TP 13237E

Commercial Motor Vehicle

Driver Drowsiness Length of Prior Principal Sleep Periods, and Naps

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TP 13237E

DRIVER DROWSINESS, LENGTH OF PRIOR PRINCIPAL SLEEP PERIODS, AND NAPS

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by
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16. Abstract

The purpose of this study was to assess the relationships between the prevalence of driver drowsiness observed on a trip, length of prior principal sleep periods, and naps taken during the trip, based on the data collected from actual revenue runs of the *Driver Fatigue and Alertness Study (DFAS)* and the *Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance Study*. A rhythmic time-of-day variation was the strongest influence found on drowsiness, followed by length of the last main sleep. A mathematical model was developed that describes these effects. It was found that half the naps studied were taken in apparent absence of drowsiness, and half appeared to be taken in response to sudden increases in drowsiness. Naps in trips with judged drowsiness appeared to result in a recovery effect, compared to the relatively high levels of drowsiness seen in the hour prior to napping. However, drowsiness remained substantially elevated for two hours after napping.

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16. Résumé

Cette recherche avait pour objet l'étude des liens entre la prévalence de la somnolence, la quantité de sommeil pris pendant les périodes de repos précédant la période de conduite, et les sommes en cours de voyage, à la lumière des données recueillies lors de voyages en service payant effectués dans le cadre de l'*Étude sur la fatigue et la vigilance chez les conducteurs* (EFVC) et de *l'Étude sur le pouvoir de récupération associé aux périodes de repos chez les conducteurs de véhicules utilitaires*. Il est ressorti de la recherche que le rythme circadien est le facteur qui influe le plus puissamment sur la somnolence, suivi par la durée de la dernière période principale de sommeil. Un modèle mathématique a été construit, qui représente les effets des divers facteurs en jeu. La recherche a révélé que la moitié des sommes étudiés étaient le fait de conducteurs qui ne présentaient pas de signes de somnolence, et que l'autre moitié semblaient être pris à la suite d'une aggravation soudaine de la somnolence. Les sommes pris par les conducteurs qui avaient été jugés somnolents ont semblé mener à une récupération, par rapport au degré relativement élevé de somnolence observé dans l'heure précédant le somme. N'empêche que les conducteurs continuaient de montrer des signes de somnolence prononcée pendant les deux heures suivant leur somme.

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SUMMARY

The purpose of this study was to assess the relationships between the prevalence of driver drowsiness observed on a trip, length of prior principal sleep periods, and naps taken during the trip, based on the data collected from actual revenue runs of the *Commercial Motor Vehicle Driver Fatigue and Alertness Study (DFAS)* and the *Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance Study*. It was found that a rhythmic time-of-day effect had the strongest relationship, and length of the last main sleep had the next-strongest relationship, to observed variations in drowsiness. The lengths of earlier main sleeps added little or nothing to describing the observed variations in drowsiness. A mathematical model was developed that described the drowsiness data very well. The model indicated that amount of prior sleep most affected drowsiness during the middle of the night and affected it least during the middle of the day. Plots derived from this model may be useful for training drivers, administrators, and others involved in shift work to improve work/rest scheduling.

For about half the naps studied, the drivers were never judged "drowsy" during the trip, either before or after the nap. In the other half, there were large within- and between-driver differences in the duration and timing of drowsiness before and after naps. On average, naps appeared to be taken in response to sudden increases in fatigue and drowsiness during the hour prior to napping. On average, these naps appeared to result in a recovery effect compared to the relatively high levels of drowsiness indicators seen in the hour prior to napping, but signs of drowsiness remained substantially elevated for two hours after napping.

SOMMAIRE

Cette recherche avait pour objet l'étude des liens entre la prévalence de la somnolence, la quantité de sommeil obtenu pendant les périodes de repos précédant la période de conduite, et les sommes en cours de voyage, à la lumière des données recueillies lors de voyages en service payant effectués dans le cadre de *l'Étude sur la fatigue et la vigilance chez les conducteurs* (EFVC) et de *l'Étude sur le pouvoir de récupération associé aux périodes de repos chez les conducteurs de véhicules utilitaires*. Il est ressorti de la recherche que le rythme circadien est le facteur qui influe le plus puissamment sur la somnolence, suivi par la durée de la dernière période principale de sommeil. La durée des autres périodes principales de sommeil précédant le voyage n'a pas suffi à expliquer les écarts observés relativement à la somnolence chez les conducteurs. Un modèle mathématique très utile pour comprendre les données sur la somnolence a été construit. Ce modèle indique que le facteur quantité de sommeil pris avant le voyage influe à son degré maximal sur la somnolence survenant au milieu de la nuit, et à son degré minimal sur celle survenant au milieu du jour. Nul doute que les liens mis en lumière par ce modèle s'avéreront fort utiles à la formation des conducteurs, et aux gestionnaires et autres personnes concernées par le travail par postes, qui y trouveront de précieuses pistes pour améliorer la confection d'horaires axés sur des cycles travail/repos.

Sur tous les sommes compris dans le champ de l'étude, environ la moitié ont été pris par des conducteurs qui n'ont jamais été jugés «somnolents» au cours du voyage, ni avant ni après le somme. Dans l'autre moitié des cas, une grande variabilité a été observée, d'un conducteur à l'autre et chez un même conducteur, dans la durée et le moment d'apparition des épisodes de somnolence, avant et après les sommes. Règle générale, la décision de prendre un somme semblait faire suite à une augmentation soudaine de la fatigue et de la somnolence dans l'heure précédant le somme. Toujours de façon générale, ces sommes semblaient mener à une récupération, par rapport au degré relativement élevé de somnolence observé pendant l'heure précédant le somme. N'empêche que les conducteurs continuaient de montrer des signes de somnolence prononcée pendant les deux heures suivant leur somme.

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1. INTRODUCTION

The purpose of this study was to assess the relationships between the prevalence of driver drowsiness observed on a trip, the amount of sleep obtained on prior nights, and naps, based on the data collected from actual revenue runs during the Driver Fatigue and Alertness Study (Wylie et al., 1996) and the Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance study (Wylie et al., 1997). (The former study will be referred to here as the "DFAS," and the latter will be referred to as the "Recovery" study.) It is recommended that the reader become acquainted with the technical reports of the DFAS and Recovery studies to facilitate the understanding of the data used and results presented here.

2. DATA ANALYSIS

SLEEP AND VIDEO DATA

Figure 1 shows the distribution of sleep lengths in the combined DFAS and Recovery studies. Sleep length refers to the interval between the onset of sleep, determined by physiological instruments, and awakening to go on duty. The distribution is approximately Gaussian (normal) with a mean of 265 minutes and standard deviation of 86 minutes. There was enough dispersion to suggest that we could use these data to study the relationship, if any, between sleep length and drowsiness.

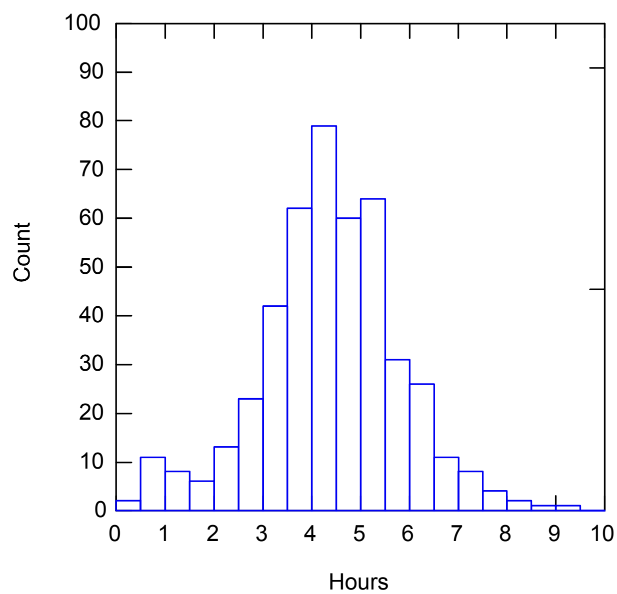

Figure 1. Distribution of principal sleep duration measured using EEG, etc. during the DFAS and Recovery studies.

This study also required that a sufficient number of records exist in the video review data bases (DFAS pp. 3-32) to permit adequate characterization of driver drowsiness. In the DFAS and Recovery studies, six-minute epochs or periods of the video tapes of drivers' faces were sampled every 30 minutes for signs of drowsiness and other data. A data base record was generated for each such sample, to create a "30-minute video review" data base. In addition, whenever a sample was judged to show a drowsy driver, the video was viewed continuously from 30 minutes before to 30 minutes after its occurrence, to obtain information about the duration of drowsiness. A data base record was generated for each of these ten consecutive six-minute epochs, to create a "six-minute video review" data base. Analysis results concerning drowsiness are given in the DFAS report (pp. 4-34) and Mitler, Wylie et al., 1996 (see their Table 4).

We selected records from the 30-minute video review data base that were marked "normal speed" (i.e., truck was not stopped or parked) and tabulated these by hour of the day. There were 140 to 230 records for each hour, with a mean of about 180 records per hour, around the clock, which we judged to be adequate coverage.

We also tabulated the number of video review records by driver, and found that records for about 50 hours of truck video per driver existed. Since each driver drove a total of about 50 hours, accumulated over about 60 hours on duty, the per-driver video coverage was judged to be adequate. (Recovery study drivers drove additional trips, and there were corresponding additional records in the video data base for those trips.)

Another consideration about the data was whether the results from the Recovery study were comparable to the DFAS, since only a subset of drivers participated in the Recovery study. There were clear differences in sleep and drowsiness among the four driving schedules of the DFAS. Therefore, our examination of the equivalence of DFAS and Recovery study drivers was done within driving schedule. All the participants in Condition 4 of the DFAS also participated in the Recovery study, so there is no question of equivalence there. However, in Condition 3, only 5 of the 20 drivers of the DFAS participated in the Recovery study. Therefore, using multiple discriminant analysis, we identified each driver by his average total sleep (without naps) and by his total proportion of drowsiness, and tested whether the DFAS Condition 3 group was different from the Recovery group. There was no statistically significant difference between the groups.

SLEEP AND DROWSINESS DATA

The sleep length and the drowsiness (six-minute video review) data bases were queried to form a new data table with a record for each six-minute video review record that was marked "drowsy" but not marked "stopped." Each new record contained the time of day of the associated drowsy video epoch and the lengths of that driver's preceding principal sleeps. The new table contained a total of 2,825 records. These new records were then divided into nine categories, according to time of day of the corresponding drowsy epoch, and the duration of the last principal sleep prior to that epoch. The three time-of-day categories were 0800-1600, 1600-0000, and

0000-0800. The three sleep categories were less than three hours, three hours to six hours, and greater than six hours.

Inspection of the data revealed that one driver (No. 67) was atypical because he had nearly the greatest drowsiness rate while being in the greatest sleep category. Perhaps the driver was unusually disposed to drowsiness and was attempting to compensate by obtaining as much sleep as possible. However, the objective of this study was to characterize average behavior, not to focus on extreme individual differences. Therefore, the data of driver No. 67 were excluded from the summary discussed below. The total record count was reduced to 2,621.

Table 1 shows the summary data. The numerators provide the number of six-minute video epochs in which the driver was judged to be drowsy, and the denominators show the total number of video epochs in which a driver could have been judged to be drowsy, for each of the nine categories of time of day and sleep length.

Table 1. Total number and percentage of six-minute epochs of video recordings judged to show a drowsy driver, according to the time of day and duration of last principal sleep.* (Includes data from 79 of 80 drivers in DFAS and Recovery study observational conditions.)

SLEEP	< 3 HOURS		3-6 HOURS		> 6 HOURS	
	No. of Epochs	Percent	No. of Epochs	Percent	No. of Epochs	Percent
0800-1600						
Drowsy	24	2.9	162	1.4	28	1.0
Total	830		11,275		2,720	
1600-0000						
Drowsy	30	7.5	495	5.3	87	2.6
Total	400		9,425		3,335	
0000-0800						
Drowsy	260	17.3	1,428	15.9	107	13.1
Total	1,505		8,975		815	

* The total number of six-minute epochs of driving for each entry in the table was used as a denominator. Since the video recordings were sampled every 30 minutes, we estimated the required number by counting, for each entry in the table, the number of these 30-minute sampling periods that occurred while the truck was moving at a normal speed (as opposed to being parked or stopped) and multiplying this number by 5, since 30 minutes equals five 6-minute epochs. According to these calculations, there were 39,280 six-minute epochs during which a driver could have been judged to be drowsy.

Figure 2 presents a graphical representation of the drowsiness data derived in Table 1. It can be seen that the least amount of drowsiness was observed in the 8 a.m. to 4 p.m. interval, an increased amount in the 4 p.m. to midnight interval, and a substantially greater amount in the midnight to 8 a.m. interval. This is consistent with the findings presented in the DFAS report concerning the relative importance of time of day. It can also be seen that greater amounts of prior night's sleep were associated with less drowsiness. The differences in drowsiness are not as great along the sleep dimension as they are for time of day. These findings linking the drivers' drowsiness jointly to time of day and prior night's sleep have not been available before.

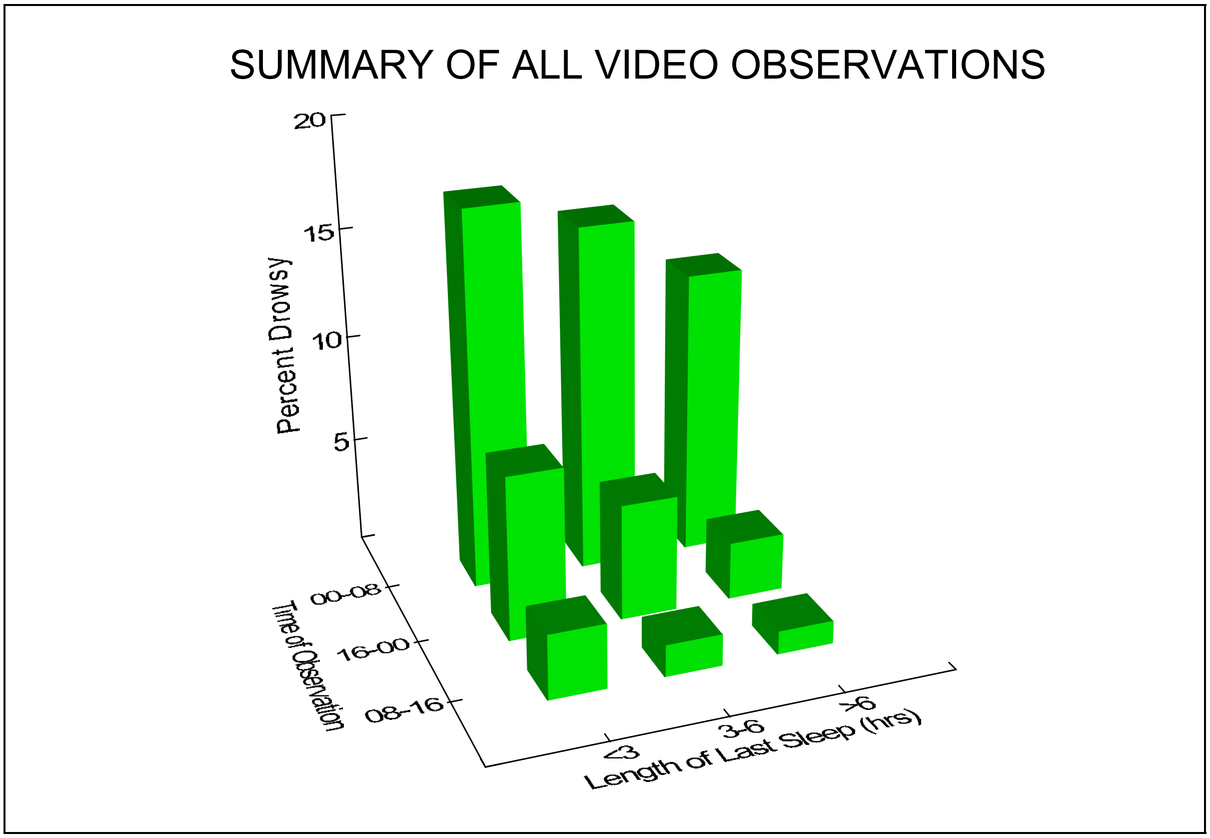

Figure 2. Graphical view of percentage of six-minute epochs of video recordings judged to show a drowsy driver according to time of day and duration of last principal sleep (includes data from 79 of 80 drivers in DFAS and Recovery Study observational conditions).

MATHEMATICAL MODEL RELATING DROWSINESS TO TIME OF DAY

The data presented in Table 1 and Figure 2 show varying proportions of the drivers were judged drowsy in the three different eight-hour time-of-day periods. We will use the logistic probability distribution function in modeling this variation of drowsiness by time of day. The function is given by:

$$F(t) = 1/(1+\exp(K1-K2*t))$$

This function is bounded between zero and one, and is a never-decreasing curve with a gentle slope, which becomes steeper at t=K1/K2, then falls away as the function asymptotically approaches one. These characteristics are useful in describing the data at hand, but of course they are not unique to this particular function. (Feller, 1966, p. 52, provides an interesting discussion of this function.) Note that we do not use it as a probability distribution function per se, but as a basis for describing the observed prevalence of drowsiness, as follows.

We assume that the effects of time of day on drowsiness are periodic (with a 24-hour period), and will use the cosine function to represent them. Thus, the model to be fit to the data of Figure 2 (for the middle category of “length of last sleep”) is given by:

Proportion drowsy = 1/(1+exp(K1-K2*cos(6.28*(tod-2)/24)))

where K1 and K2 are parameters to be adjusted to optimize fit to the data, 6.28 is (approximately) 2 pi, and “tod” is time of day in hours, offset to give a peak at 2 a.m., midway between the phase factor of 0 hours associated with DFAS Condition C4-13daystart and 4 hours associated with Condition C3-13nightstart (DFAS, p. 4-126).

A nonlinear regression program was used to estimate the parameters. The computer program converged satisfactorily to a solution (K1 = 2.897, K2 = 1.380) with good fit (R-squared = 0.972). A plot of this model is shown in Figure 3, together with actual drowsiness data from Table 1, plotted at 4 a.m., 12 p.m., and 8 p.m. (the midpoints of the time-of-day categories), representing drowsiness levels for 2, 4.5, and 7 hours of sleep (which are “midpoints” of the length-of-last-sleep categories, being equally-spaced points close to the mean sleep lengths of 2.00, 4.47, and 6.75 hours observed in the three categories).

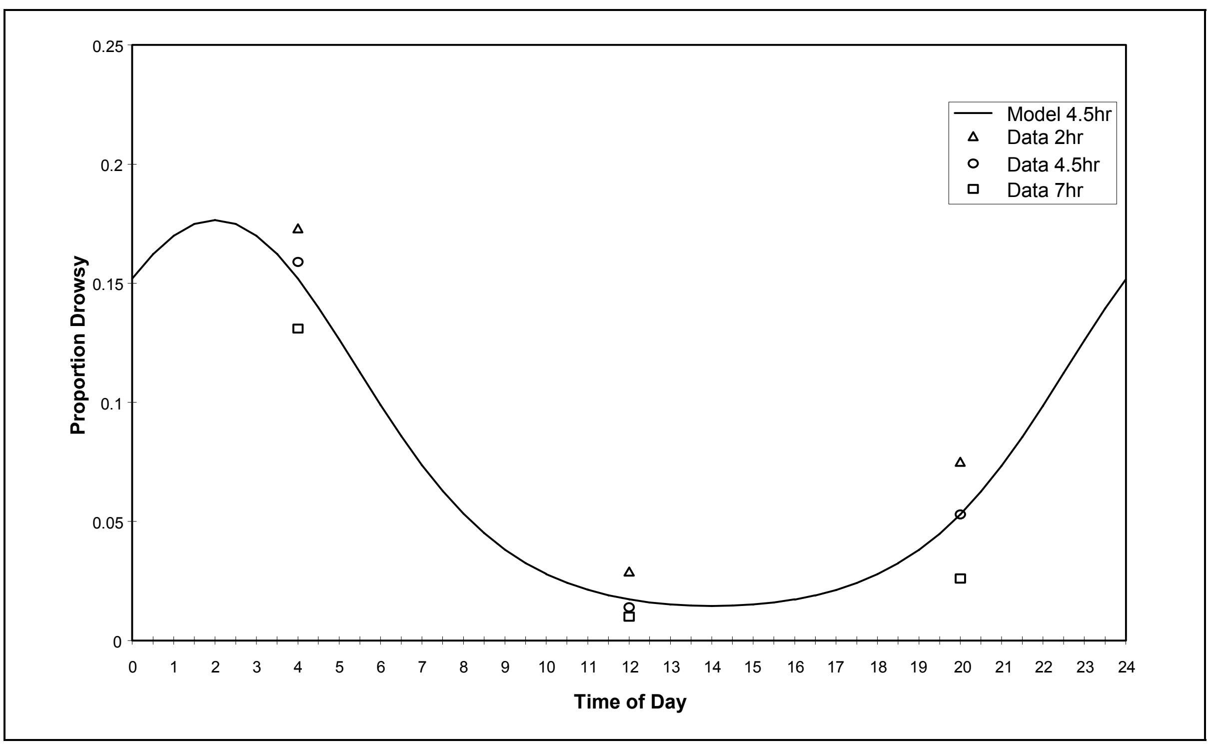

Figure 3. A model of time-of-day variation in proportion of drowsy epochs.

MATHEMATICAL MODEL RELATING DROWSINESS TO TIME OF DAY AND LENGTH OF LAST PRINCIPAL SLEEP

The model described above was extended to include the length of last sleep in a simple linear (additive) relationship, which is preferred in modeling human behavior, provided that the data can thereby be satisfactorily represented. Thus we have:

Proportion drowsy = 1/(1+exp(K1-K2*cos(6.28*(tod-2)/24)+K3*sleep))

where K3 is an added parameter and "sleep" is the duration of the last principal sleep. The nonlinear regression program was used to estimate the parameters. The computer program converged satisfactorily to a solution (K1 = 2.568, K2 = 1.342, K3 = 0.069) with good fit (R-squared = 0.992). A plot of this model is shown in Figure 4.

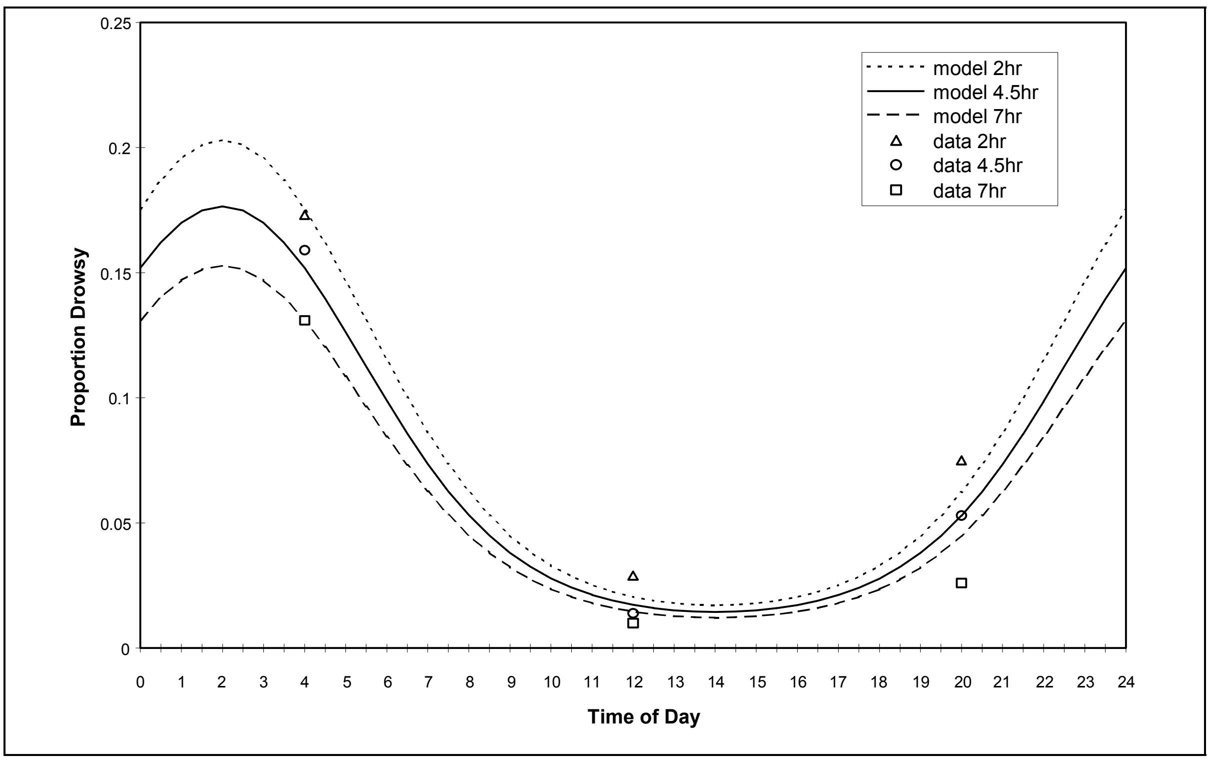

Figure 4. A model of time-of-day and length-of-last-principal-sleep variations in proportion of drowsy epochs.

RELATIVE IMPORTANCE OF TIME OF DAY, LAST PRINCIPAL SLEEP, AND EARLIER SLEEPS

We have seen that the model with only time of day in it accounts for about 97 percent of the variance in the drowsiness data. The addition of "length of last principal sleep" is conceptually very important, but proportionally adds little quantitative improvement to goodness of fit. We will look at the matter of relative importance further.

To investigate the impact on drowsiness of sleeps earlier than the "last principal sleep," the sleep length data base and the sampled video (30-minute video review) data base were jointly queried to form a new data table with a record for each 30-minute video review record that was not marked "stopped." This new table had 7,951 records. Each new record contained the time of day of the associated video epoch; the corresponding value of the model discussed above and shown in Figure 3, representing time-of-day effects only ("model"); whether the driver was judged drowsy for that six-minute epoch ("drowsy"); length of last sleep ("last sleep"); next-to-last sleep ("S-1"); and so on, to "S-8."

One way to measure the strength of association between drowsiness and length of prior sleeps is to use statistical correlation procedures. Table 2 shows the Spearman and Pearson correlations between the variable "drowsy" and the variables "model," length of last sleep ("last sleep"), next-to-last sleep ("S-1"), and the sleep prior to that ("S-2"). Since the objective was to compare these correlations with one another, we required that they all be calculated from the same set of data records. Therefore, the correlations shown in Table 2 were calculated from 4,920 data records of the set of 7,951 mentioned above, because including sleep "S-2" excludes data from drivers' first and second trips (since no sleep history was available prior to the night before the first trip). Sleeps earlier than "S-2" are not shown in the table because they restrict the sample size too much (e.g., if sleep "S-8" were to be included, only data from the 10 drivers who drove four extra days could be used).

The absolute values of the correlation coefficients shown in Table 2 indicate a diminishing association between drowsiness and the tabled variables, from left to right. Time of day had a stronger association with drowsiness than the lengths of prior sleeps did. The absolute values of the correlations were not very large, nor were they expected to be, because "drowsy" is a binary variable (0 or 1, depending upon whether a driver was judged drowsy in a particular six-minute epoch), and the sleeps were continuous variables with approximately normal distributions but with many repeated values.

Table 2. Spearman and Pearson correlations between the variable "drowsy" and the time-of-day model, length of last principal sleep, next-to-last sleep (S-1), etc.

Drowsy	Model	Last Sleep	S - 1	S - 2
Spearman	.220	-.110	-.046	-.039
Pearson	.238	-.091	-.022	-.032

Discriminant analysis is another way to measure the strength of association between drowsiness and the other variables of interest. It is better suited than Spearman and Pearson correlations are to the binary nature of the variable “drowsy.” Discriminant analysis is a statistical technique related to multivariate analysis of variance and multiple regression. If individual cases under study are described by several variables (which are approximately multivariate normal), and if the cases form two or more groups, discriminant analysis can be used to determine which variables are most useful for discriminating among groups.

The 7,951 data cases discussed at the beginning of this section could be considered to be comprised of a “drowsy” group and a “not drowsy” group, with group membership in accordance with the value in the “drowsy” field of each record. Furthermore, each of these data cases was characterized by values of the variables “model,” “last sleep,” “S-1,” etc., which were expected to be useful in predicting drowsiness. Therefore, discriminant analysis was used to identify and properly weight the “best” variables, and to test how well the cases could thereby be classified into the two groups.

The computer program that we used to perform the discriminant analysis (SYSTAT 6.0) calculates an F-ratio for each variable (i.e., ratio of between-groups variability to within-groups variability, which is a statistical measure of the discriminability between the groups on a given variable) to help the analyst select the most potent variables. Larger F’s indicate greater separation of the groups on that variable. The F-ratios (based on the 4,920-case subset that includes “S-2”) are given in Table 3. It can be seen that there is approximately an order of magnitude decrease (i.e., a factor of ten) between “model” and “last sleep,” and *another* such decrease between “last sleep” and the earlier sleeps “S-1” and “S-2.” It was not surprising, then, that when the “model” and “last sleep” variables were included in the discriminant analysis, the “S-1” and “S-2” variables were found to have F-ratios too small to meet the default criterion for inclusion. The lengths of these two- and three-day-old sleeps had a very weak relationship to “today’s” drowsiness.

Table 3. “F-to-enter” statistic (df=1, 4,918) showing relative importance of time-of-day model and previous principal sleeps (Last, S-1, S-2) in discriminant analysis of drowsy vs. not-drowsy six-minute epochs data records.

Model	Last Sleep	S - 1	S - 2
294.94	40.91	2.48	5.21

The discriminant analysis correctly classified 436 of the 602 “drowsy” records (72.4%) and 5,029 of the 7,349 “not drowsy” records (68.4%) based solely on the values of “model,” the time-of-day model shown in Figure 3. With the addition of “last sleep,” the discriminant analysis classified 419 of the 602 “drowsy” records (69.6%) and 5,149 of the 7,349 “not drowsy” records (70.1%). Classification performance was not changed much by adding “last sleep.”

DROWSINESS AND NAPS

Sixty-three naps taken during rest breaks and verified by physiological recordings were reported in the DFAS study from the standpoint of the added sleep they provided. In the present analysis of combined DFAS and Recovery study data, we focused on the relationship between naps and drowsiness. Because the source of drowsiness information was video of drivers' faces, naps in the DFAS and Recovery study were selected for analysis only if they had video recordings both before and after the nap. There were 49 such naps, in the course of 47 trips taken by 25 drivers. The distribution of the lengths of these naps is shown in Figure 5. It can be seen that all but two of the nap lengths were almost uniformly distributed between zero and 90 minutes duration. The median nap length was 34 minutes. The duration of naps was not related to the duration of the preceding principal sleep period ($r=.21$, $p>.14$). Naps were taken by drivers who had a total of many drowsy epochs, few drowsy epochs, and no drowsy epochs. The Spearman rank-order correlation between drivers' number of naps and number of drowsy epochs was statistically significant ($t=3.8$, $df=87$, $p<.001$) but not strong (r sub s = 0.38). The naps were not uniformly distributed among observational conditions: C1=1, C2=9, C3=15, C4=9, C5=11, C6=0, C7=2, C8=1, and C9=1. Considering Recovery study drivers only, Condition 3/5 had 10 naps the first week, 11 the second; and Condition 4/9 had 0 the first week, 1 the second.

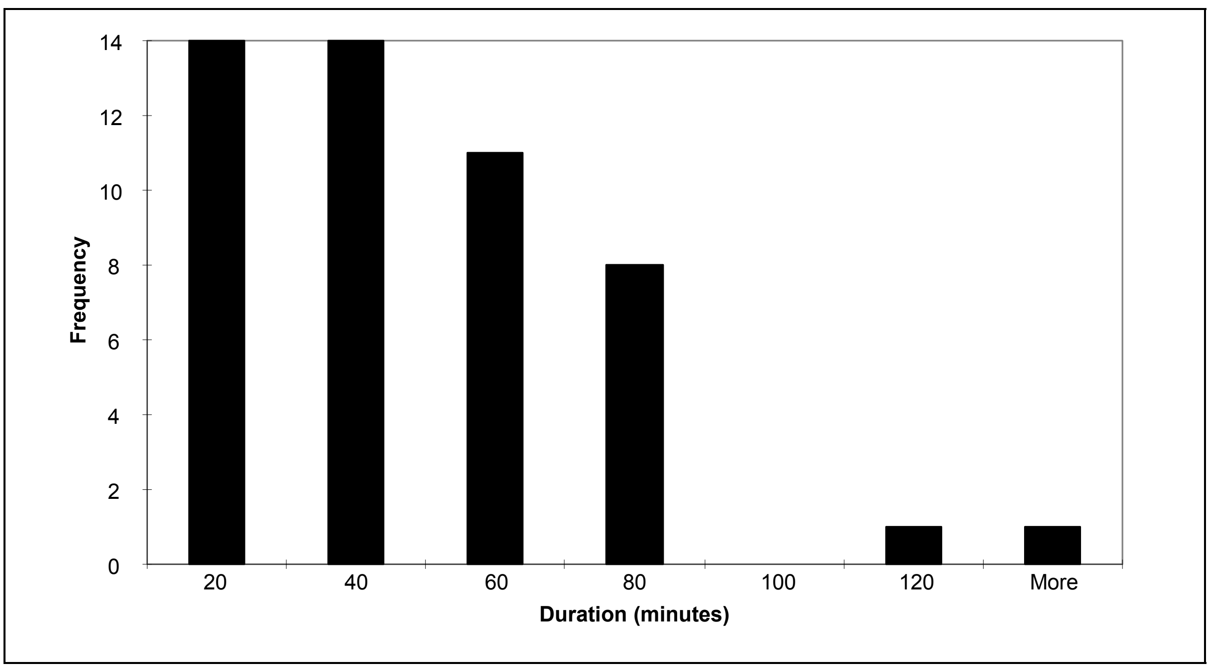

Figure 5. Histogram of nap lengths.

The time of day that the naps were taken is described by the histogram presented in Figure 6. It can be seen that most of the naps were begun during the night and early morning hours. The lag between the start of the trips and the start of the naps is summarized in Figure 7.

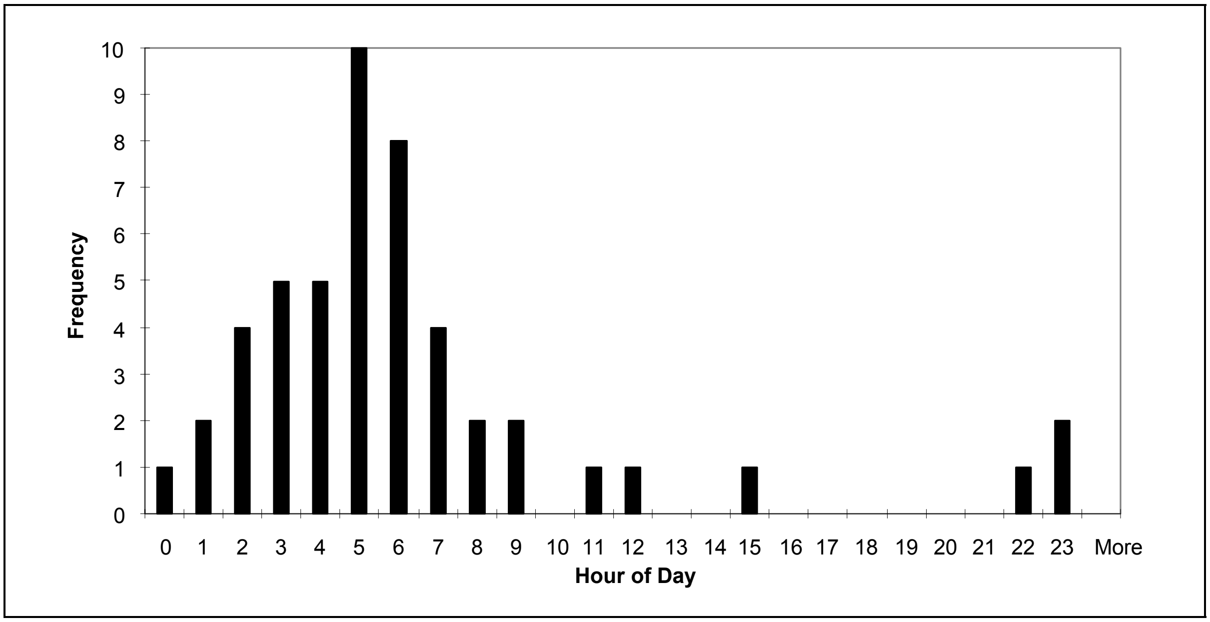

Figure 6. Time of day of nap onset.

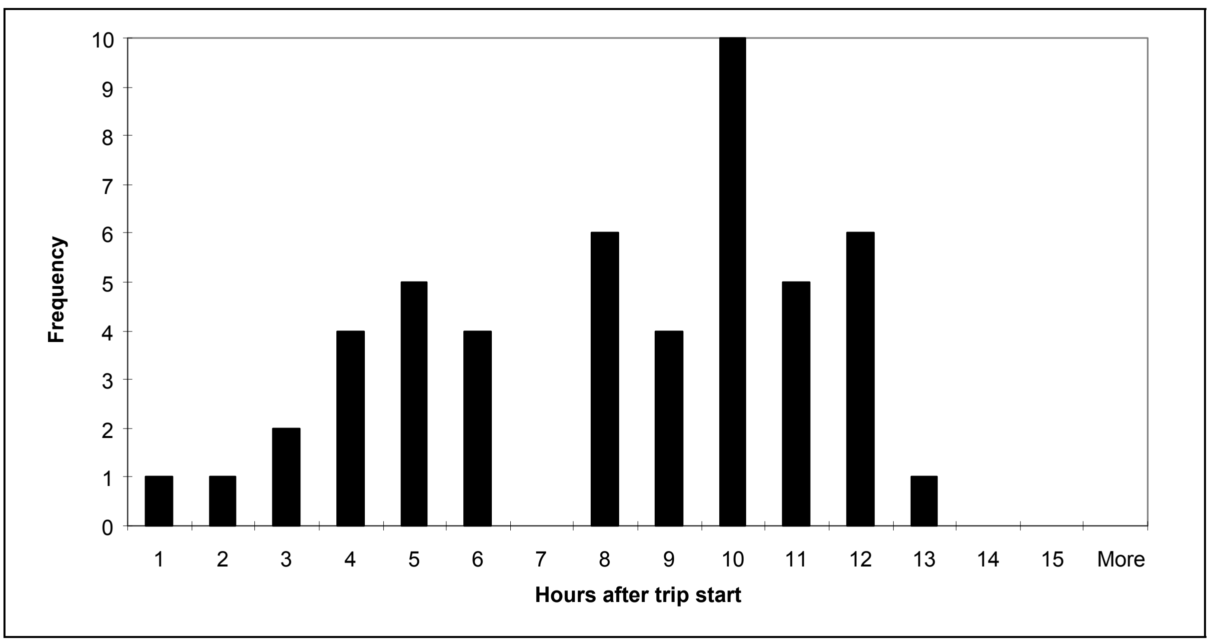

Figure 7. Nap "lag" (hours after trip start that nap was begun).

For each of the 49 naps, the total number of six-minute periods judged "drowsy" prior to the nap was compared to the total number of six-minute periods judged "drowsy" after the nap. It was found that in 24 trips the drivers were never judged "drowsy" either before or after the nap, in 12 trips the drivers were judged to have less drowsiness after the nap than before, and in 13 trips the drivers were judged to have more drowsiness after the nap than before. This finding might be taken to mean that there was no relationship between naps and drowsiness, but aggregating the drowsiness data over the entire period preceding and following each nap did not allow a very clear or detailed picture to be drawn.

Consequently, each of the 25 nap trips (taken by 16 drivers) that had one or more six-minute epochs judged to show a drowsy driver were analyzed in greater detail. For each such trip, the number of each drowsiness indicator was tabulated for the 60-minute interval preceding the onset of the nap and for the 60-minute interval following the end of the nap, for the 60-120 minute interval preceding and following the nap, etc. These data were then aggregated across all 25 trips on an hour-by-hour basis. The drowsiness indicators tabulated were responses recorded by video reviewers in the 50-item Video Detail Record Form (DFAS, pp. 3-32) under three pre-defined categories "drowsy," "droopy eyelids," and "pronounced blinks." The results are shown in Figure 8.

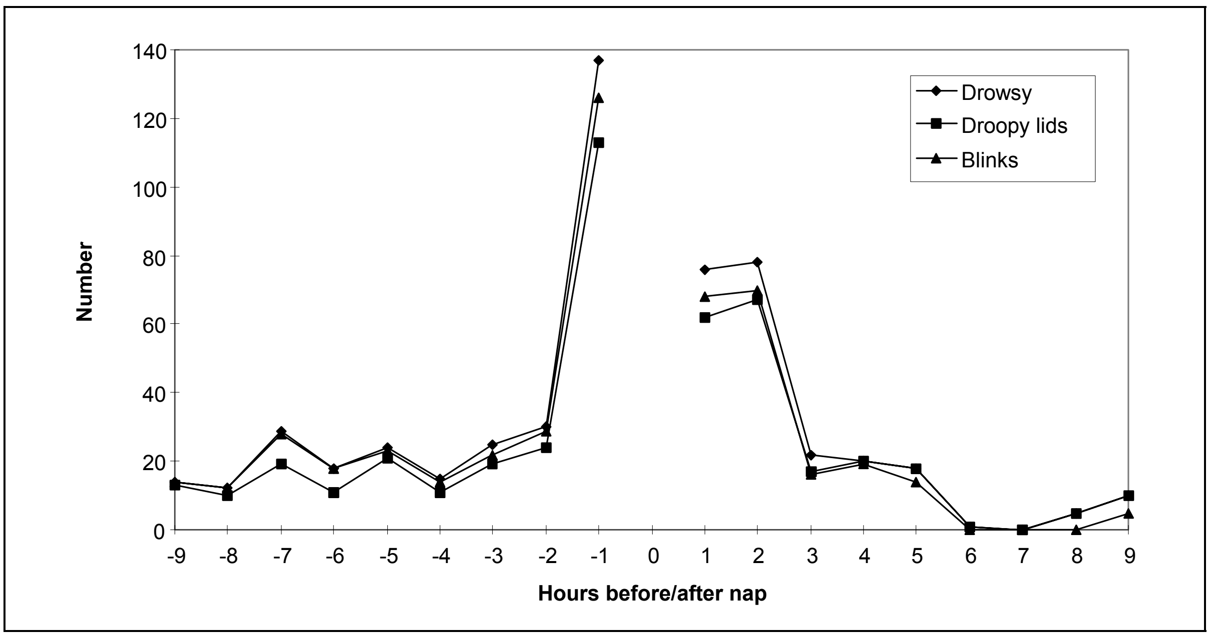

Figure 8. Drowsiness indicators by hour before/after nap.

The three drowsiness indicators were highly correlated. From nine hours preceding the nap until two hours preceding the nap, there was a "background" level of drowsiness having a count of approximately 20 per hour for each type of indicator. However, in the 60 minutes immediately preceding the nap, the count for each drowsiness indicator increased sharply, to a level of about 120 per hour per indicator, a factor of six greater than the background level.

After the nap, it can be seen that the level of drowsiness was about 70 per hour per indicator, for two hours. While this was about half the level of drowsiness seen in the hour preceding the nap, it was still substantially above the background level. In the third, fourth, and fifth hours after the nap, the level of drowsiness returned to the background level, and in succeeding hours it dropped lower, perhaps because of dawn.

We wondered how many of the individual trips showed the distinctive pattern seen in Figure 8. Therefore we plotted the number of non-zero drowsy epochs per hour, by hour, prior to and after each of the naps underlying Figure 8. (The plots are shown in Appendix A.) It can be seen that there were large within- and between-driver differences in the amount, duration, and timing of drowsiness before and after naps. It is averaging over many trips that allows the pattern of Figure 8 to emerge, and the key to this averaging is having behavioral anchor points (nap beginning time, ending time) in each underlying trip. In trips without naps, we do not have these anchor points to permit aligning trip histories. Therefore one is hampered in looking for characteristic patterns regarding the waxing and waning of drowsiness in the majority of trips. The best general description of the temporal characteristics of drowsiness judged by video in this data collection probably remains that given in the DFAS report (p. 4-34). There were a total of 305 “runs” (sequences of drowsy epochs uninterrupted by a “not drowsy” epoch). There were 70 runs of drowsiness during the hours 0700 to 1859, and 235 runs during the hours 1900 to 0659. Although there were more runs at night, a Mann-Whitney U test did not reveal any difference in the frequency distribution of run lengths between day and night. The frequency of run lengths could be described by the exponential density function (R-squared=0.92). Longer runs of drowsiness occurred with decreasing frequency. The minimum run length was 1, the mode (the most frequent) was 1, the median run was four six-minute drowsy epochs (=24 minutes), the mean was 6.44 epochs, and the maximum run length was 37 six-minute drowsy epochs (3.7 hours).

The relative infrequency of naps and the large within- and between-driver differences in drowsiness obscured a precise formula or model for combining nap time with principal sleep time to predict subsequent alertness. While naps could be expected to reduce sleep debt and therefore drowsiness, this was not confirmed empirically in this data analysis. There was evidence (Figure 8) that naps were associated with increased drowsiness, which on average was seen as a precursor to naps, and also was seen for two hours after naps.

3. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were made as a result of the study.

- The rhythmic time-of-day effect had the strongest relationship to observed variations in drowsiness, compared to other DFAS and Recovery study variables investigated to date, including time on task, cumulative number of trips, and amount of prior sleep.

- After time of day, the length of the last principal sleep had the next-strongest relationship to observed variations in drowsiness.

- The lengths of earlier principal sleeps added little or nothing to describing the observed variations in drowsiness.

- A mathematical model was developed that incorporated a sinusoidal 24-hour rhythmic component and the duration of the last principal sleep. This model described the observed drowsiness data very well.

- The model indicated that probability of drowsiness is most sensitive to amount of last sleep at the circadian peak of drowsiness in the middle of the night, and least sensitive in the middle of the day.

- Plots of the model (e.g., Figure 4) might be useful for training drivers, administrators, and others involved in shift work to improve work/rest scheduling. The plot is similar in this respect to Akerstedt and Folkard's (1995) "alertness nomogram."

- A multiple discriminant analysis classified 72.4% of the "drowsy" and 68.4% of the "not drowsy" records accurately based solely on time of day. This method or something similar might provide useful a priori information for incorporation into planned real-time drowsiness detection devices that measure driver physiology and/or performance. Consideration of time of day and amount of last principal sleep may improve the operating characteristics of such devices.

- Naps taken during trips in which drivers were judged to be drowsy (25 out of the 49 analyzed) appeared to be taken in response to sudden increases in fatigue and drowsiness.

- Naps in trips with judged drowsiness appeared to result in a recovery effect, compared to the relatively high levels of drowsiness seen in the hour prior to napping. However, signs of drowsiness remained substantially elevated for two hours after napping.

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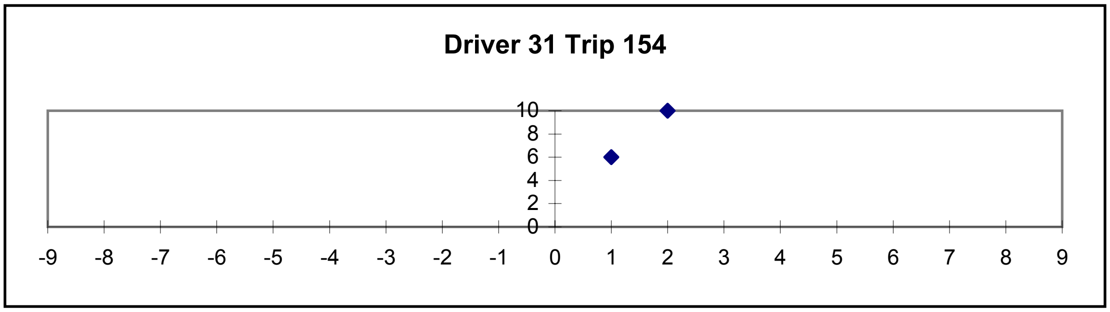
Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. Commercial Motor Vehicle Driver Fatigue and Alertness Study. Report No. FHWA-MC-97-002. Washington, D.C.: Federal Highway Administration, 1996. (Also available from the Transportation Development Centre, Transport Canada, Report No. TP 12875E, 1996.)

APPENDIX A

NUMBER OF DROWSY EPOCHS BY HOUR BEFORE AND AFTER NAPPING, FOR EACH OF THE 25 TRIPS AGGREGATED IN FIGURE 8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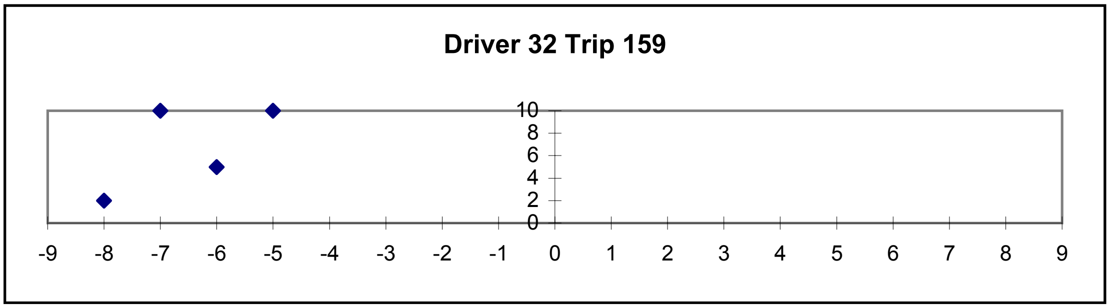
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8
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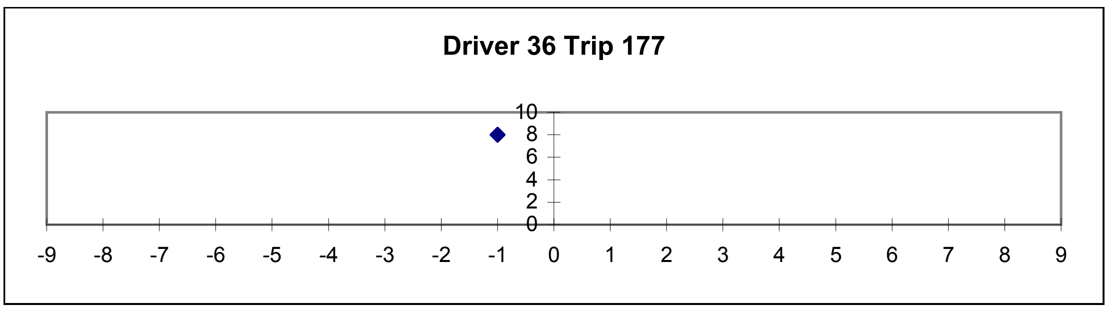
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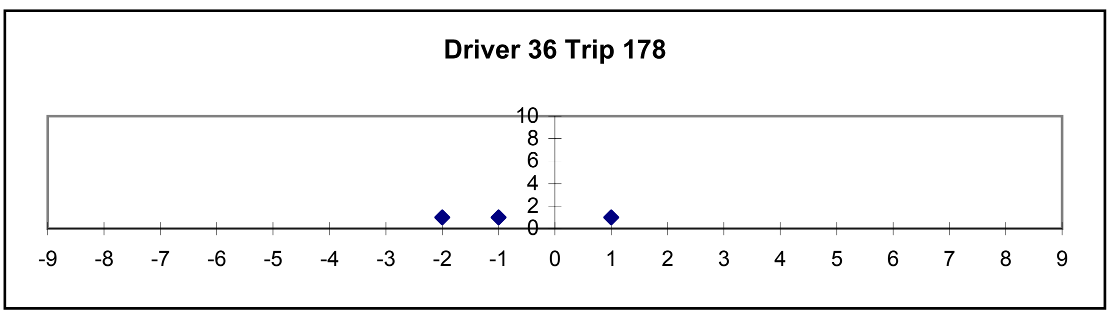
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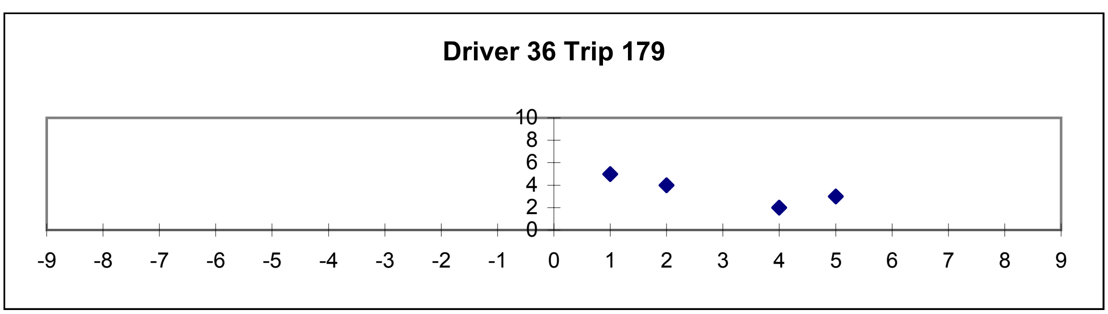
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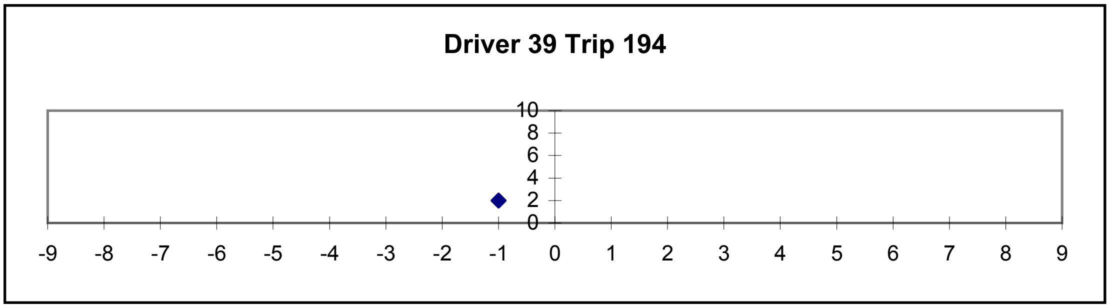
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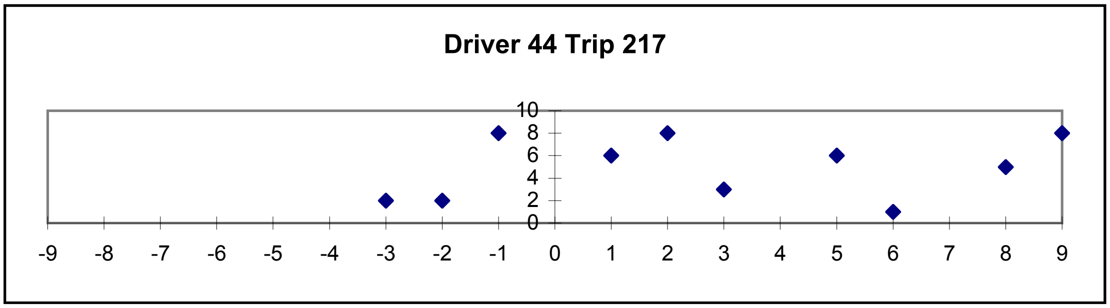
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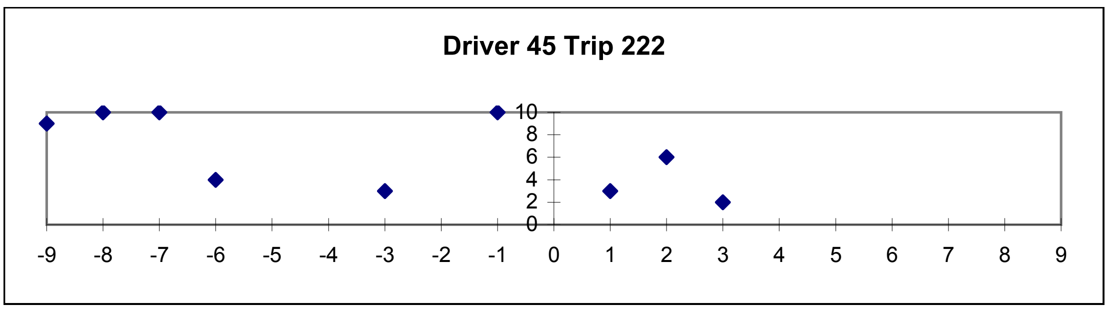
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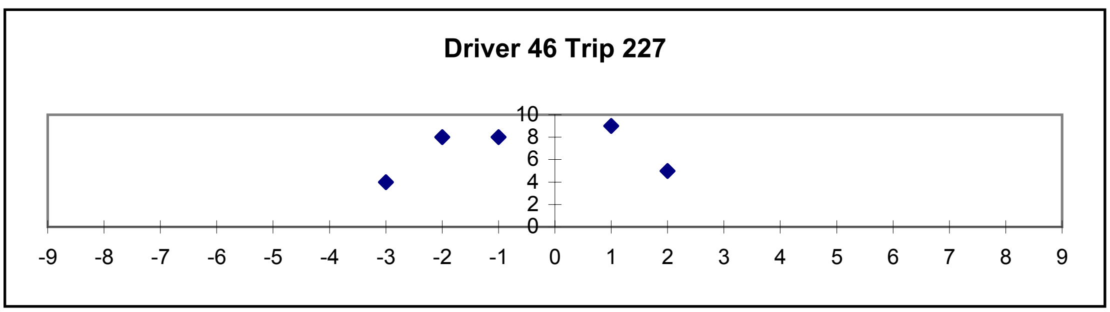
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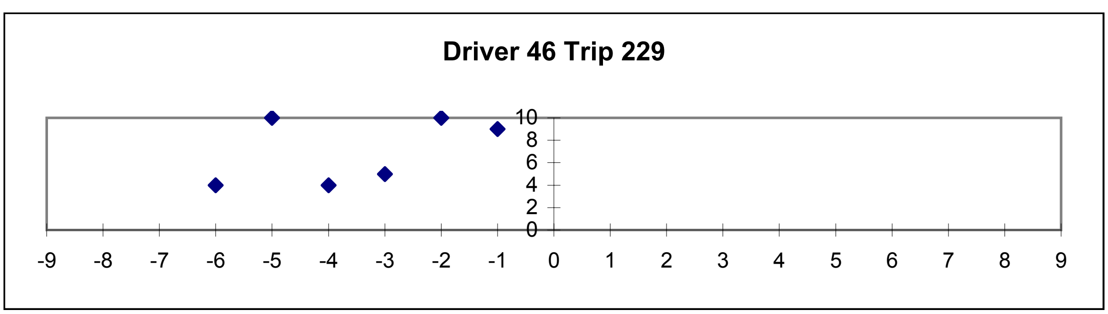
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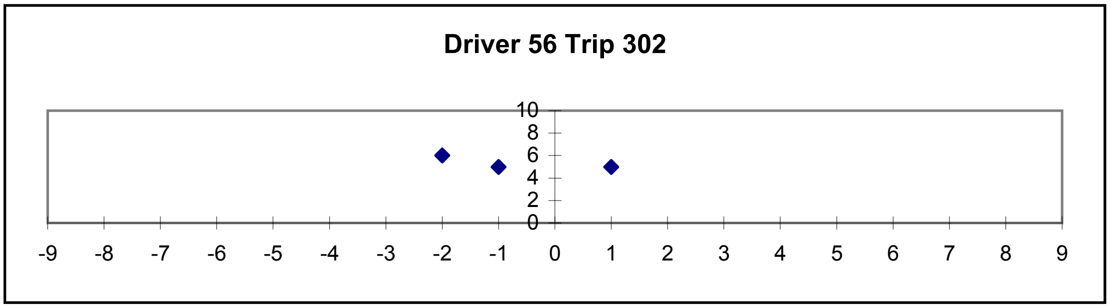
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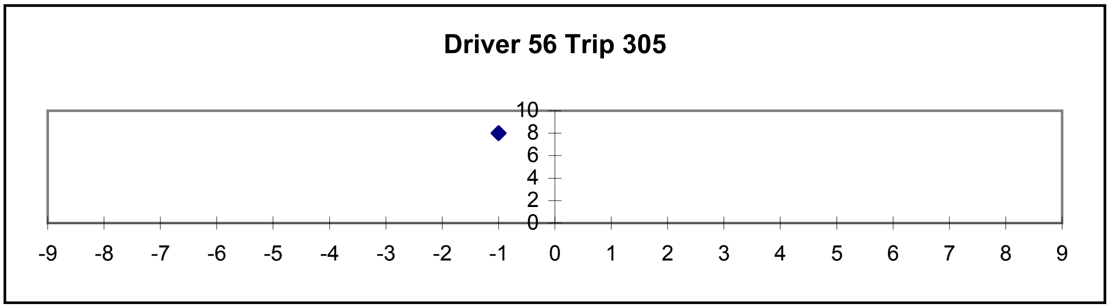
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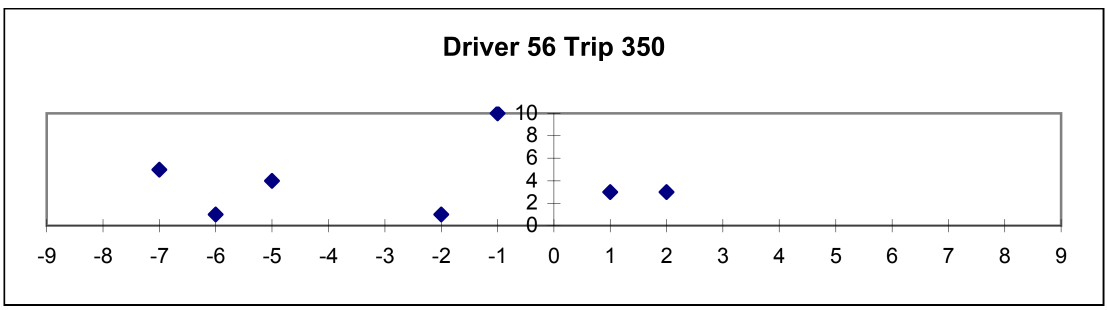
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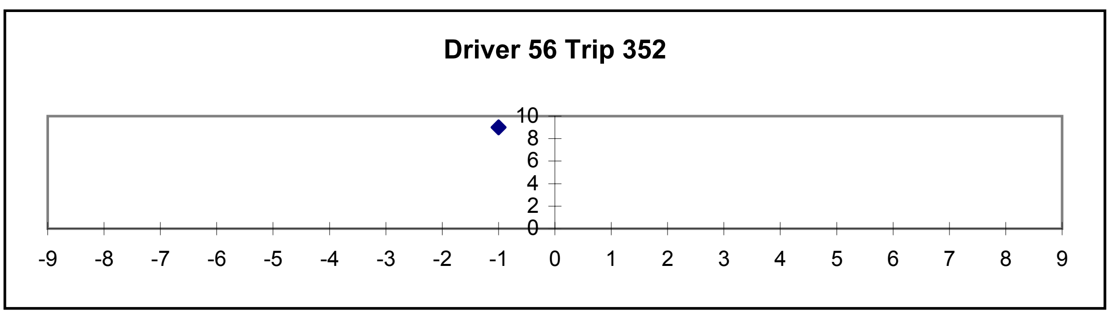
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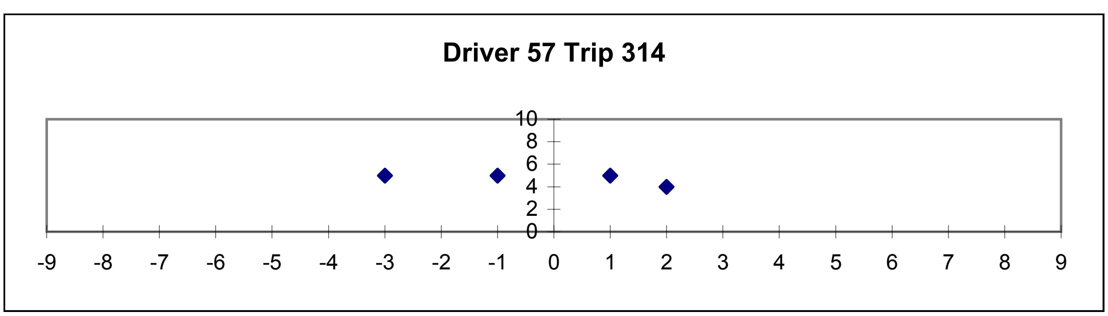
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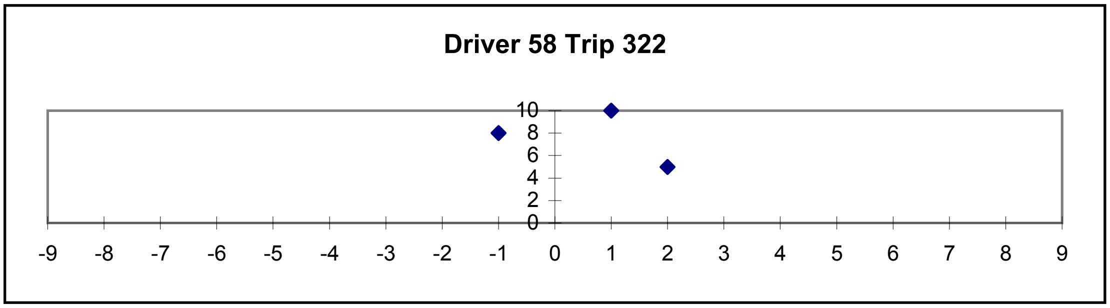
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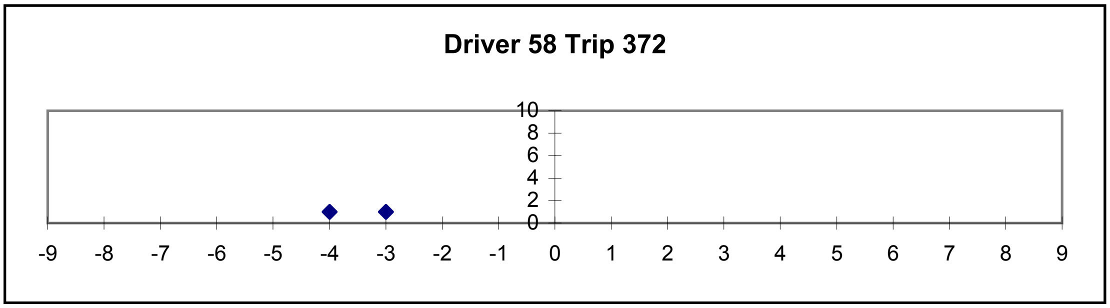
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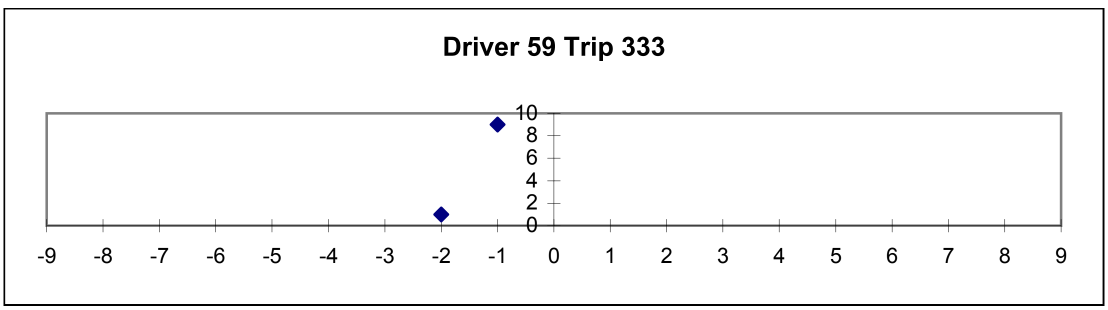
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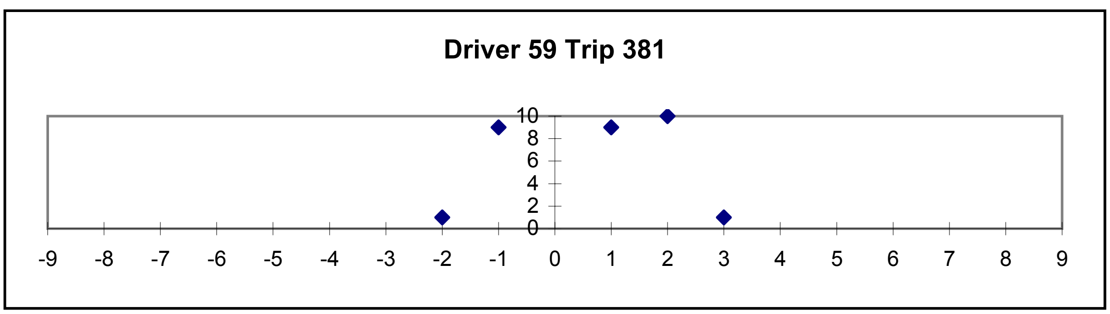
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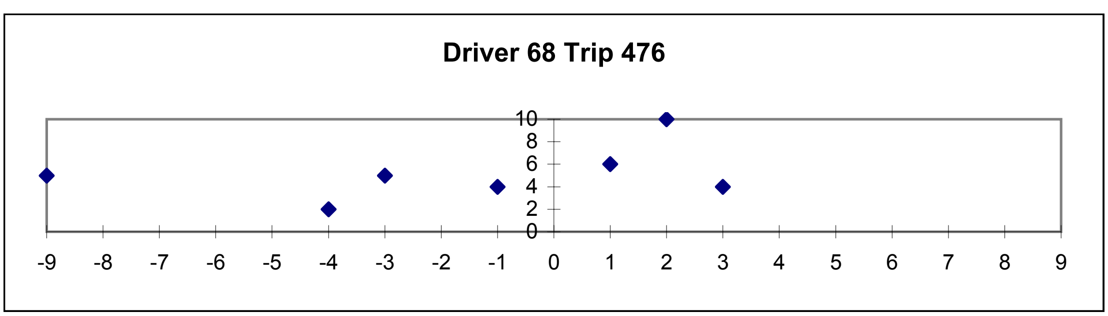
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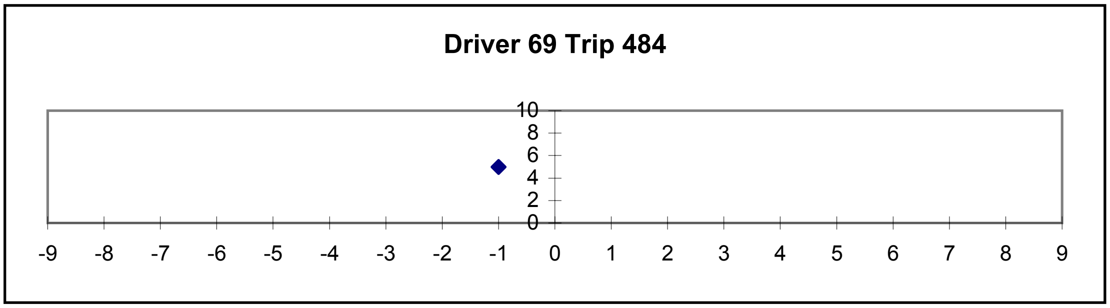
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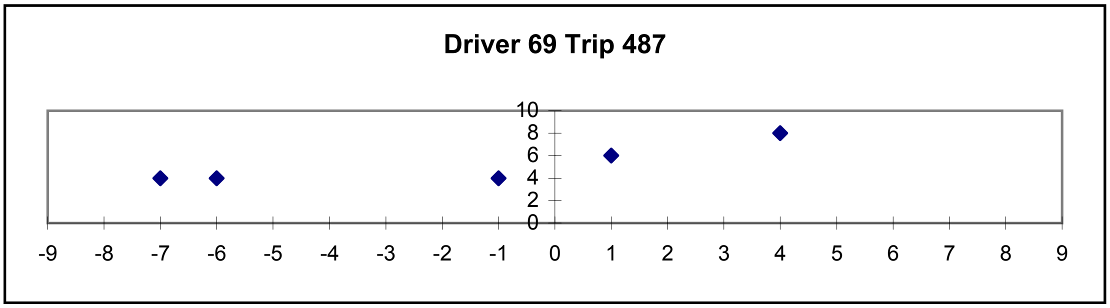
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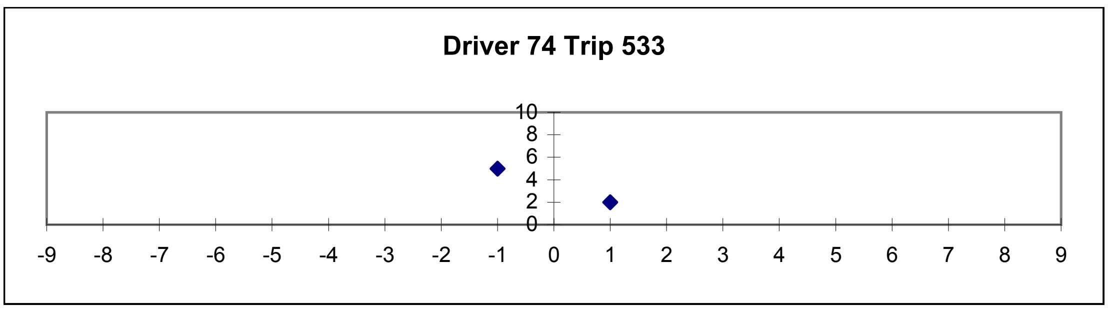
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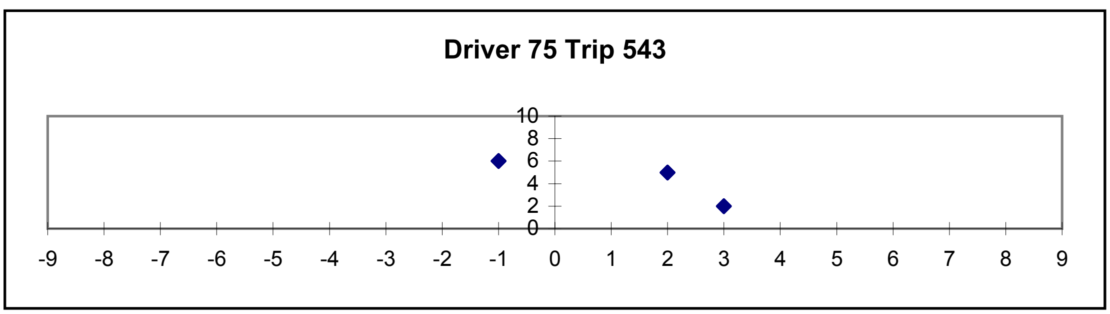
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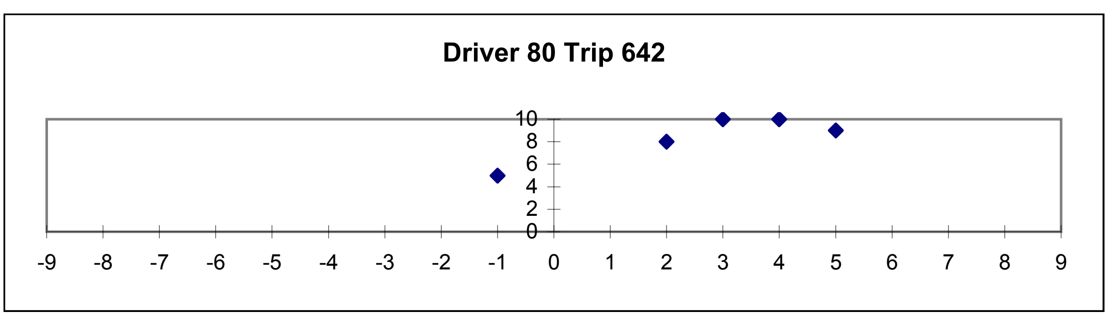
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