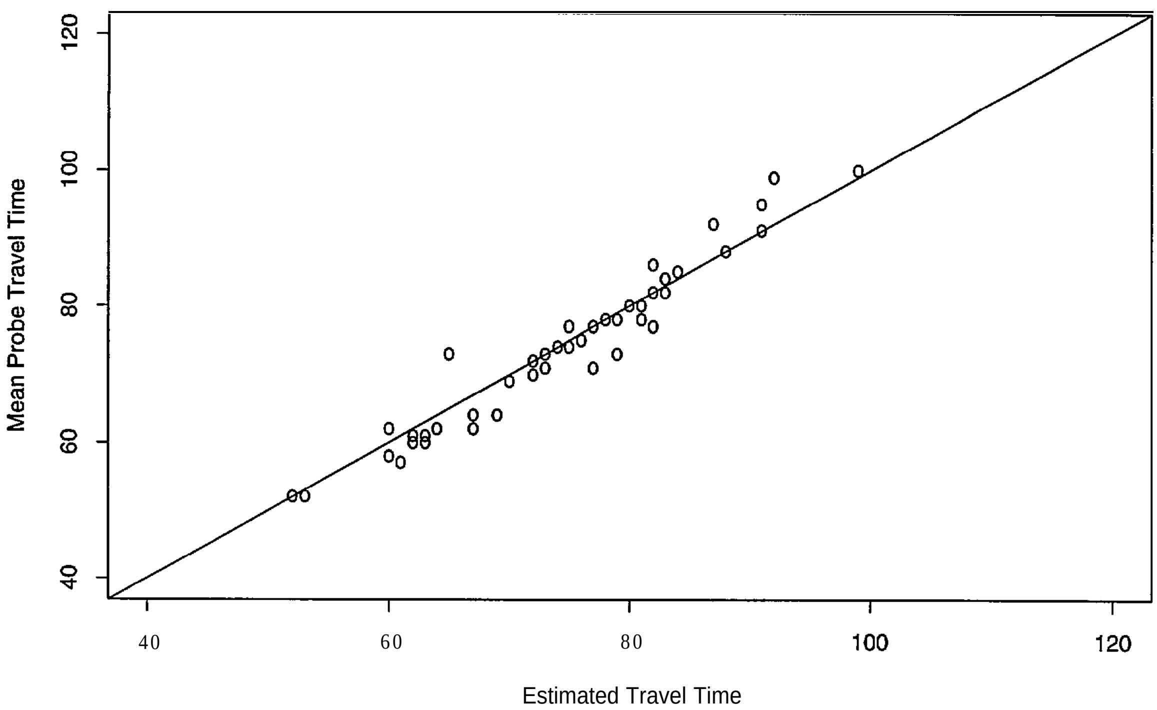


Figure 20: Difference between Probe and Estimated Travel Time: Link 11, Peak, Deployment Level 3



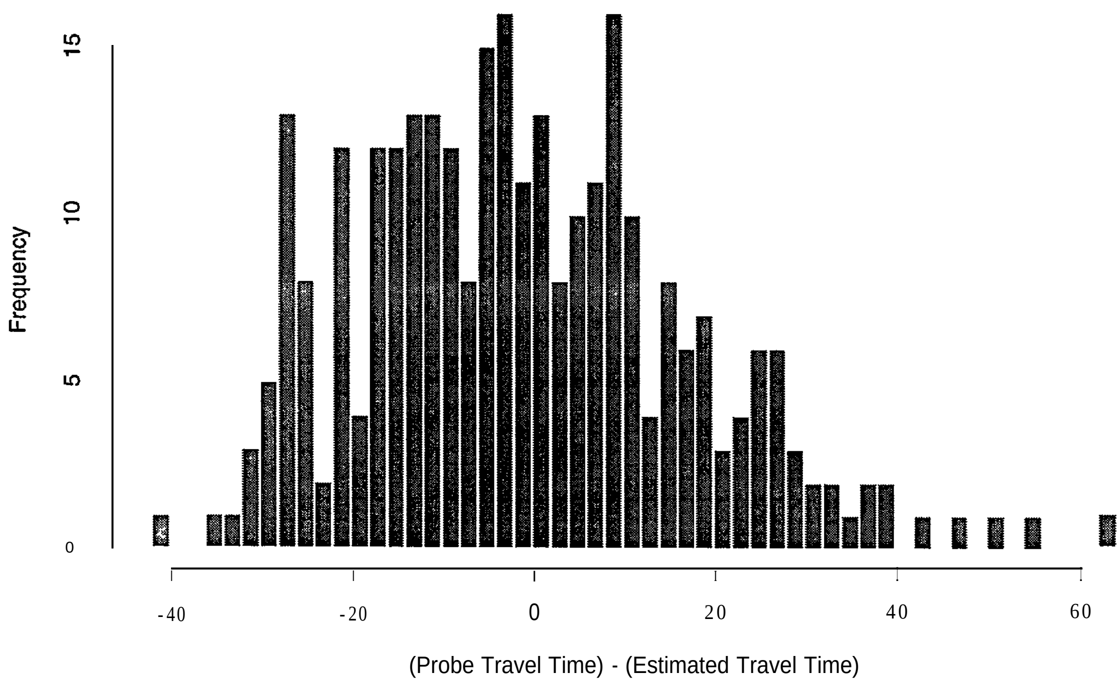
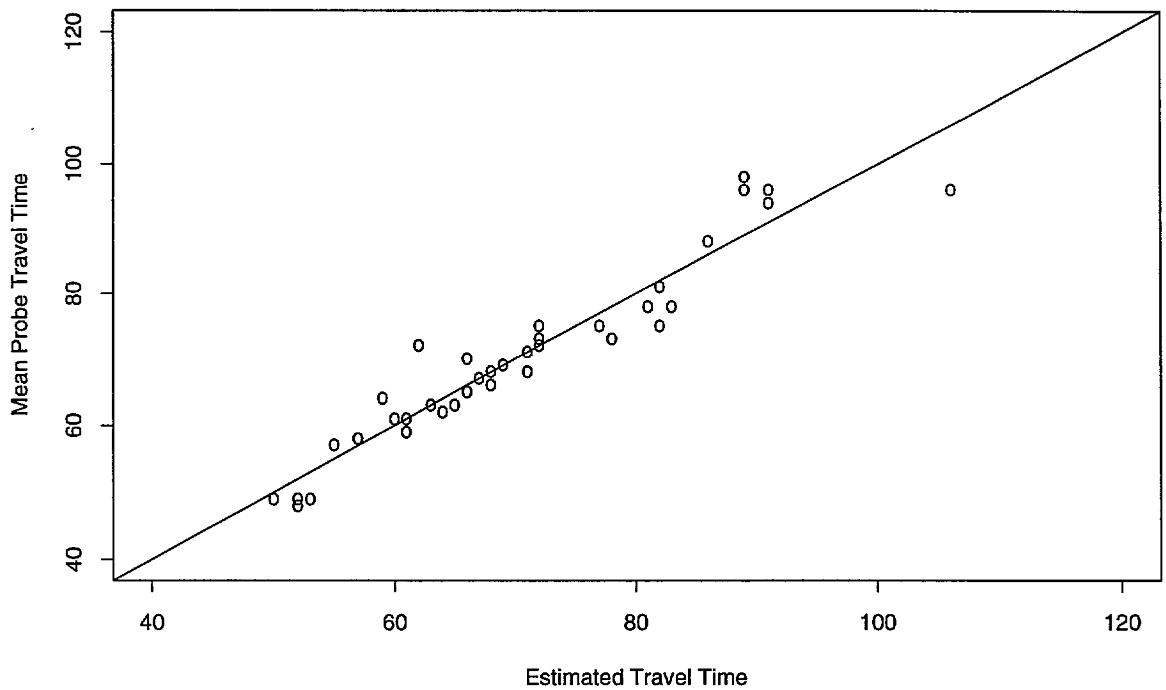


Figure 21: Difference between Probe and Estimated Travel Time: Link 1, Off-Peak, Deployment Level 5



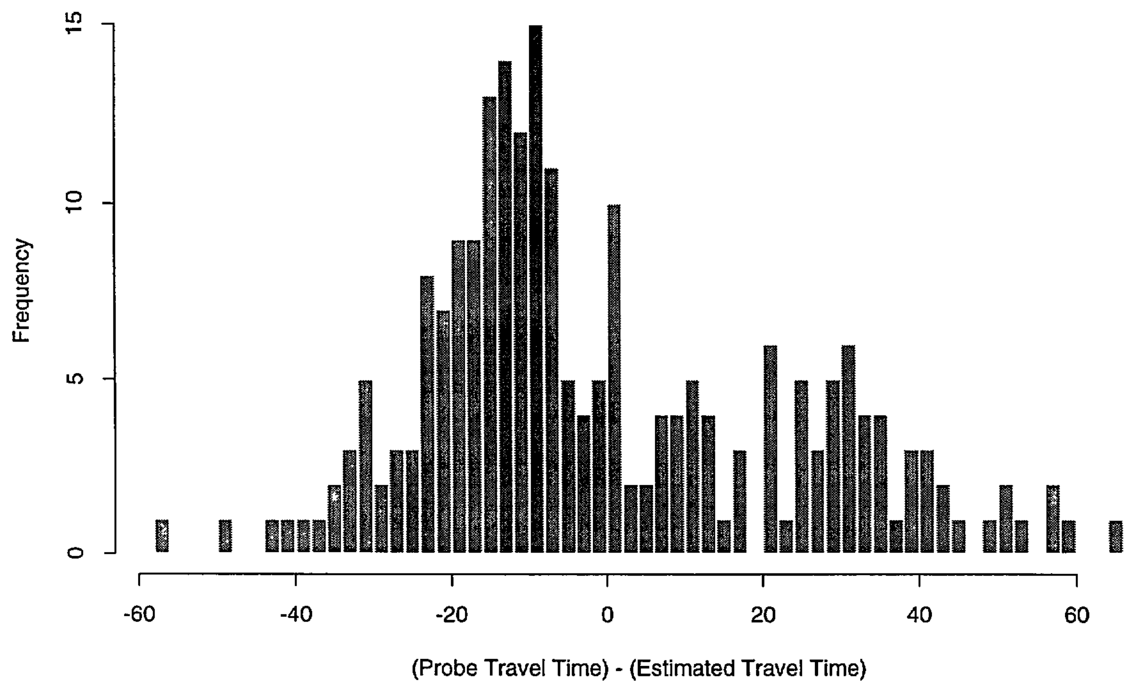


Figure 22: Difference between Probe and Estimated Travel Time: Link 1, Peak, Deployment Level 5

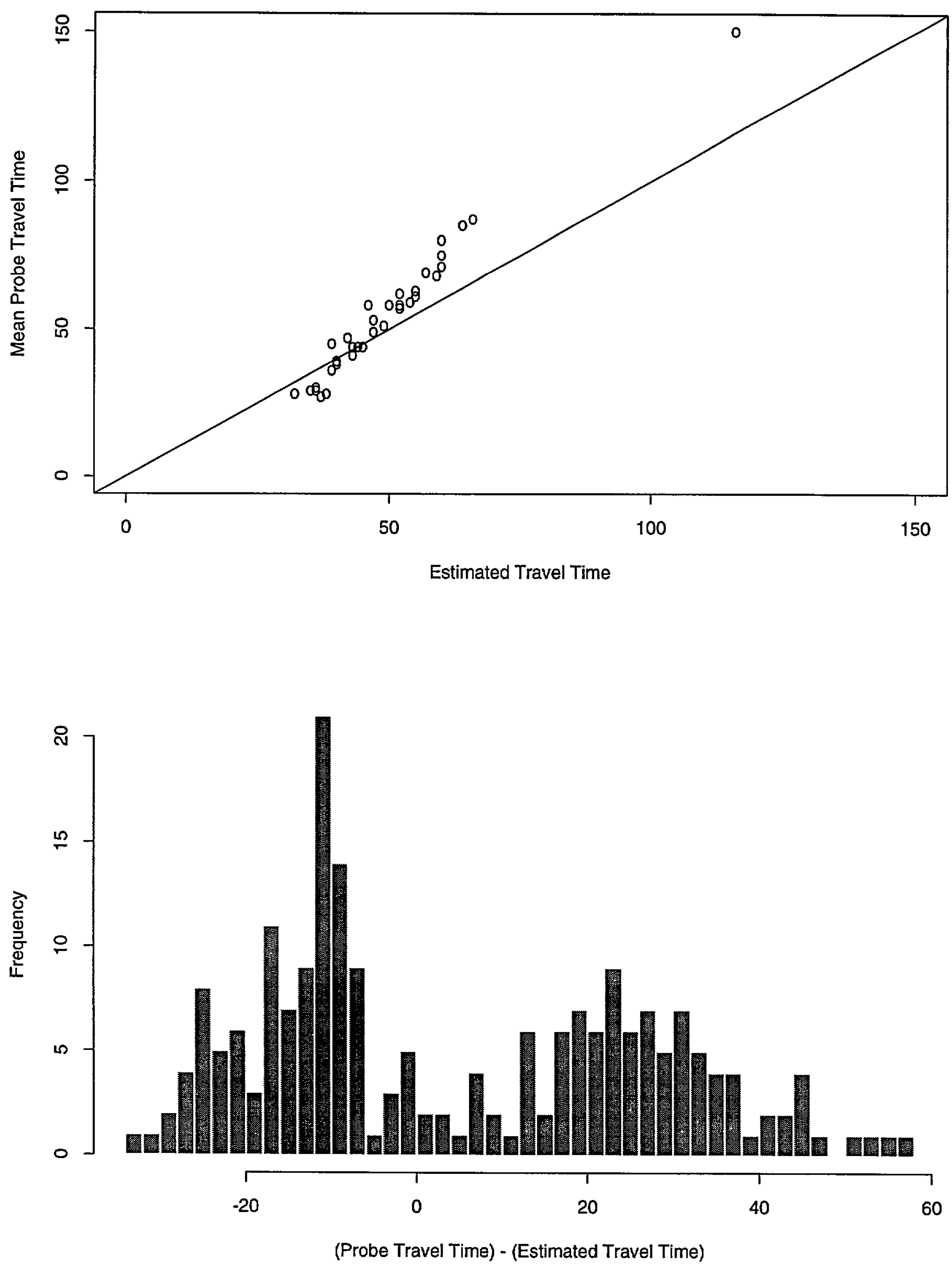
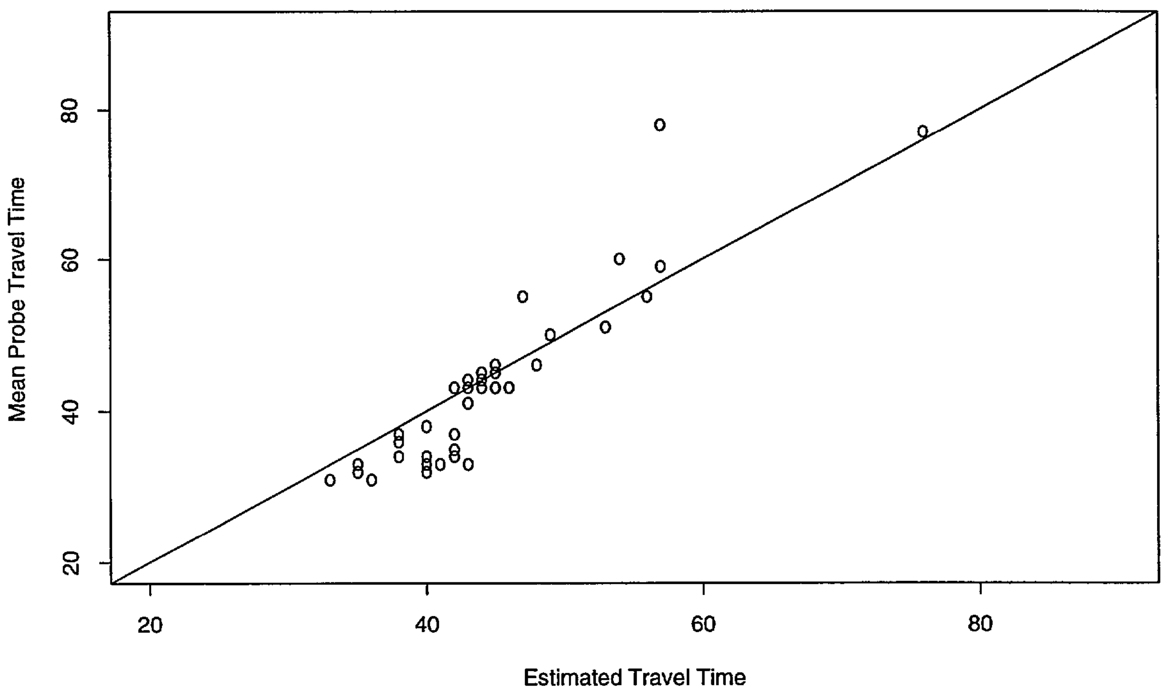


Figure 23: Difference between Probe and Estimated Travel Time: Link 11, Off-Peak, Deployment Level 5



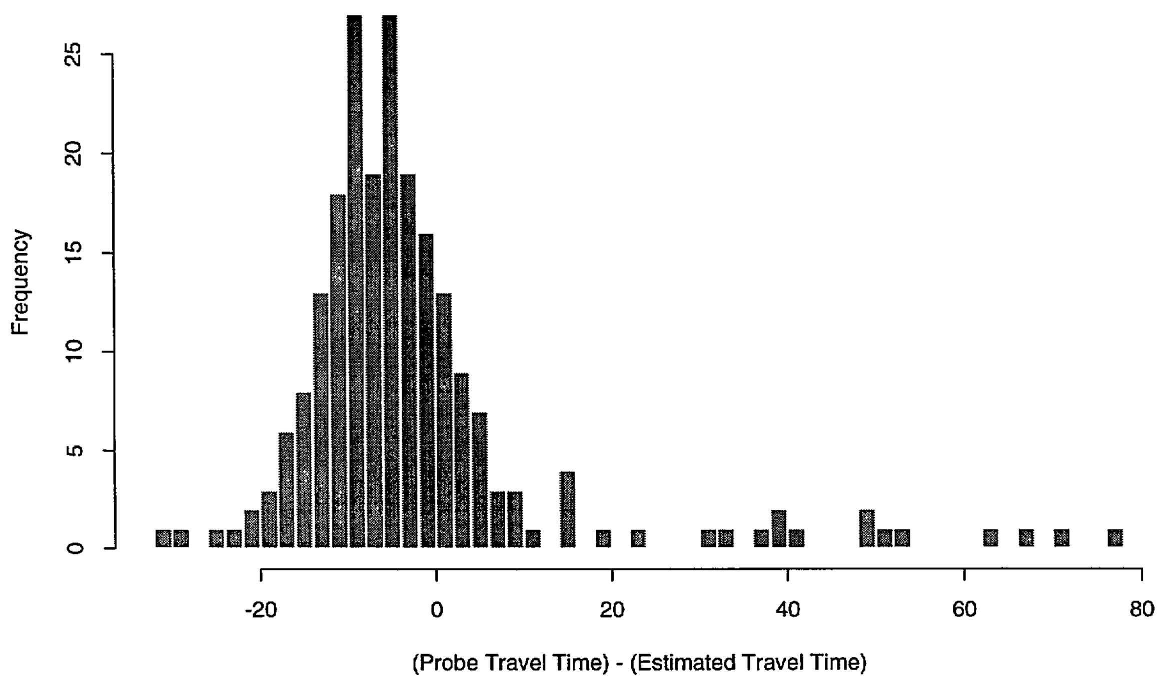


Figure 24: Difference between Probe and Estimated Travel Time: Link 11, Peak, Deployment Level 5

8.1.4 Overall Analysis of Various Deployment Levels

The decreased marginal improvement in estimate accuracy at Deployment Level 5 level could indicate that DTTC's travel-time predictive capabilities at higher deployment levels could reach a level where increased deployment would lead to incrementally small marginal improvements in estimate quality. This idea is illustrated in Figure 25. The overall difference between the average probe travel times and the DTTC estimates is decreasing as deployment levels go up. However, the slope is flattening out between Deployment Levels 3 and 5.

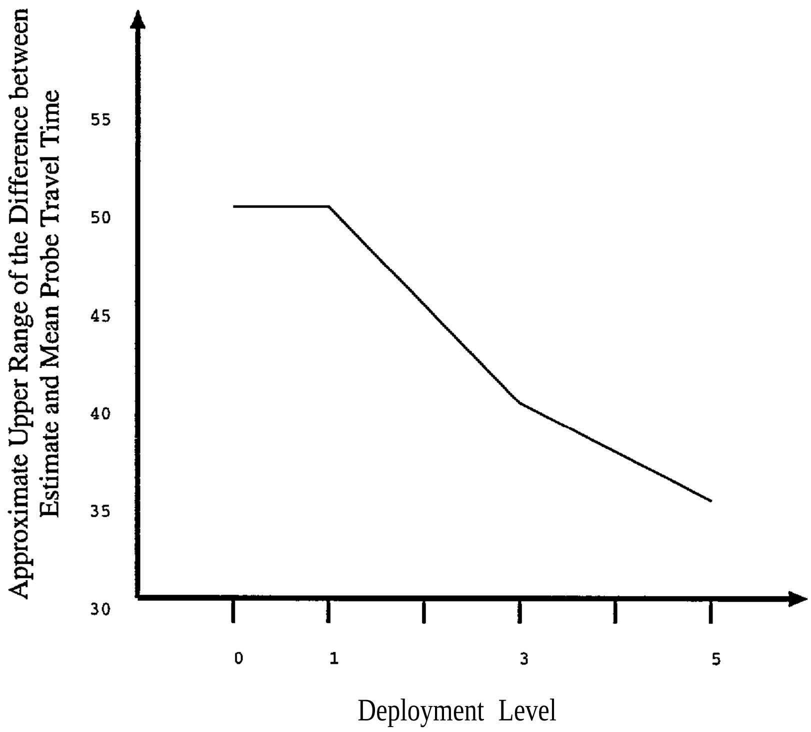


Figure 25: Changes in Estimate Quality by Deployment Level, Moderately Congested Case

Note: As our analysis covered only deployment levels 0, 1, 3 and 5 the average difference between probe and estimated travel times for deployment levels 2 and 4 can only be approximated by this curve.

The greatest marginal increase in travel-time estimate quality for the most moderate increase in deployment size is observed for Deployment Level 3. Because level 3 evidences such a good level of quality, Deployment Level 1 provides limited benefit for experimental purposes. In other words, because Deployment Level 3 results are so much more accurate than those at Level 1, there really is no purpose to proceeding with further examinations of Level 1 estimate results; their accuracy would not compare to Level 3 results. There is a marginal increase in estimate quality at Deployment Level 5.

The improvement in accuracy of travel-time estimates in moving from Level 3 to Level 5 is less than from moving from Level 1 to Level 3. The system designers must weigh the extra costs of moving to this level against desired levels of estimate accuracy.

A comparison of the overall quality of travel-time estimates based on detector data only and those estimates utilizing the fused data shows a significant improvement in estimate quality by adding the probe travel times at a deployment level of 3 or more probes per 5-minute interval. For example, the difference between the estimated and probe-reported travel time calculated using DTTC fused with probe data at Deployment Level 3 is rarely higher than 30 seconds for Links 1 and 11 in the off-peak (Figures 17 and 19) and 40 second in the peak period (Figures 18 and 20). The corresponding value for DTTC without DF is 50 seconds for these links (Figures 7, 9, 8, 10).

The analysis of the means and standard deviations of the differences between the travel time estimate and the mean probe travel time presented in Table 7 shows that the bias of the estimate (the mean of the differences) in most cases is less than 10 seconds. Compared to the absolute value of the travel time on Links 1 and 11 (shown on the y-axis of the scattergrams), this figure is rather low. It can also be observed that the bias for Link 1 is consistently negative, and that for Link 11 is positive. These phenomena are most likely due to the fact that the DTTC model was calibrated using very small data samples (a sufficiently large data sample was not available at that time). The bias drops significantly with the increased deployment level; even at Level 3, the absolute value of the bias drops to 0.6 and 5.6, for Links 1 and 11, respectively.

Table 7: Summary Characteristics of Differences Between Travel-Time Estimates (Moderately-Congested Case) and Mean Probe Travel Times.

Deployment Level	Link	Mean	Variance	Standard Deviation
0	1	-7.922	478.1087	21.866
0	11	13.42	794.916	28.194
1	1	-2.072	491.212	22.163
1	11	8.071	672.9087	25.940
3	1	-0.6048	373.8674	19.336
3	11	5.595	540.7971	23.255
5	1	-0.6151	322.41	17.956
5	11	5.057	495.3077	22.256

8.2 Congested Case

8.2.1 Deployment Level 1

Several observations can be made about Figures 26 and 27, on the following pages. For Link 7 in the peak period (see the scattergram in Figure 27) the number of observations

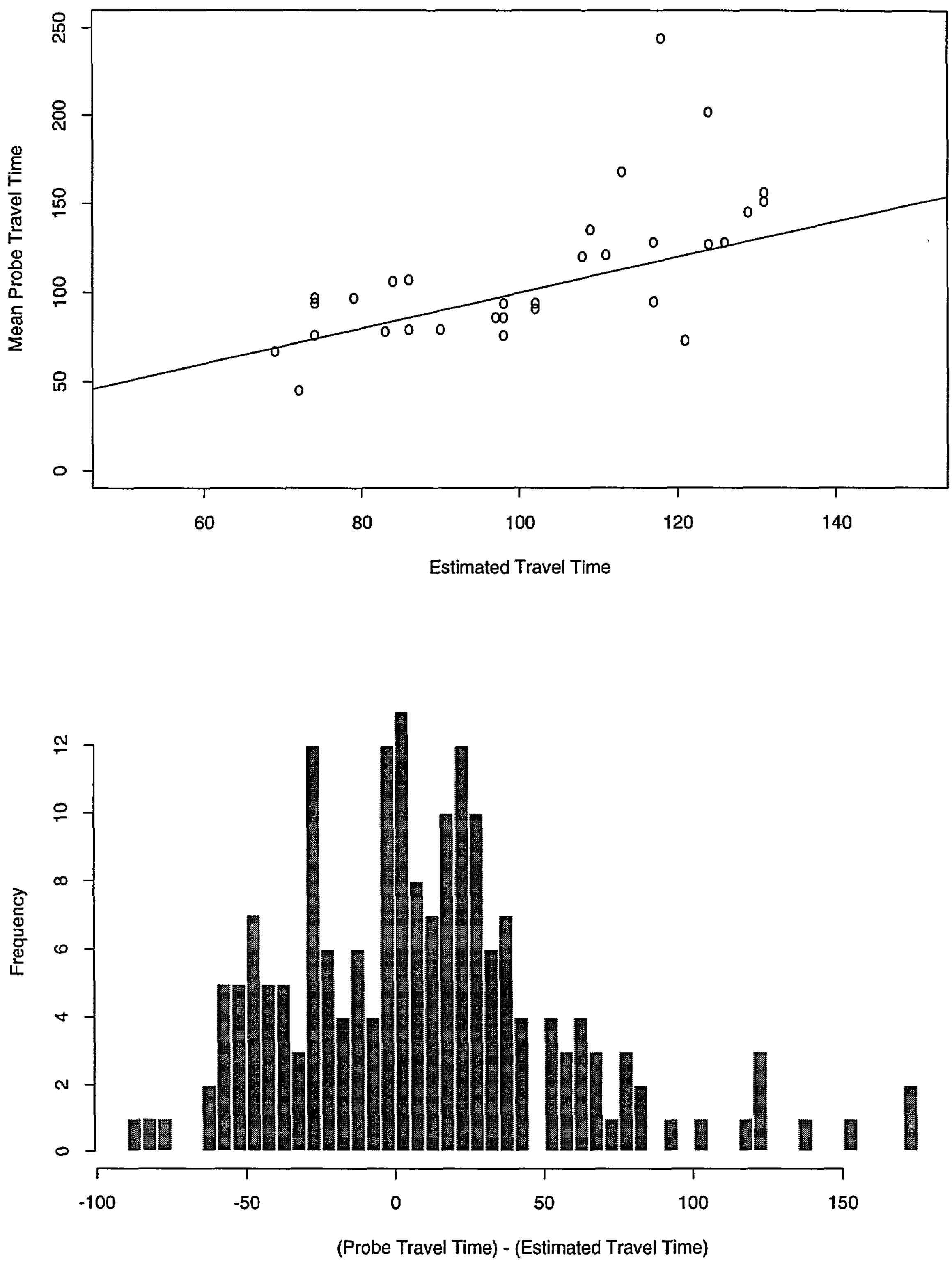


Figure 26: Difference between Probe and Estimated Travel Time: Link 7, Off-Peak, Deployment Level 1

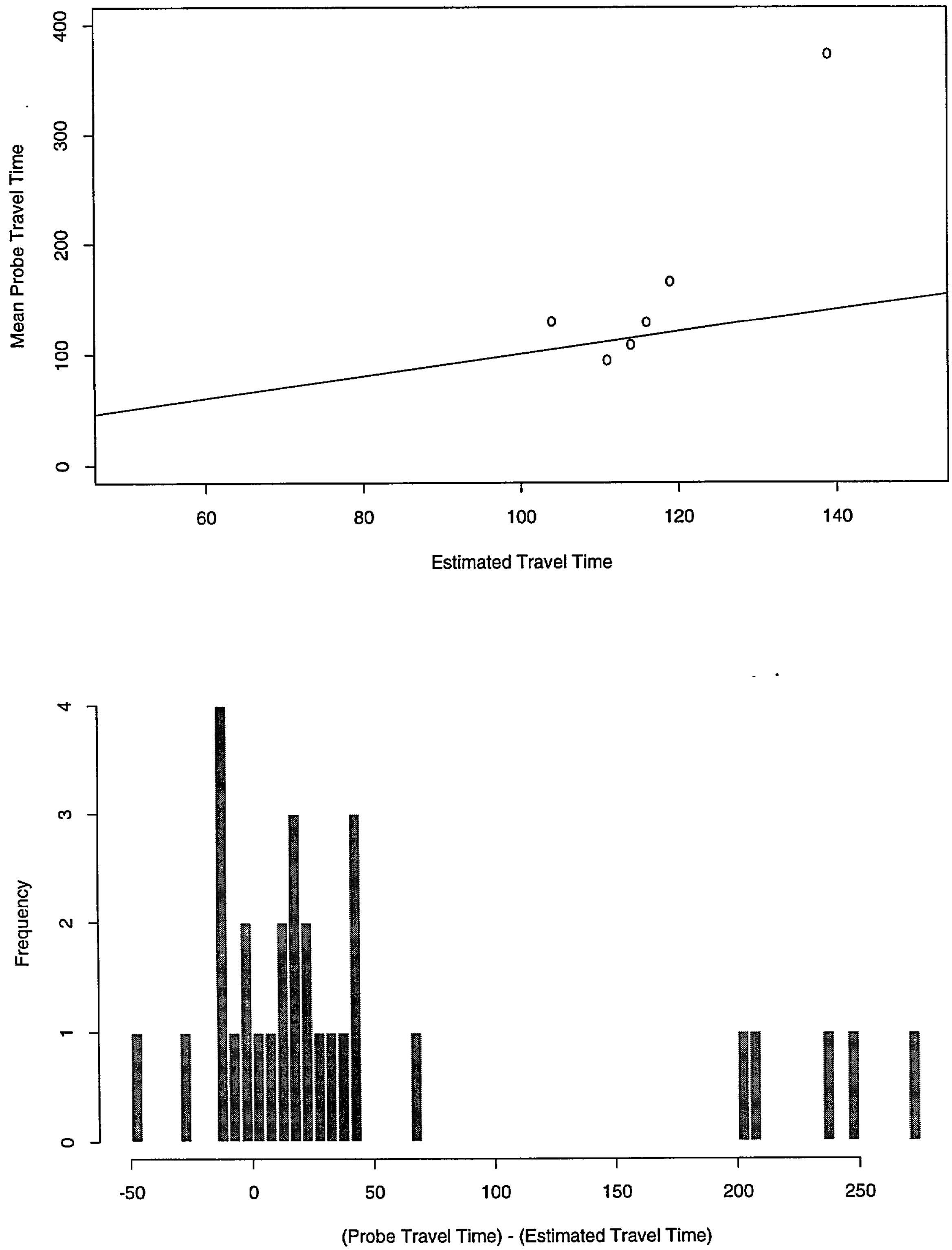


Figure 27: Difference between Probe and Estimated Travel Time: Link 7, Peak, Deployment Level 1

is too low to make a good judgement, but out of the available six intervals five show a difference between probe and estimated travel time within 30 seconds. The maximum difference between probe travel times and estimated travel times (off-peak) dropped from almost 300 seconds for DTTC only (Figure 11) to about 150 seconds for probes (at Deployment Level 1) and detectors (Figure 26). A similar improvement can be seen for peak estimations: the maximum difference between probe data and estimates dropped from over 400 seconds (Figure 12) to about 250 seconds (Figure 27).

These comments indicate that in the congested case, even one report per interval is useful in increasing the quality of the DTTC estimate.

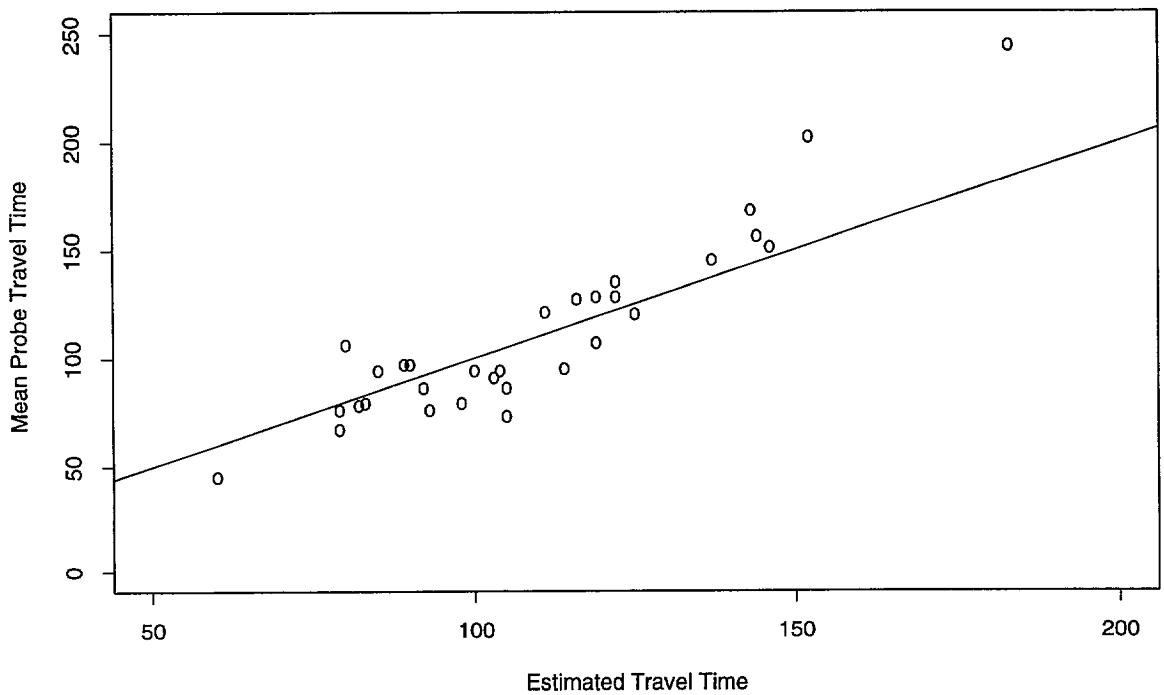
8.2.2 Deployment Level 3

In similar fashion to Deployment Level 1, the introduction of probe data at Deployment Level 3 increases the overall quality of the travel-time estimation process. This may be seen in Figures 28 and 29. As for Deployment Level 1, the maximum difference between probe and estimated travel times also dropped here, to about 100 seconds during the off-peak period, (see the scattergram in Figure 26). This is less true for the peak period, for which a small amount of data is available. No immediate conclusion can be drawn about the peak period (there are too few observations), but the off-peak period evidences significant improvements in the travel-time estimates between DTTC only and DTTC fused with probe reports.

8.2.3 Deployment Level 5

This discussion refers to Figure 30 (while Figure 31 presents results for the same case for peak period, the number of observations is much lower than in the off-peak period and may provide only supporting evidence for the conclusions drawn below). As with the previous sections, the upper range of the difference between estimated and probe-reported travel times again dropped as the deployment of probes increased.

Comparing the scattergrams in Figures 28 (Deployment Level 3) and 30 (Deployment Level 5) shows the points to be moving closer to the line x = y; comparing the frequency distributions in the same two figures shows the differences between the probe travel time and the estimated travel time to be lower and more concentrated around zero at Deployment Level 5



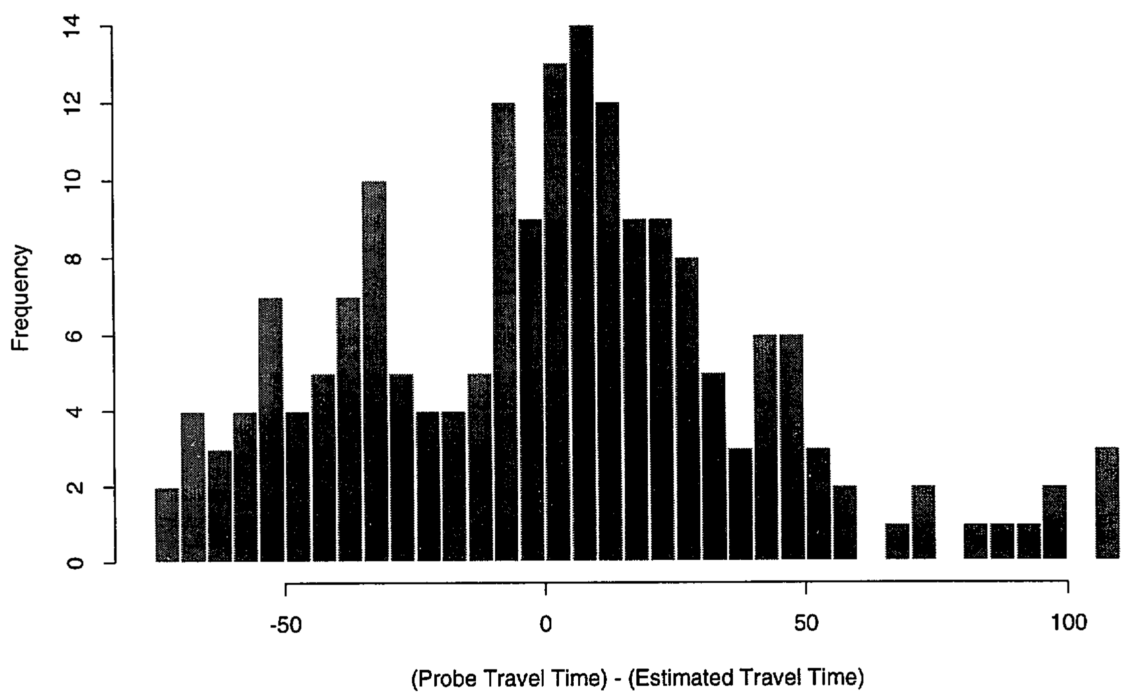


Figure 28: Difference between Probe and Estimated Travel Time: Link 7, Off-Peak, Deployment Level 3

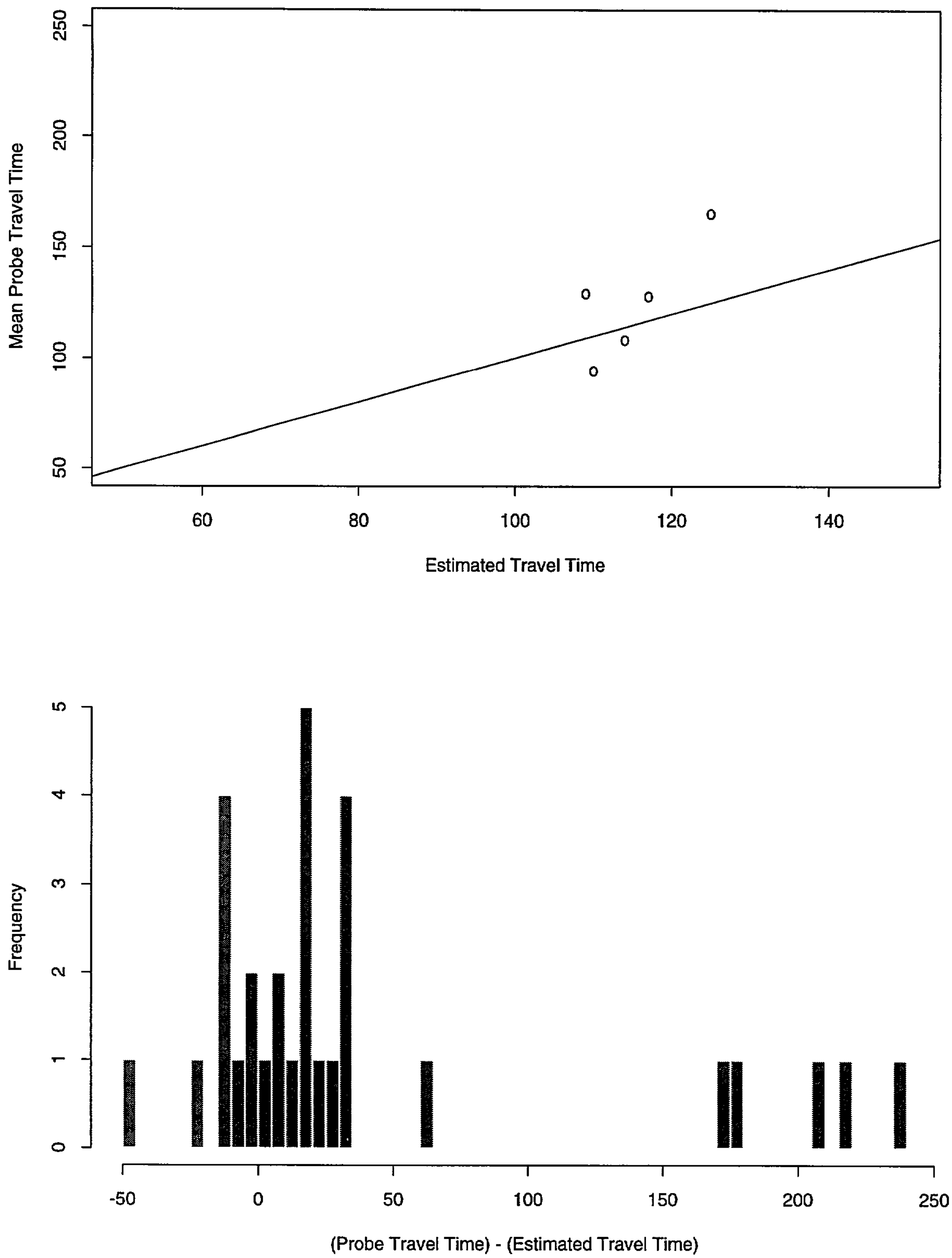


Figure 29: Difference between Probe and Estimated Travel Time: Link 7, Peak, Deployment Level 3

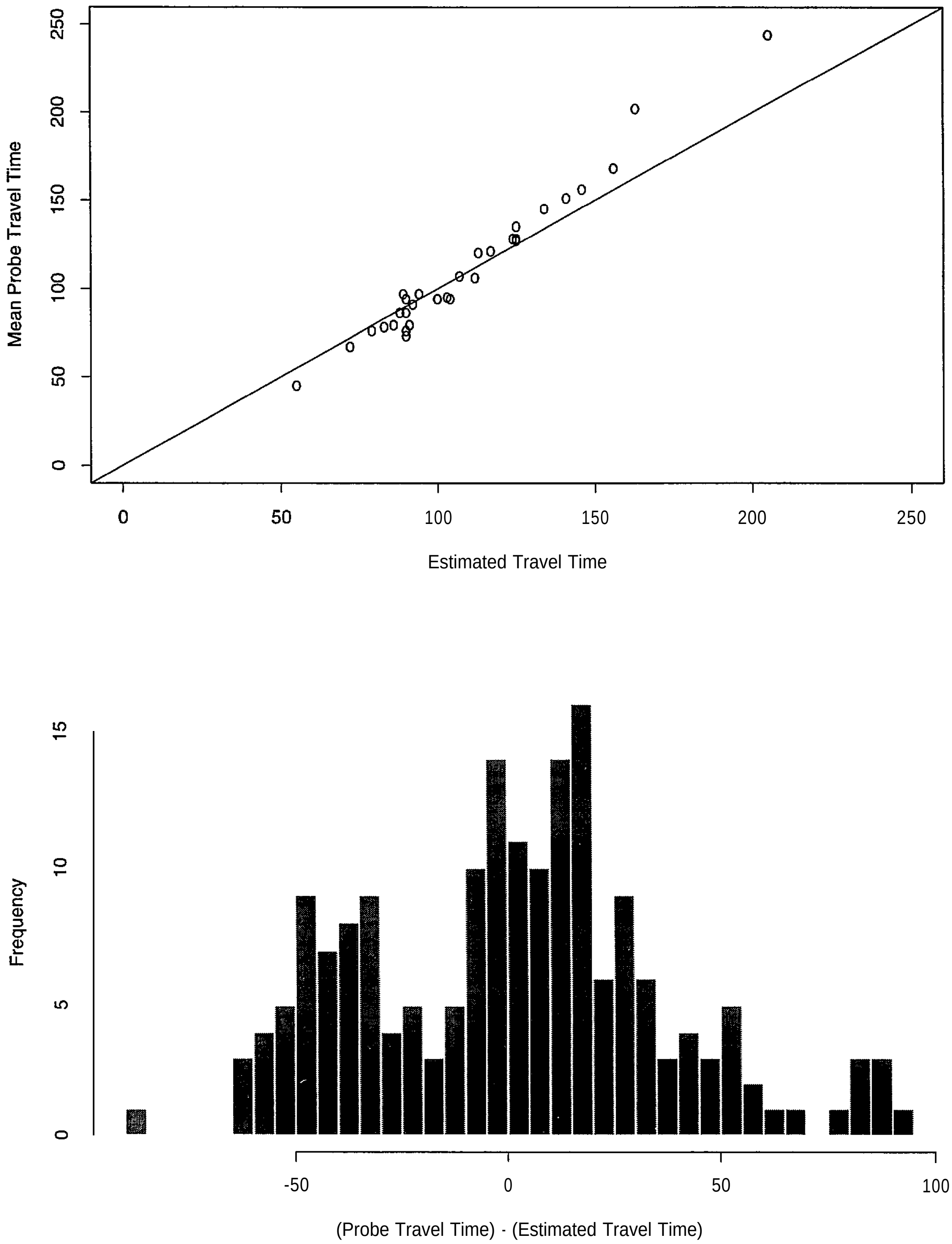
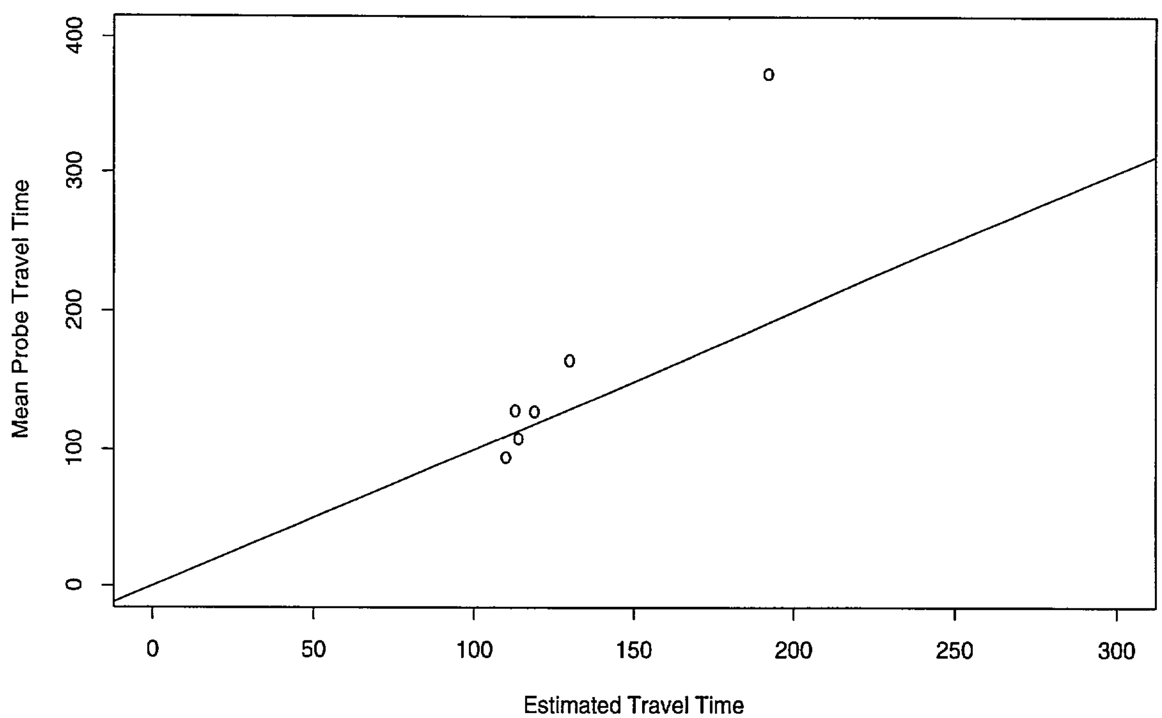


Figure 30: Difference between Probe and Estimated Travel Time: Link 7, Off-Peak, Deployment Level 5



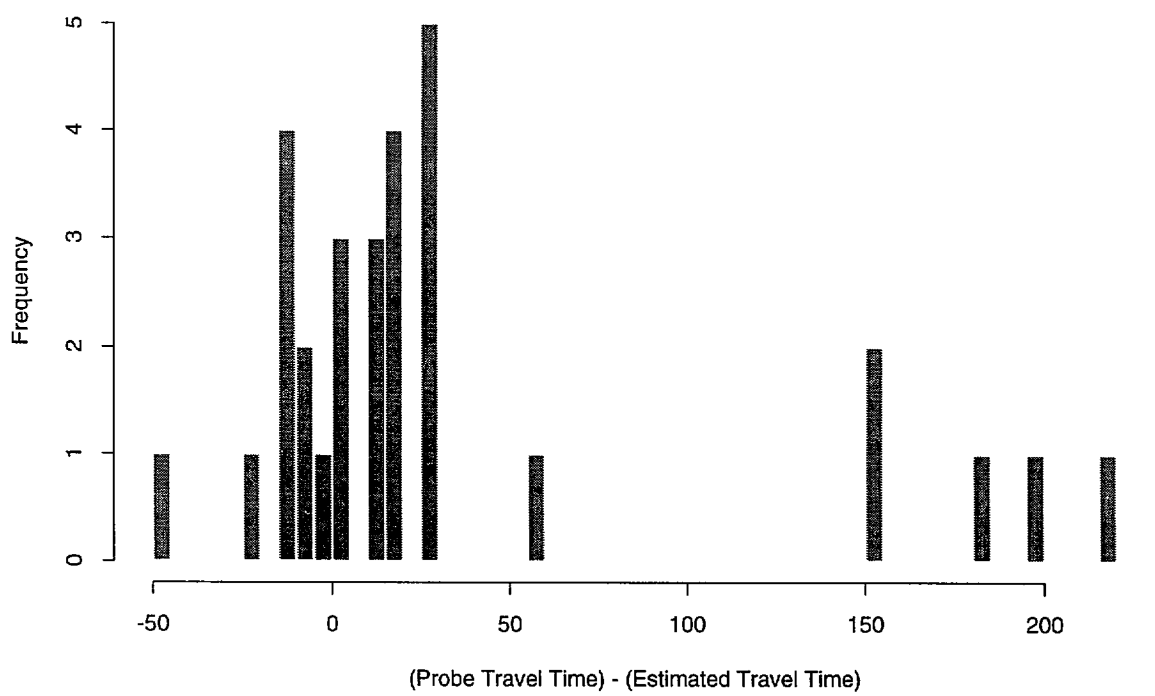


Figure 31: Difference between Probe and Estimated Travel Time: Link 7, Peak, Deployment Level 5

8.2.4 Overall Analysis of Various Deployment Levels

Several conclusions can be drawn from the above analysis. It is easier to comment on the off-peak case, comments on the peak case are less valid due to the paucity of data available. Marginal increases in quality, observable from the slope of the line in Figure 32, appear to peak at Level 1; at Level 5, this increase is lower. It appears possible that when DTTC is combined with probe data, the marginal effectiveness of increased deployment in promoting result quality peaks at Level 1, and then drops. It is possible that these marginal gains in quality could eventually be superseded by costs of deployment. Thus, the nature of the problem is different in congested condition than in the moderately congested case. While the addition of a single probe report may even impair the estimate in the moderately-congested case, adding one probe report to the DTTC procedure significantly increases the quality of the output in the congested case.

Figure 33 illustrates this conclusion for the off-peak case. The top diagram in Figure 33 presents estimates which significantly diverge from mean travel times. In the second scattergram from the top, these same estimates are only about 100 seconds away from the mean travel time (in the worst cases). The bottom two diagrams present further improvements accompanying the increase in probe-deployment levels. As noted in the previous section, the greatest improvement in accuracy of estimates is for Deployment Level 3. This quality assessment can be seen in Figure 32.

Here we should note that the analysis of the quality of the estimate for higher levels of deployment (especially Level 5), is biased by the fact that the probe travel-time data used to assess the estimate come from the same data-collection exercise as the data used as the input for the DTTC and DF processes. However, as can be seen from Figure 6, the DF input is screened through the data-screening algorithm while the other data set is not. The simplistic screening algorithm applied to the latter data is quite different from the Data Screening algorithm.

The analysis of means and standard deviations of the differences between the travel time estimate and the mean probe travel time presented in Table 8 shows that the bias is consistently positive for all deployment levels. As with the moderately-congested case, the phenomena in this situation are most likely due to the fact the the DTTC model was calibrated using very small data samples (a very large data sample was not available at that time). The bias for Level 1 (with probe data) is slightly higher than the bias for those estimates based on DTTC alone; the bias from Level 0 (without probe data) is 8.0. Other than this observation, the bias decreases with the increased deployment level.

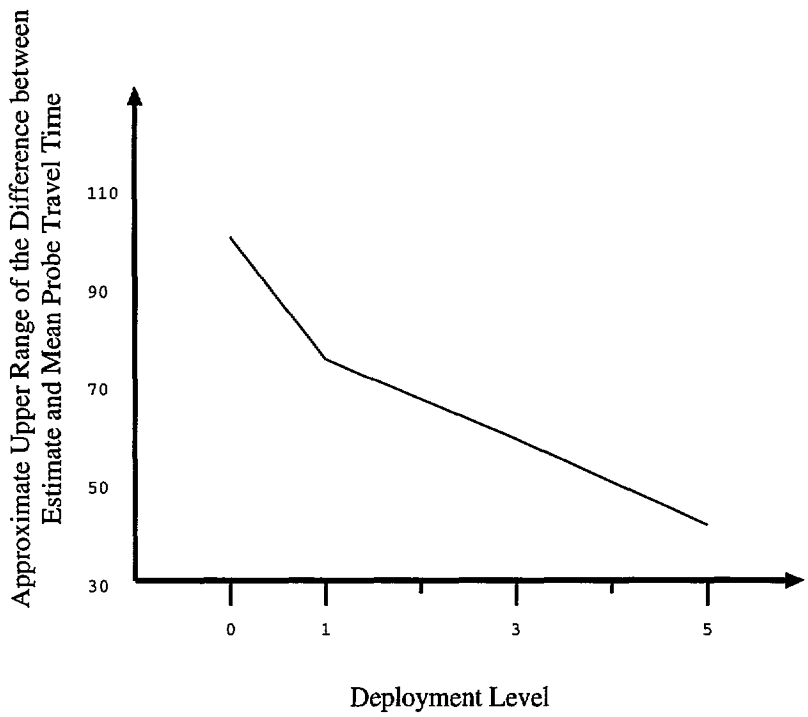


Figure 32: Changes in Estimate Quality by Deployment Level, Off-Peak, Congested Case

Note: As our analysis covered only deployment levels 0, 1, 3 and 5 the average difference between probe and estimated travel times for deployment levels 2 and 4 can only be approximated by this curve.

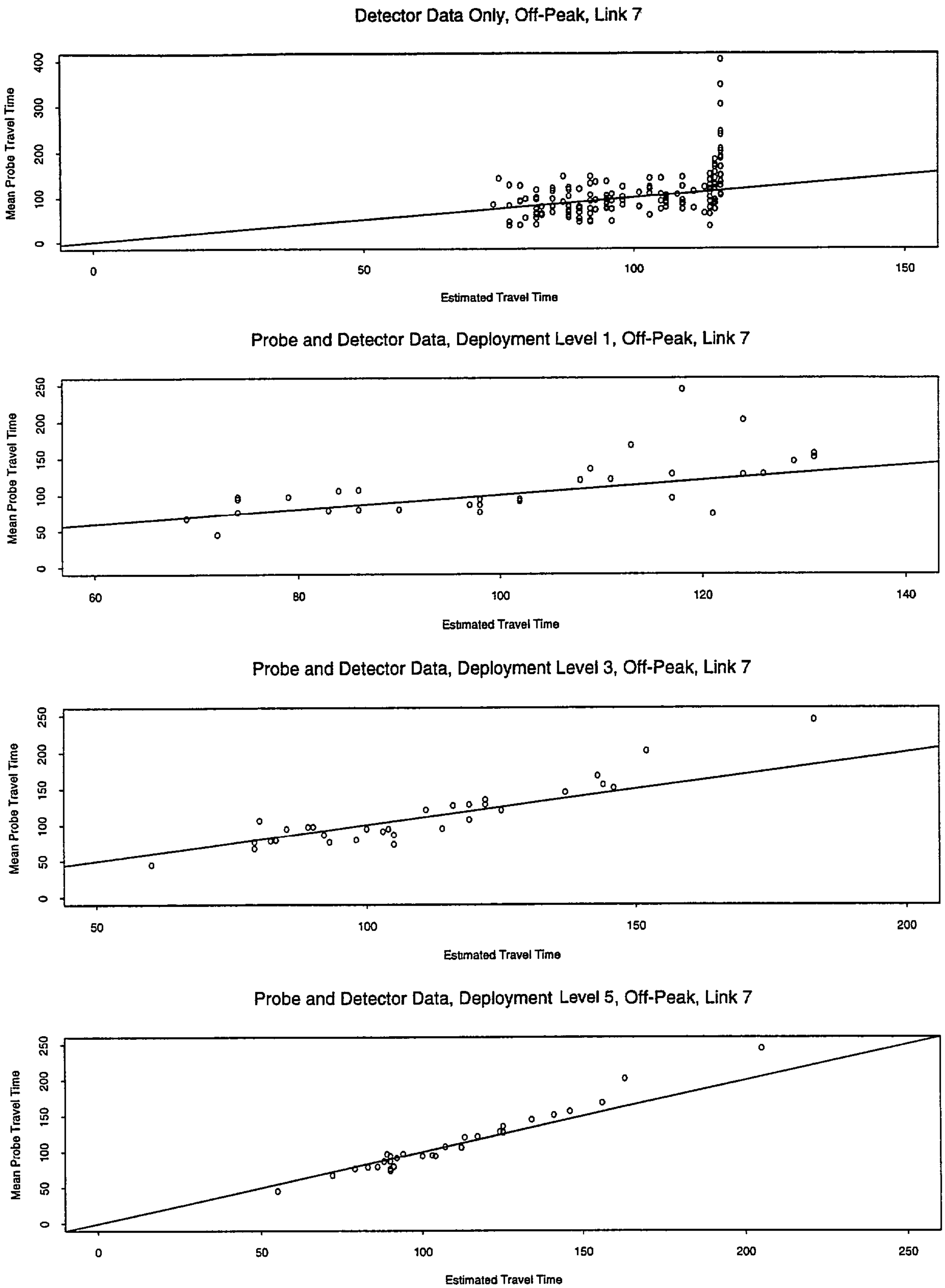


Figure 33: Estimated Travel Time vs. Probe Travel Time: Link 7, Off-Peak, All Deployment Levels

Table 8: Summary Characteristics of Differences Between Travel-Time Estimates (Congested Case) and Mean Probe Travel Times.

Deployment Level	Link	Mean	Variance	Standard Deviation
0	7	8.038	2540.67	50.405
1	7	9.882	2167.24	46.554
3	7	2.097	1491.731	38.623
5	7	1.796	1264.088	35.554

9 Conclusions

The estimates of the link travel times produced by the DTTC and DF procedures are accurate as long as overcongested conditions do not persist over long periods of time. During the overcongested periods, the loop detectors do not provide any information on changes in traffic conditions. It is conceivable that we could develop a more advanced semi-dynamic DTTC algorithm which would yield reasonable estimates in this case, but it would require more data to be available for the calibration process than that which was available during the development of the TRF Data Fusion subcomponent of ADVANCE.

The comparison of the quality of the DTTC/DF estimates for various deployment levels suggests that the greatest improvement in using DF, when compared to using DTTC only, is visible for Deployment Level 3. However, for Deployment Level 1, the estimates are much better than without DF, especially for the cases when the quality of the DTTC estimate fused with probe data is lower (as in the case of prolonged congest ion).

References

Berka, S., Tian, X., (1994) *Changes in Parameters of Data Fusion Subcomponent,* Memo, Urban Transportation Center, University of Illinois at Chicago.

Berka, S., Tian, X. and Tarko, A., (1995) Data *Fusion Algorithm for ADVANCE* Release 2.0, ADVANCE Working Papers Series, Number 48, Urban Transportation Center, University of Illinois, Chicago.

Berka, S., Sheffey, A. and Sen, A., (1996) *ADVANCE* Evaluation: *Data Screening,* Urban Transportation Center, University of Illinois, Chicago.

Hicks, J.E., Boyce, D.E., Sen, A., (1992) *Static Network Equilibrium Models and Analyses of Dynamic Route Guidance Systems,* A Technical Report in Support of the Design Phase of the ADVANCE Project, Urban Transportation Center, University of Illinois, Chicago.

Sen, A., et al, (1996) *ADVANCE Evaluation: Base Data and Static Profile,* Urban Transportation Center, University of Illinois, Chicago.

Soot, S. and Condie, H., (1996) *ADVANCE Evaluation, Quality of Probe Reports,* Urban Transportation Center, University of Illinois, Chicago.

Urban Transportation Center, (1995) *Detector Travel Time Conversion and Fusion of Probe and Detector* Data, *Evaluation Test Plan,* University of Illinois, Chicago.