Vehicle headway analysis on the freeway of Taiwan

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In this paper we find the headway distributions between different lanes, sites which separated more than hundreds of meters away, traffic volume and days are statistically different. The circumstance of very close traffic flow rates, say no more than 150 VPH is the exception.

1 Introduction

The car braking system, tire and road materials have been improved a lot in these years. This may results the fact of shorter time headway and larger capacity than 1960s. According to the following table excerpted from Lin *et al.* (1997), if we try to decelerate the car speed from 100KPH to 90KPH, we need no more than ten meters. Imaging that if we drive a car on the freeway at 100.8 KPH, this equals to drive forward 28 meters per second, and the time headway is 0.5 seconds. Then multiplying the speed by the time headway, and the product, distance-gap, is 14 meters. This allows the speed difference between these two cars to be approximately 13KPH either for the case of light-duty or heavy-duty cars. Observing the practical situation of driving from the freeway in Taiwan, it happens whenever the following car attempts to pass the front car. Thus, under the driving condition of heavy traffic volume and the speed difference between two consecutive cars is not as large as 13 KPH. It is quite reasonable to say that the headway not over 0.5 second is normal while collecting them from the freeway. This also implies the fact of large traffic volume observed from the freeway. We also believe that this phenomenon happens anywhere as long as we hear that the over-capacity condition happens whenever we did the traffic performance evaluation. Therefore, the effort of increasing time headway by improved vehicle technology to avoid the close driving, such as Huddart *et al.* (1990), seems redundant and effortless. Because everyone who believes a good driver himself, would like to take his chance of having an accident or not being late for an appointment.

As the fact that the headway might be shorter than before. To recheck this headway character is one of the main purposes in this paper. We also know that the investigation of time headway between vehicles in a traffic stream is an important and well-studied flow characteristic. However, a few theoretical assumptions need to be made whenever we apply a statistical headway distribution to traffic simulation. For example, we usually make the constant assumption of the mean flow rate and the mean headway over time and spaces. Moreover, all the headway distribution is treated the same despite of the data being collected at different lanes, sections of freeway, flow rates or days. Therefore, we usually may reach a biased conclusion. The statistical tests of the headway distribution for the above different cases are the main approach of this paper. To undertake this paper, we take the following procedures. First, we review some famous headway related literatures. Second, we illustrate how the headway data were simultaneously collected by videotape at five different sites on the southern parts of the Sun Yat-Sen National Freeway. This effort implies that we can consider the traffic temporal variations, i.e. different traffic volume between holidays, arrival distributions on different freeway lanes and different freeway sections on the same lane. The image-type data was then transformed into an electronic file by visual inspection. Third, we test all the combination of data sets to check whether the headway distributions at different volumes, lanes, sites, or days are the same at 1% significance level. Later we combine the statistically equivalent data sets to check the goodness-of-fit with several known headway distributions. Finally, we provide some conclusions and suggest certain directions for further studies.

2 The types of headway distributions

May (1990) and Gerlough *et al.* (1975) had classified

Stopping Distance (m)	Speed (KPH) Drag Factor	50	60	70	80	90	100	110	120
Light-Duty	0.8	12.3	17.7	24.1	31.5	39.9	49.2	59.5	70.9
Distance difference between two speed category		0	5.4	6.4	7.4	8.4	9.3	10.3	11.4
Heavy-Duty	0.68	14.5	20.8	28.4	37.1	46.9	57.9	70.1	83.4
Distance difference between two speed category		0	6.3	7.6	8.7	9.8	11	12.2	13.3

Table 1: The relationship between the car breaking length and the car traveling speed

SOURCE: LIN ET AL. (1997)

headway distribution as three types. One branch is derived theoretically from the random counting distribution, Poisson Distribution. This applies whenever all the vehicles are travelling independent of one another, of course, the low flow traffic conditions. There are several statistical distribution developed based on it. Such as negative exponential distribution, shifted negative exponential distribution, Erlang distribution, Gamma distribution, and Pearson Type III distribution. Alternatively, you may say that these distributions are the special cases of Pearson Type III distribution.
The other branch of headway distribution is based on the traffic flow condition of near capacity. That is, when the jammed traffic appeared, almost all vehicles are interacting with each other. The time headway would then be almost constant. The normal distribution is the one attempted to apply the condition above. Lognormal distribution is the revised case of normal distribution thereafter.
The truth in the traffic flow may not always be the extreme boundary condition as above. The third generation of distribution combines the above two types of distribution to allow the intermediate headway to lie between these two extreme cases. The fact on the road may be that some vehicles are travelling independent of one another, while other vehicles are interacting. To compose the above two models may be one feasible direction to fit the observed distribution. Schuhl (1955) have proposed a model which is composite of shifted and unshifted exponential distribution and Kell (1962) modify the Schuhl (1955) model by representing free-flow vehicles with a shifted negative exponential distribution rather than by a negative exponential distribution. Dawson *et al.* (1968) had combined the improved shape of Erlang distribution and the feature of shifting itself to the right, which he calls the hyper-Erlang distribution. Buckley (1962) has proposed a Semi-random model.
Table 2 summarizes the representative authors, who had involved in the empirical headway distribution fitting.
Due to the easiness of examining the distribution fitness by graphics. Daou (1964, 1966), Greenberg (1966), May (1965) and Tolle (1971) have suggested for the use of the lognormal headway distribution especially for the traffic in platoons.
As we can see from table 2, most of the headway related studies are going straight ahead to the distribution itself. Few are dealing with checking if we can apply the same headway distribution to different area, even to the different lanes. Taylor (1989) had addressed the following problems, the constant mean headway assumption of the headway distribution

Distribution Model	Analysts	Data Features
Negative Exponential	Gerlough *et al.* (1971)	Pasadena Freeway, flow rate = 439VPH, sample size = 214.
Shifted Negative Exponential	Buckley (1962) Wohl *et al.* (1967) Lin (1996)	Hollywood Freeway, 609 headways Cambridge Mass., flow rate = 500VPH, sample size=318. Sun Yat-Sen National Freeway, flow rate =611~2246 VPH, sample size=111~585
Erlang	Gerlough *et al.* (1971)	Pasadena Freeway, flow rate=439VPH, sample size=214.
Person Type III	May (1965)	Eisenhower Freeway, flow rate=600~ 1740 VPH sample size=1320~6327
Normal	May (1965)	Eisenhower Freeway, flow rate=600~ 1740 VPH, sample size=1320~6327
Log-Normal	Daou (1964,1966) Greenberg (1966) May (1965) Tolle (1971) Minjie *et al.* (1993)	Holland Tunnel, sample size=24000. See Greenberg (1966) Eisenhower Freeway, flow rate=600-1740 VPH, sample size=1320~6327 Interstate 71, flow rate=800~1900 VPH. Interstate 279, flow rate=2500~2900 VPH, sample size =155-243.
Shifted and Unshifted Negative Exponential	Schuhl(1955) Kell (1962)	See Schuhl (1955) and Kell (1962)
Normal and Negative Exponential	May (1965)	Eisenhower Freeway, flow rate = 600 ~ 1740 VPH, sample size = 1320 ~ 6327
Hyper-Erlang	Dawson *et al.* (1968)	1965 Highway Capacity Manual Data, flow rate=150~1050 VPH, and Purdue University Data, flow rate = 184 ~ 971 VPH.
Semi-Poisson	Buckley (1962) Wasielewski (1979)	Hollywood Freeway, flow rate =1980 ~ 2100 VPH, sample size=609. Interstate 94, flow rate=922~1985VPH, sample size=992-5793.

Table 2: Some known headway distribution works and its data feature

models over time, the independence between headways and the independence assumption of vehicle arrival for the multilane traffic. Mill (1970) and Mahalel *et al.* (1983) found some evidence of correlation between vehicle arrivals in signalized multilane traffic, but such results may not support for freeway traffic flows.

Thus, the main part of this paper is to check the correlation between different headway sources. The preliminary check of headway distribution is based on the following well-reported headway distribution, the negative exponential distribution, shifted exponential distribution, Erlang distribution, Gamma distribution and lognormal distribution.

3 Data collection and reduction

3.1 Data Collection Area

In order to increase the data reliability we try to collect the vehicle data at different sites simultaneously. For the reason of easy communication, we choose several close freeway overpasses and setup the video cameras on them. To ensure the data record timing is the same, we use the RF speaker to communicate with each other for the accurate start timing. After the site selection process, the freeway overpasses, around the Hsinying Rest Area and the Yuanlin Toll Station, are our final results. Five different sites around Hsinying area were choosing to be the data collecting station and three for the Yuanlin area. The data collecting geographic locations are pictured as Figure 1 and 2. The dates to record data for the Hsinying area were on normal weekend and Sunday, October 11-12, 1996, and Taiwan constitutional consecutive holidays, October 25-26, 1996, and a holiday, April 6, 1997 for Yuanlin area. The sites we chosen for the Hsinying area were separated each other with 979, 496, 646, 1506 meters and 1724, 1616 meters for the Yuanlin area. These sections have two lanes for each direction and a flat grade level. The same cars may pass through the station 1 to station 5 for the Hsinying area. However, cars from the Hsinying Rest Area will merge to the main line, this may disturb the origin platoons coming from station 1 and 2. There needs not to consider the same condition for the Yuanlin area because these sites are not very close to either the toll station or the freeway interchange.

3.2 Data Reduction

This video survey involved the collection of 22 sets of data spanning from three and five separated data collecting stations on each of the selected dates. Each of the data set was recorded for 2 hours. Visual inspection method then applied for data extraction with the aid of computer program. Two marks stuck on the TV screen. One stuck perpendicularly to the upstream ceramic lane delineator, the other was thus stuck to the downstream ceramic lane delineator at 26 meters away. This method, as the following figure 3, can collect data without influencing the traffic behavior. The method of putting the traffic cones on the freeway might contribute for easy data identification but will make the traffic behavior unreliable. There need two persons while trying to transform the

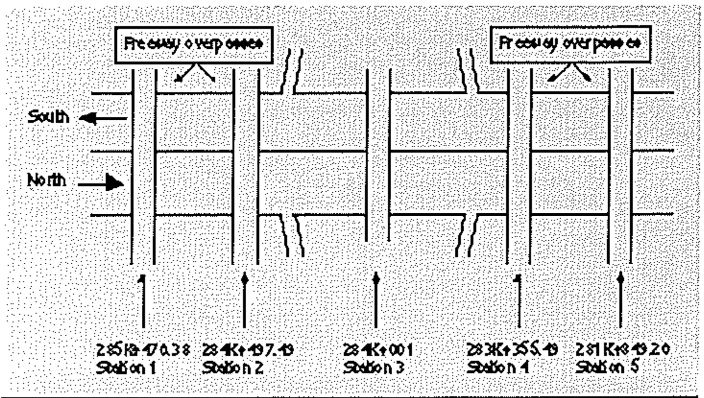

Figure 1: Data collecting location around Hsinying Rest Area

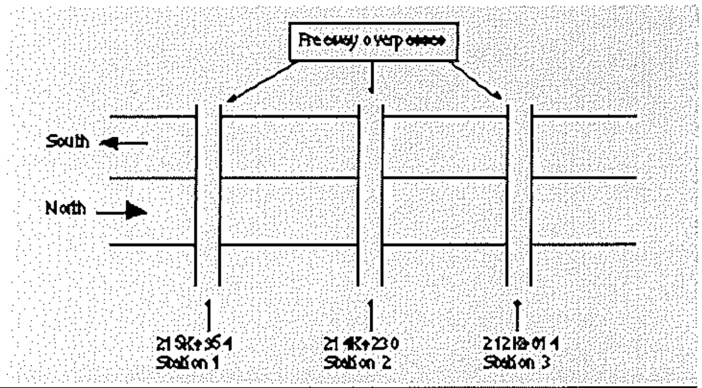

Figure 2: Data collecting location around the Yuanlin Rest Area

image-type data into the digital file. When a vehicle passed the mark, the observer recorded its passing time through the computer keyboard. Different observer watched for different lanes and check marks. The whole process took up to 2 hours for each data set.

4 Headway analysis

4.1 Data Analysis

Twenty-two data sets were generated after data collection and reduction procedures. Each data set contains the true headway information of different lanes and checkpoints on the freeway in Taiwan without any data transformation. In another words, there are 88 sets of headway information in this study. The headways collected in the previous procedure are totally 219,855.

Those traffic flow rates spread from 352 VPH to 1758 VPH. The traffic distribution between lanes around the Hsinying Rest Area is that the curb lane carries more traffic than median lane for station 1 to 4 at Hsinying area. This may because the curb lanes of station 1 to 4 carries the traffic of entering or exiting the Hsinying Rest Area. The flow returns to normal after drivers exiting the Hsinying Rest Area. For example, the changes of lane load factor on October 13, 1995 are from 56.54%, 61.74%, 60.54%, 59.55%, to 40.5%. Fourty percent may be the normal lane load factor.

Table 3 indicates the elementary statistics of two checkpoints are quite close. It might imply the statistical equivalence between two checkpoint data streams and the statistical ine-

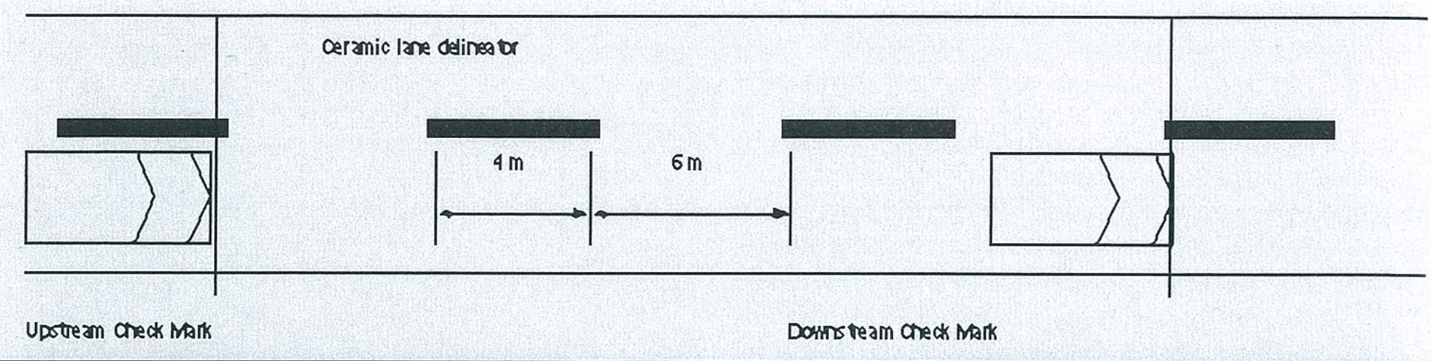

Figure 3: Data Reduction Method

quivalence for the other conditions say stations, lanes, and days. These data sets might contain the potential different information at different headway checkpoints, stations, lanes, areas and days. To analyze the headway characters of the freeway in Taiwan, we took the following steps to find out its nature. First, we have to test if the headway distributions of two checkmarks are statistically different. That is, the headway distribution collected at upstream or downstream data collection point, which is 26 meters away from upstream checkpoint, is statistically different. The equivalencies of headway distributions between days, stations and lanes are the next subjects to examine. We test these station-wide headway samples for each lane. We also examine the headway distribution differentiation between two different lanes. The headway distribution relationship between different days is the last one that we would like to understand. The following sections show the results of these comprehensive headway examinations.

4.2 Statistical Test for Each of Headway Characters[1]

The distance between two checkmarks within a station is only 26 meters. Thus, the null hypothesis is that the two headway streams are identical. The two-sample Kolmogorov-Smirnov Test method is adapted to examine the relationship between them. While applying the KS method, we have to check if two distribution samples are coming from each other. Because the KS method assumes one data stream are generated from the other. Therefore, if there is no further information to reject the two data streams are coming from each other significantly, we might conclude the two data sets are identical statistically.

If we assumed the upstream data is the data generated source, few are rejected at the 0.1 significance level. On the contrary, it does increase the cases of rejection. This may imply the data structures are changed when the traffic travels from upstream to downstream, which is only 26 meters away from the upstream checkmark[2]. We merge these two identical data sets if the result shows that there is no significant difference between two checkpoints. The combined data sets are then used for the following tests.

These data testing results represent the headway distribution between different stations, lanes, and days cannot be treated as the same. Although most of the cases are statistically different, there are still some cases fail to reject their null hypothesis, such as the flow rate difference less than 150 VPH. In the other low P-value cases, the difference between the two testing data is a little bit larger than the cases of failing to reject their null hypothesis. This might imply the complexity of the microscopic road traffic. The headway distribution structure will change when the flow changes slightly over 150VPH.

4.3 Test of Headway Distribution

We concentrate our effort in the following task, fitting the headway distribution. We test some famous types of headway distribution, including negative exponential distribution, shifted exponential distribution, Erlang distribution, Gamma, and lognormal distribution. Chi-square method was choosed for the distribution goodness-of-fit tests. After a cumbersome test process, we find all data sets tend to present the lognormal distribution although their chi-square value is larger than a critical value. Because the lognormal distribution is only better than others, we can conclude that the headway distribution for each data set on freeway might be the lognormal distribution, but their parameters are different. The relationship between parameters and flow rate needs further studies to find out. There are some factors, which will effect the quality of these goodness-of-fit tests. For example, the number of groups will effect the chi-square critical values so as to the shape of the data set histogram. We use some computer programs to help us for the determination of distribution type. However, it might fail to compute the optimum chi-square values for the reason of irregular trend for different group numbers. Tolle (1969) has discussed the difficulties of finding an optimum value. Besides, few outliers may also cause a great chi-square value.

5 Conclusion

As we know from the May (1965, 1990), the headway distribution is highly correlated with traffic flow rate. We find the similar conclusions in this research. Most of the checkmark data sets are statistically insignificant to reject the null hypothesis. That is, the headway distribution within 26 meters may consider as the same one. On the contrary, most of the other headway distribution tests are statistically significant to reject the distribution equivalence hypothesis. More

	Oct. 12						Oct. 13[3]					
	Min[4]	1stQ	Med.	Mean	3rdQ	Max.	Min.	1stQ	Med.	Mean	3rd-Q	Max.
S1SLI[5]	0.4	1.9	3.1	3.9	5.1	26.2	0.2	1.4	2.4	3.3	4.1	23.6
S1SLO	0.3	1.9	3.2	3.9	5.2	25.8	0.3	1.4	2.5	3.3	4.2	24.0
S1SRI	0.2	1.1	1.9	2.8	3.4	22.7	0.1	1.0	1.6	2.5	2.9	32.1
S1SRO	0.2	1.1	1.9	2.8	3.5	22.7	0.2	1.1	1.6	2.5	2.9	32.1
S2SLI	0.5	2.3	4.0	5.4	7.1	45.1	0.4	1.8	3.1	4.3	5.4	37.0
S2SLO	0.4	2.2	4.1	5.6	7.1	45.2	0.2	1.9	3.4	4.7	6.0	37.3
S2SRI	0.2	1.3	2.0	3.1	3.9	26.0	0.2	1.1	1.8	2.6	3.0	30.5
S2SRO	0.2	1.3	2.0	3.1	4.0	26.3	0.2	1.2	1.8	2.7	3.1	30.3
S3SLI	-	-	-	-	-	-	0.4	1.8	3.1	4.3	5.6	29.9
S3SLO	-	-	-	-	-	-	0.3	1.8	3.1	4.3	5.8	29.5
S3SRI	-	-	-	-	-	-	0.2	1.2	1.9	2.8	3.2	31.8
S3SRO	-	-	-	-	-	-	0.2	1.2	1.9	2.8	3.3	31.7
S4SLI	0.2	1.8	2.8	3.7	4.7	24.3	0.4	1.6	2.7	3.5	4.5	19.8
S4SLO	0.2	1.8	2.9	3.8	4.8	24.6	0.2	1.6	2.7	3.6	4.7	20.5
S4SRI	0.1	1.2	1.9	2.9	3.6	25.5	0.3	1.1	1.7	2.4	2.9	27.8
S4SRO	0.3	1.2	1.9	3.0	3.7	25.9	0.2	1.1	1.7	2.4	2.9	27.6
S5SLI	0.2	1.1	1.9	2.7	3.5	24.7	0.3	1.1	1.7	2.4	2.8	22.9
S5SLO	0.3	1.2	2.0	2.8	3.5	24.5	0.2	1.1	1.7	2.4	2.9	23.0
S5SRI	0.2	2.0	3.4	4.2	5.5	28.5	0.3	1.5	2.6	3.5	4.5	24.5
S5SRO	0.2	2.0	3.4	4.2	5.6	28.8	0.2	1.5	2.6	3.6	4.6	24.6

Table 3: Basic Statistics Summary of Data Sets

specifically, the headway distributions between median and curb lane are different. Different freeway sections can not apply the same headway distribution to any traffic simulation. However, the headway distributions between different days are statistically the same. This might due to their very close flow rate. In addition, whenever the flow rate difference between two data collection sites is less than 150 VPH, say the two-hour flow rate level 1710 and 1686, 2721 and 3029, 3260 and 3346, they are statistically the same. There is also a curious finding that the two headway distributions, one flow rate is about one-third than the other, say 2991 and 1049, 2931 and 1059, can also be treated as the same. There are also other flow rate pairs similar to this phenomenon, although they are not statistically significant, say 2409 and 711, 2391 and 705, 1049 and 3223, 1059 and 3257, 711 and 2562. Now we can conclude that the time issue is not as important as flow rate or traffic location. It means that when we consider the application of headway distribution, things we should note are the flow rate and the places to apply it. If the flow rate can fully reflect the effect of different days, it is not important whether or not the date is weekday, weekend or holiday.

By the way, it seems that the larger sample size, the more difficult to conclude the two headway distributions are the same. The headway data in this research preferred the lognormal distribution. Outliers might also cause a large chi-square value. Although the method to determine the number of groups is not optimal, the results indicate the lognormal distribution is better than the other type for all data sets in this paper. Something still needs study further. The careful examination of the headway characters is worth to do it again. Some other composite types of headway distribution may need another consideration to test for the same data. The relationship between headway distribution parameters and flow rate is rather a practical issue to find out.

Acknowledgments

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NOTE

[1] Here we do not show the statistical test results, because they need more spaces to be present in this paper.
[2] The direction of this traffic flow data is northbound.
[3] The Min, 1stQ, Med., Mean, 3rdQ, and Max means it is the minimum, first quartile, median, Mean, last quartile, and the maximum of this data set.
[4] The first two characters S1 means station No.1, the following S or N means southbound or northbound direction, and then L or R means Median or Curb lane. The final characters, I or O, means cars drive in or out the visual inspection area.
[5] We also did another sample mean tests, there is only one case of rejecting the null hypothesis at 0.1 significance level.

	Oct. 25						Oct. 26					
	Min	1stQ	Med.	Mean	3rdQ	Max.	Min.	1stQ	Med.	Mean	3rdQ	Max.
S1SLI	0.3	1.5	2.4	3.0	3.9	17.2	0.3	1.5	2.6	3.2	4.1	18.7
S1SLO	0.3	1.4	2.4	3.0	4.0	17.5	0.4	1.5	2.6	3.2	4.2	18.7
S1SRI	0.2	1.0	1.6	2.1	2.5	17.8	0.2	1.1	1.6	2.2	2.6	17.8
S1SRO	0.2	1.1	1.6	2.1	2.5	17.9	0.3	1.1	1.6	2.2	2.7	17.9
S2SLI	0.3	1.7	3.1	4.0	5.1	35.6	0.4	1.9	3.2	4.4	5.7	32.8
S2SLO	0.3	1.7	3.0	4.1	5.2	36.1	0.2	1.9	3.2	4.6	6.0	32.3
S2SRI	0.2	1.2	1.8	2.4	2.9	23.4	0.1	1.2	1.8	2.5	3.0	24.9
S2SRO	0.2	1.2	1.8	2.5	3.0	23.1	0.3	1.2	1.9	2.6	3.1	25.1
S3SLI	0.4	1.6	2.6	3.3	4.2	20.2	0.1	1.8	3.0	4.0	5.1	32.9
S3SLO	0.4	1.5	2.6	3.4	4.2	20.8	0.3	1.8	3.0	4.0	5.2	32.9
S3SRI	0.2	1.1	1.8	2.3	2.9	18.4	0.2	1.2	1.9	2.6	3.1	23.1
S3SRO	0.2	1.2	1.8	2.3	2.8	18.6	0.3	1.2	1.9	2.6	3.2	23.2
S4SLI	0.4	1.4	2.3	2.8	3.6	20.3	0.3	1.4	2.2	2.9	3.6	22.0
S4SLO	0.3	1.4	2.3	2.8	3.5	20.3	0.2	1.5	2.3	2.9	3.7	21.6
S4SRI	0.2	1.1	1.6	2.2	2.6	21.1	0.2	1.1	1.7	2.3	2.8	20.5
S4SRO	0.2	1.1	1.6	2.2	2.6	20.8	0.2	1.2	1.8	2.4	2.8	20.6
S5SLI	0.2	1.1	1.6	2.1	2.6	16.5	0.2	1.1	1.7	2.2	2.8	15.9
S5SLO	0.3	1.1	1.6	2.1	2.6	16.5	0.2	1.1	1.7	2.3	2.8	15.9
S5SRI	0.2	1.5	2.4	3.0	3.9	20.1	0.2	1.5	2.4	3.0	3.9	21.6
S5SRO	0.3	1.5	2.4	3.1	4.0	19.9	0.2	1.5	2.4	3.1	4.1	21.6

	Apr. 6					
	Min	1stQ	Med.	Mean	3rdQ	Max.
S1NLI	0.2	1.3	1.9	2.3	2.7	79.5
S1NLO	0.3	1.4	1.9	2.3	2.8	74.3
S1NRI	0.3	1.3	1.7	2.1	2.4	59.9
S1NRO	0.3	1.3	1.7	2.1	2.4	61.8
S2NLI	0.1	1.4	1.9	2.3	2.6	58.3
S2NLO	0.4	1.5	2.0	2.3	2.6	52.8
S2NRI	0.2	1.4	1.8	2.1	2.4	44.9
S2NRO	0.3	1.4	1.9	2.1	2.4	27.0
S3NLI	0.1	1.4	1.9	2.2	2.6	45.2
S3NLO	0.4	1.4	1.9	2.2	2.6	42.3
S3NRI	0.2	1.4	1.9	2.2	2.5	33.5
S3NRO	0.2	1.5	1.9	2.2	2.5	31.9

Table 3: Basic Statistics Summary of Data Sets (continued)

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