CHAPTER 3

MACROSCOPIC LIKE TRIP ANALYSIS

This chapter compares the usage and safety impacts of Intelligent Cruise Control (ICC) relative to Conventional Cruise Control (CCC) using data gathered as part of the Field Operational Test (FOT) in Ann Arbor, Michigan. The results presented in this chapter are based upon aggregated data for each trip performed by each volunteer driver. Further analysis of similar trips was performed at the micro-level (deci-second data) to determine differences between ICC and CCC usage with respect to car-following behavior. This micro-level analysis is presented in the succeeding chapter.

In order to compare ICC usage against CCC usage like trips were extracted from the FOT database. These like-trips were defined as trips conducted by the same driver, within a pre-defined time-of-day temporal window, and originating and ending within a pre-defined spatial window. The data extraction resulted in a total of 60 like trip sets for each type of control (ICC versus CCC).

The ICC system that was evaluated in this thesis integrated a forward-looking sensor with a normal cruise control to automatically maintain a pre-specified headway between the ICC-equipped vehicle and a vehicle that preceded the equipped vehicle. When other vehicles were encountered, ICC-equipped drivers were relieved from engaging, disengaging, or manually resetting speed, as might more often be necessary with a conventional cruise control. When not in traffic, drivers equipped with ICC achieved the benefits of regular cruise control.

The following section describes the FOT including the data collected. The second section describes why and how like trips were extracted from the entire database. The third section describes how ICC was compared to CCC and presents the findings of the study. The final section summarizes the conclusions of the analysis.

3.1 ICC Field Operational Test Description

The ICC Field Operational Test was the result of a cooperative agreement between the National Highway Traffic Safety Administration (NHTSA) and the University of Michigan Transportation Research Institute (UMTRI). Other parties contributing to the field operational test were Leica AG, the Michigan Department of Transportation, and Haugen Associates.

The Field Operational Test (FOT) used 10 1996 Chrysler Concorde vehicles. Each vehicle was equipped with the standard Chrysler cruise control, Lecia sensors, intelligent (adaptive) cruise control logic and hardware, and a data acquisition system that collected data to support the evaluation (Robinson et al., 1997). Figure 2-1 illustrates the Chrysler cruise control interface. The data collection system collected video data and a variety of vehicle performance measures. The video data captured a 60-degree field of view in front of the vehicle for 2 – 60 second periods for various vehicle performance thresholds (Robinson et al., 1997). The non-video data was recorded 10 times per second. These data included range, rate of change of range, vehicle velocity, headway selected by the driver, curve radius, and throttle setting.

One hundred and eight volunteers were recruited to drive ICC equipped Chrysler Concordes for 2 or 5 weeks. Both groups of drivers experienced one week of driving the Concorde in a standard configuration (no ICC) before ICC functions were made available. One and four week exposures to ICC were included in the research design to enable an assessment of longer term changes in behavior as a function of experience with ICC. The one week without ICC was intended to provide baseline data for driving performance without ICC.

Volunteer selection was based primarily on four parameters: annual driving rate, age, previous cruise control usage, and driver type. Only volunteers who typically drove more than 12,000 km per year were considered for the FOT. The age groups selected were 20 to 30 years old, 40 to 50 years old, and 60 to 70 years old. Figure 3-1 illustrates that gender and age group equally stratified the test participants in order to reduce the potential for systematic biases. The 108 drivers were selected to include 66 drivers who had used cruise control before and 42 drivers who had not used cruise control before, as illustrated in Figure 3- 1. The University of Michigan Transportation Research Institute (UMTRI) has identified three driver types: hunters, gliders, and situation specific (Robinson et al., 1997). Hunters are aggressive drivers who close headway quickly, follow vehicles at close distances and pass frequently. Gliders are more likely to travel with the traffic flow or slower and have longer following distances. Situation specific drivers shift between hunters and gliders. This driver classification was derived from volunteer self-report. The FOT used approximately equal numbers of each driver classification.

Before the FOT began, a 12-minute instructional video was shown. Each volunteer had a test drive of the vehicle with an UMTRI staff member. Each vehicle had an ICC system manual and a cellular phone for the driver to contact the ICC help desk with further questions.

The 108 drivers, who were encouraged to drive as much as possible, drove a total of approximately 11,000 trips. During these trips the speed, acceleration and other measures (GPS coordinate, range, range rate, brake status, usage of the cruise control, etc.) of the ICC-equipped vehicle were recorded every deci-second. A trip summary file was generated from these raw data, which included the trip length and duration, the number of times various cruise control buttons were pressed during a trip, the number of brake presses during a trip, and the number of brake interventions and close encounters during the trip. Using the trip summary file, this chapter describes how ICC usage was compared to Conventional Cruise Control (CCC) usage, in addition to analyzing these findings.

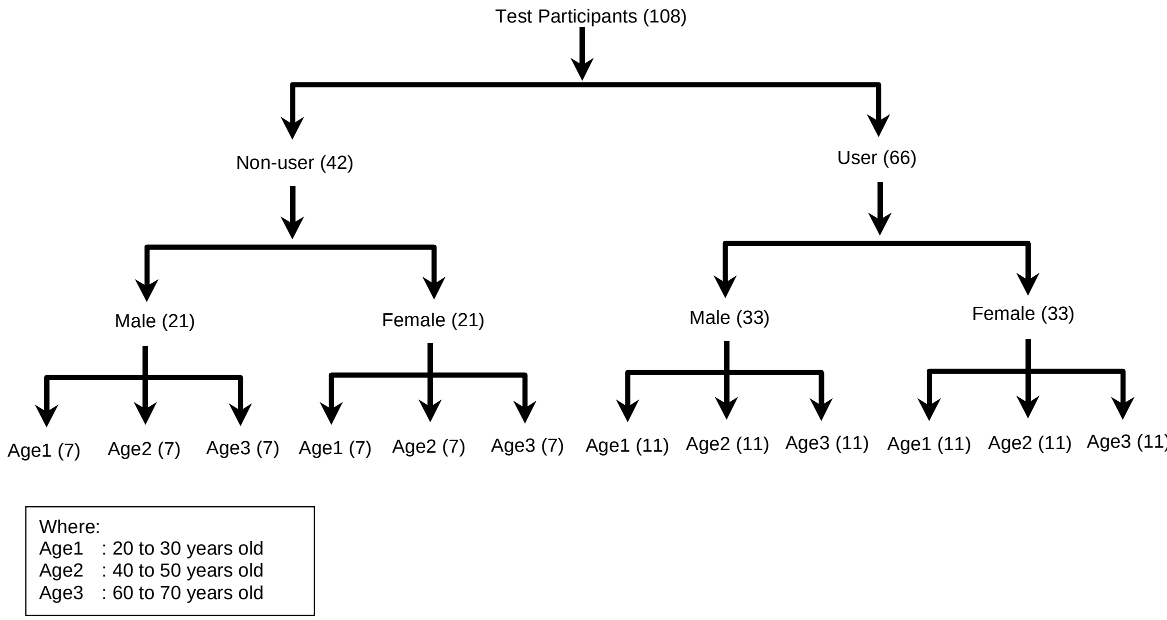

Figure 3- 1 Stratification of ICC field operational test participants

3.2 Definition and Extraction of Like Trips

In order to compare the usage of two systems, it is paramount that the before and after conditions be consistent and similar except for the factor that is under consideration. In the case of this study an effort was made to ensure that the trips without ICC were as similar as possible to the trips with the ICC logic in order to isolate the effect of ICC. This section describes how these similar trips were defined and extracted.

3.2.1 Like Trip Pairs

The classification of like trips was based on four parameters: origin and destination zone location, trip start time, length of trip, and minimum trip length. The usage or availability of intelligent cruise control does not affect the pairing of trips. Trip pairs were created for each driver in the data set but trip pairs were not created across drivers. Both trips of a like trip pair were therefore performed by one driver. Using the four parameters, two similar trips can be viewed as trips that start and end within a similar spatial and temporal window, as illustrated in Figure 3- 2. In this example, trips 1 and 2 are similar and trips 3 and 4 are similar. Trips 1 and 2 are not similar to trips 3 and 4, however, because they start and end from different space/time windows.

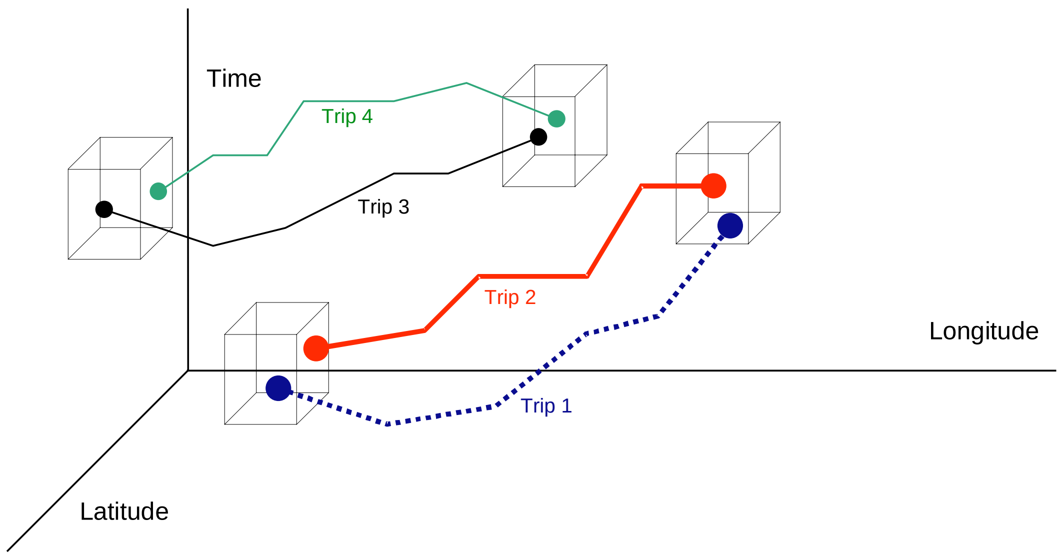

Figure 3- 2 Determination of Like Trip Pairs

3.2.2 Like Trip Sets

Once trip pairs were identified for each driver, the pairs were assembled into groups of like trips. A trip pair became part of a particular group when one of the pair was similar to a trip of another pair. For example, if two trip pairs for a particular driver contain trips 1 and 2 in the first pair and trips 1 and 3 in the second pair, the group would include trips 1, 2 and 3 since trip 1 is similar to 2 and also to 3. This does not mean that every trip in the group is similar to every other trip but similar to the mean trip of the group. For Figure 3- 2 above, trips 1 and 2 are a similar set while trips 3 and 4 constitute another similar trip set.

3.2.3 Stratification of Like Trips

Tools were developed in order to extract from the ICC trip summary file all the trips that were similar as defined by the similar-trip criteria. Depending on the magnitude of the similar trip criteria, the number of similar trips could differ. On one hand, usage of very restrictive criteria would ensure that any similar trips were identical, however, it could result in a very small number of similar trips. On the other hand, relaxed criteria could result in a large number of trips that are not necessarily very similar. In the former case, the statistical analysis could be impacted as a result of the small sample size, while in the latter case the analysis could be impacted as a result of comparing trips that have little in common. Consequently, the first step in the similar trip extraction exercise was to investigate the sensitivity of the number of similar trips to the similar trip criteria. The sensitivity of similar trips to the time and space criteria is illustrated in the figures below.

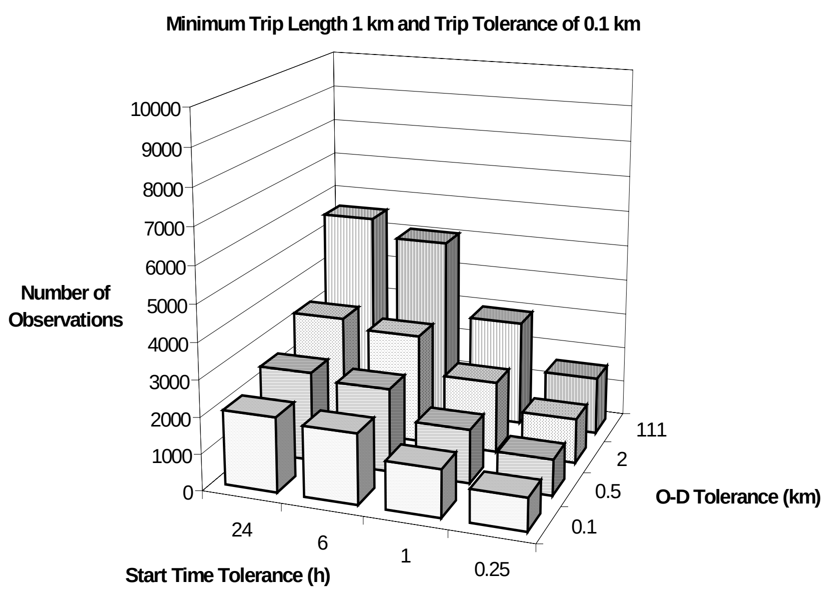

Figure 3- 3 Trip Stratification with Trip Tolerance of 0.1 km

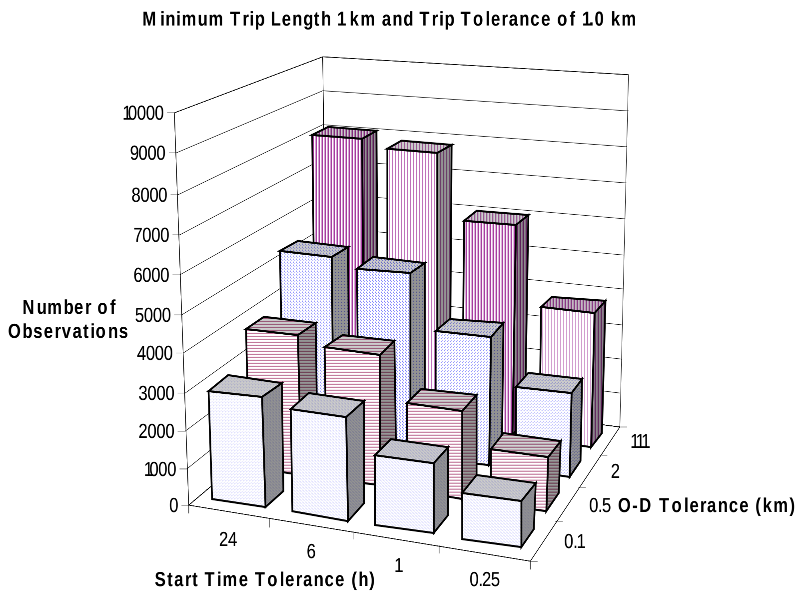

Figure 3- 4 Trip Stratification with Trip Tolerance of 1.0 km

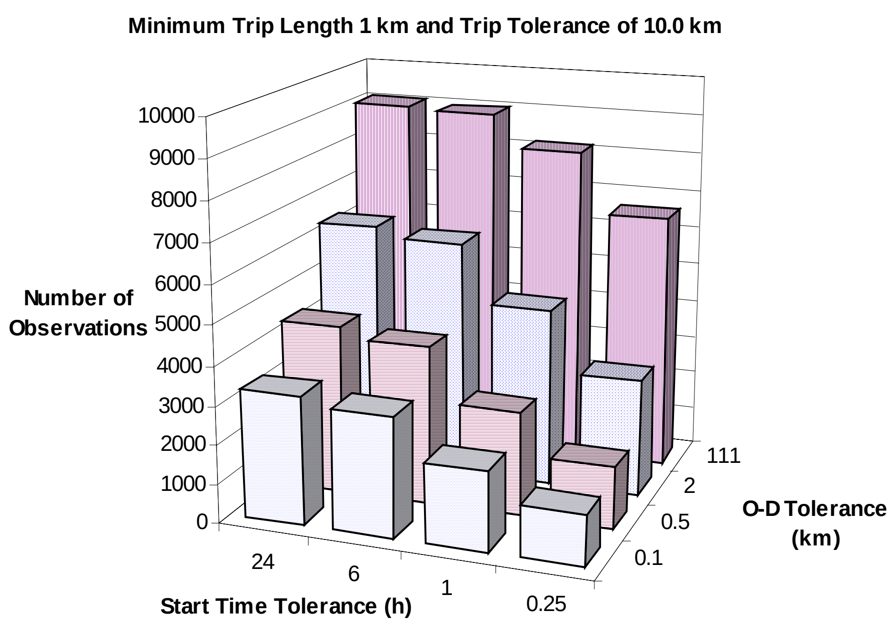

Figure 3- 5 Trip Stratification with Trip Tolerance of 10 km

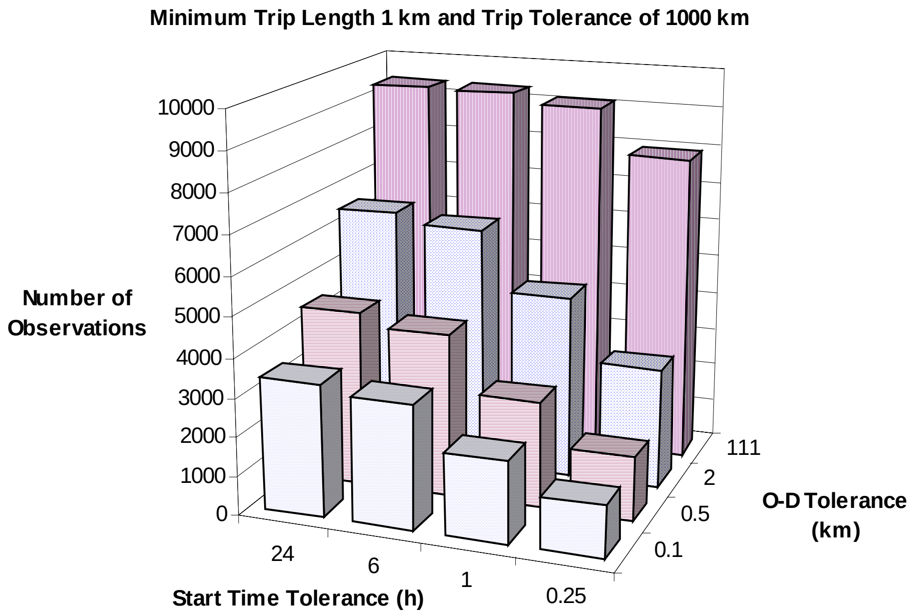

Figure 3- 6 Trip Stratification with Trip Tolerance of 1000 km

Each of the above charts shows the changes in the number of observations based upon start time tolerance and origin-destination spatial location tolerance. The minimum trip length remains at 1 km and the trip length tolerance values are 0.1 km, 1.0 km, 10.0 km, and 1000 km. As expected, as the tolerances are relaxed, the greater number of like trip observations recorded. In each chart this can be seen as the number of observations increases with the increase in start time tolerance and with the increase in O-D tolerance. From the 1000-km trip tolerance chart it is noted that the total number of like trips for a 0.1 km origin-destination tolerance and start time tolerance of 0.25 hours is 1309. The maximum number of like trips for an origin-destination tolerance of 111 km and start time tolerance of 24 hours is 9351. The number of observations varies across charts as well within charts. The maximum number of like trips from the trip tolerance chart of 0.1 km is 5557 while the maximum number of like trips from the trip tolerance chart of 1000 km is 9351.

A decision was made to keep the trip length tolerance at its maximum value of 1000 km in order to capture any potential re-routing that could have resulted from the use of ICC. Furthermore, a decision was made to use the most rigorous like-trip criteria (departure times within 15 minutes and O-D's within 100 m) because a significant number of like trips were available (1309 trips).

The resulting 1309 like trips included a total of 37 drivers (statistics available on 36 drivers only), as illustrated in Figure 3- 7. The stratification of these like trips involved a very small sample of drivers within the 60-70 age group, with the majority of drivers in the 40 to 50 age group.

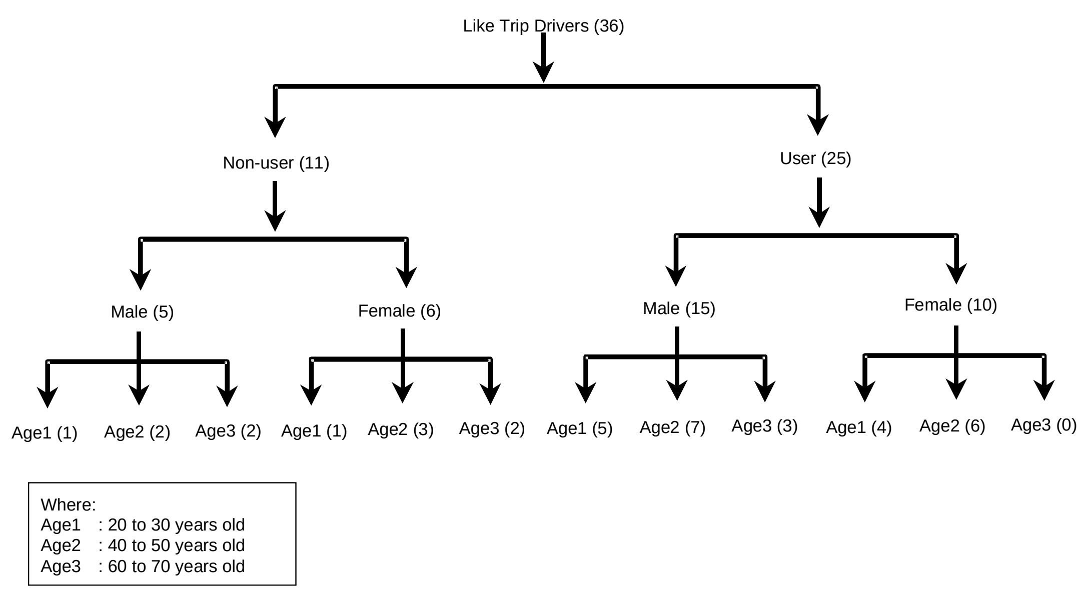

Figure 3- 7 Stratification of Like Trip Driver Sample

3.3 ANOVA Results

The previous sections described how similar trips were extracted from the trip summary logs that were gathered as part of the ICC field operational test. These similar trip sets were utilized in order to verify statistically whether the use of

Intelligent Cruise Control resulted in different driving behavior relative to the use of conventional cruise control. This section describes how the data were compiled in order to apply the statistical techniques to the data. This section also describes the various types of data manipulations that were required in order to conduct the statistical analysis of the data. Finally, this section describes the results of the comparisons that were conducted.

3.3.1 Screening of Data

A number of summary parameters were gathered at the trip level. These parameters included the trip length, trip duration, percentage of trip length that cruise control was active, statistics regarding the usage of the cruise control system, and some safety measures, as described in Table 3- 1.

The similar trips that were described in the previous sections were screened in order to ensure that each similar trip set was composed of at least one Conventional Cruise Control (CCC) trip and one Intelligent Cruise Control (ICC) trip. Furthermore, trips that did not involve the use of either CCC or ICC were removed from the data set (distance of cruise control engaged = 0.0). The reason for ensuring that only CCC and ICC trips were included in the analysis stems from the fact that the majority of parameters that were analyzed could only be associated with the use of cruise control (e.g. number of times the ON button was pressed). It was felt that the use of trips that did not involve any type of cruise control usage would only bias the results because they would involve zeros for most measures.

The screening of the data resulted in a total of 60 similar trip sets that constituted a total of 266 similar trips. Of the 266 trips 103 were CCC and 163 were ICC trips. The similar trip sets ranged from 2 similar trips to 10 similar trips per set with an average of 4.4 trips per set.

Table 3- 2 demonstrates how the average, minimum and maximum parameter values varied for trips that involved CCC and ICC type of control across all sets. Although there were a larger number of ICC versus CCC trips (163 versus 103), the mix of trip sets resulted in comparable trip characteristics (in terms of trip duration and trip length) for both the ICC and CCC configurations. Specifically, the average trip duration and length were within 2 percent for the CCC and ICC configurations. In addition, Figure 3- 8 and Figure 3- 9 demonstrate a close match between the CCC and ICC trip duration and trip length distributions. Consequently, the mix of CCC and ICC trips across the various similar trip sets allowed for an unbiased comparison of the CCC and ICC configurations.

As described earlier, each similar trip set was comprised of a group of trips that involved a common driver, a common origin, a common destination, and a common time window. Table 3- 3 demonstrates a sample of two similar trip sets. The first set involves five trips without ICC (ICC flag equals zero) and five trips with ICC available (ICC flag equals one) for driver 43. The second set involves three non-ICC trips and four ICC trips for driver 9. It is important to note that the trip lengths for the first set were in the range of 8 kilometers while they were in the range of 55 kilometers for the second set. In order to overcome any biases that would result from the trip length (e.g. longer trips could typically involve a larger number of counts of RESUME button presses) dividing by the trip length normalized the various parameters. This normalization of parameters attempted to remove any biases that could have resulted from different trip lengths, however, it did not address biases that could result from differences in driving habits across drivers or differences in traffic conditions by origin/destination or time-of-day. A summary of the various parameters that were computed is presented in

Table 3- 4.

Figure 3- 13 illustrates that the trip duration varied considerably across the various sets, with some sets involving travel times in the range of 80 to 100 minutes and other sets involving travel times in the range of 10 to 15 minutes. Alternatively Figure 3- 14 illustrates less variability in the distance normalized travel time "TimeP". Specifically, most of the sets were centered on a value of 1 minute/kilometer. Figure 3- 14 still demonstrates some variability in trip duration across trip sets that could have resulted because of varying levels of congestion along the route.

Table 3- 1 Trip Summary Parameters Collected as Part of the ICC FOT

Variable	Description	Units
Time	Trip travel time	Minutes
Dist	Trip length	Km
Engage	Percentage of trip length that cruise control was engaged	N/A
ICCOn	Number of times the cruise control ON button was pressed during a trip	N/A
Set	Number of times the cruise control SET button was pressed during a trip	N/A
Coast	Number of times the cruise control COAST button was pressed during a trip	N/A
Resume	Number of times the cruise control RESUME button was pressed during a trip	N/A
Accel	Number of times the cruise control ACCEL button was pressed during a trip	N/A
Cancel	Number of times the cruise control CANCEL button was pressed during a trip	N/A
Brake	Number of times the brakes were pressed during a trip	N/A
CCBi	Number of times a brake intervention was required during a trip (deceleration greater than 0.05g with speed greater than threshold)	N/A
CCNe	Number of times a near encounter was observed during a trip (deceleration greater than 0.05g with headway between front and back of preceding vehicle less than 0.3 seconds)	N/A

Table 3- 2 Variation in Parameters across Similar Trip Sets by Type of Control

	Conventional Cruise Control			Intelligent Cruise Control		
	Avg.	Min.	Max.	Avg.	Min.	Max.
Time	29.4	9.1	96.1	28.2	9.0	97.4
Dist	33.5	8.2	148.1	35.4	8.1	149.0
Engage	39.7%	0.2%	88.0%	55.1%	0.8%	89.0%
ICCon	1.2	1	6	1.4	1	6
Set	2.0	0	15	2.0	1	17
Coast	5.5	0	104	3.5	0	48
Resume	1.5	0	12	1.6	0	11
Accel	4.3	0	62	6.2	0	101
Cancel	0.5	0	7	0.5	0	8
Brake	33.3	7	106	28.1	8	82
CCBi	0.8	0	5	1.3	0	7
CCNe	0.6	0	4	0.7	0	6

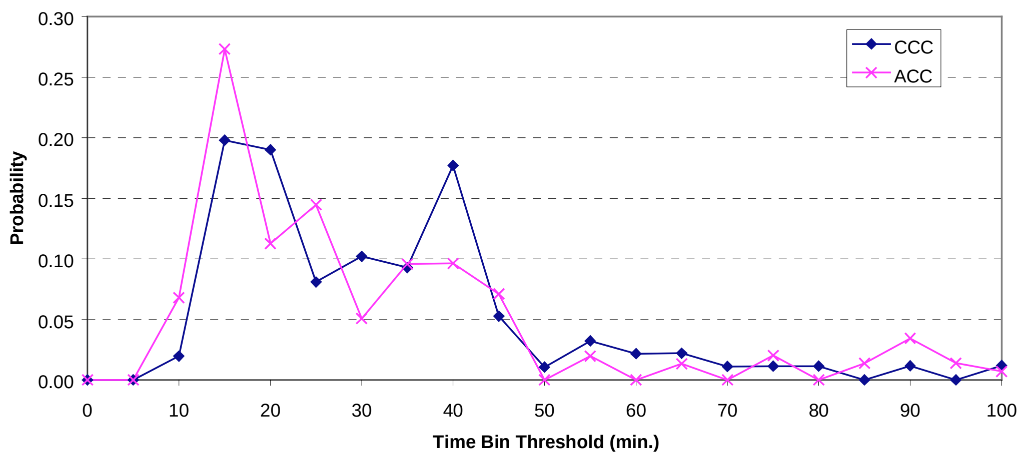

Figure 3- 8 Trip Time Distribution

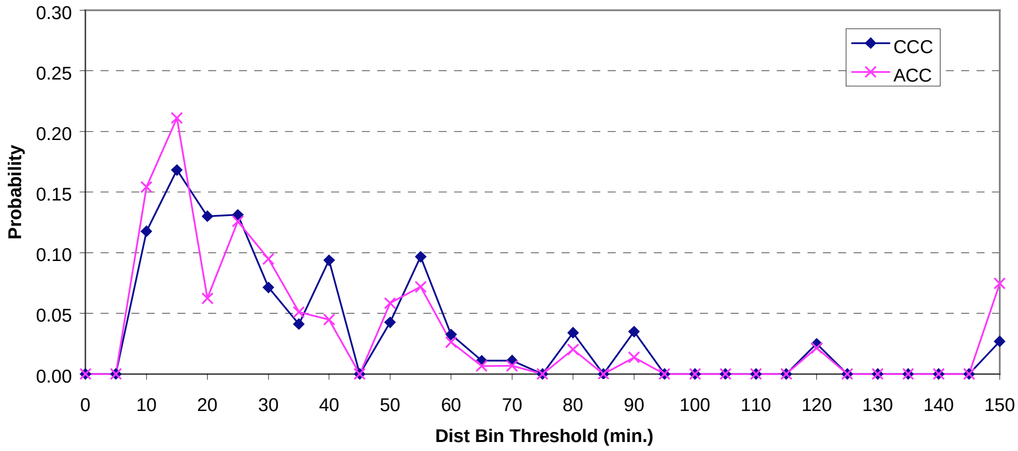

Figure 3- 9 Trip Length Distribution

Table 3- 3 Example Illustration of Similar Trip Sets

Set1	Driver	Trip	Time	Dist	Engage	ACCon	Set	Coast	Resume	Accel	Brake	Cancel	CCBi	CCNe	ICC Flag
25	43	5	15.100	8.400	0.350	1	2	2	1	4	29	0	0	2	0
25	43	9	12.300	8.300	0.190	1	1	1	1	1	24	0	1	0	0
25	43	13	12.800	8.400	0.260	1	1	1	0	1	27	0	0	0	0
25	43	17	23.100	8.600	0.020	1	1	1	0	0	51	0	1	0	0
25	43	23	10.000	8.200	0.470	1	2	3	3	4	22	0	2	2	0
25	43	33	12.800	8.300	0.190	1	1	1	0	0	20	0	1	0	1
25	43	39	13.700	8.300	0.480	1	1	1	1	3	27	0	0	1	1
25	43	48	11.600	8.200	0.640	1	1	1	3	3	18	0	0	0	1
25	43	54	16.000	8.300	0.230	3	2	2	0	3	32	0	0	0	1
25	43	62	15.300	8.400	0.360	1	1	1	0	0	28	0	1	0	1
4	9	12	38.200	54.800	0.610	1	1	1	1	1	20	0	0	1	0
4	9	38	36.700	54.700	0.800	1	1	3	0	1	13	0	0	0	0
4	9	42	35.500	54.700	0.410	1	1	0	1	1	13	0	0	0	0
4	9	49	36.700	54.700	0.860	1	1	1	3	11	14	0	1	0	1
4	9	54	35.600	54.700	0.860	3	3	7	3	12	18	0	2	6	1
4	9	58	35.300	54.700	0.790	1	1	1	0	2	15	0	0	1	1
4	9	84	34.200	54.700	0.760	2	2	3	0	3	19	0	0	0	1

Table 3- 4 Trip Summary Derived Parameters

Variable	Description	Units
TimeP	Travel time per kilometer	Minutes
RDist	Rank for variable Dist	N/A
AccOnP	Number of times the cruise control ON button was pressed per 100 kilometers	N/A
RaccOnP	Rank for variable AccOnP	N/A
SetP	Number of times the cruise control SET button was pressed per 100 kilometers	N/A
RsetP	Rank for variable SetP	N/A
CoastP	Number of times the cruise control COAST button was pressed per 100 kilometers	N/A
RcoastP	Rank for variable CoastP	N/A
ResumeP	Number of times the cruise control RESUME button was pressed per 100 kilometers	N/A
RresumeP	Rank for variable ResumeP	N/A
AccelP	Number of times the cruise control ACCEL button was pressed per 100 kilometers	N/A
RAccelP	Rank for variable AccelP	N/A
CancelP	Number of times the cruise control CANCEL button was pressed per 100 kilometers	N/A
RcancelP	Rank for variable CancelP	N/A
BrakeP	Number of times the brakes were pressed per 100 kilometers	N/A
CCBiP	Number of times a brake intervention was required per 100 kilometers	N/A
CCNeP	Number of times a near encounter was observed per 100 kilometers	N/A
R CCNeP	Rank for variable CCNeP	N/A

Table 3- 5 Variation in Derived Parameters across Similar Trip Sets by Type of Control

	Conventional Cruise Control			Intelligent Cruise Control		
	Avg.	Min.	Max.	Avg.	Min.	Max.
TimeP	1.1	0.6	3.1	1.0	0.6	1.9
ICConP	6.3	0.7	33.3	6.8	0.7	36.1
SetP	8.2	0.0	43.2	9.2	0.7	69.1
CoastP	16.3	0.0	119.4	15.3	0.0	141.8
ResumeP	5.9	0.0	47.6	6.9	0.0	67.5
AccelP	15.3	0.0	71.2	27.2	0.0	260.2
CancelP	2.0	0.0	33.3	1.6	0.0	15.2
BrakeP	144.9	20.9	593.0	120.4	19.0	385.5
CCBiP	3.8	0.0	24.4	5.8	0.0	27.5
CCNeP	2.5	0.0	24.4	2.6	0.0	21.6

3.3.2 Normalizing of Data

Crow and others (1960) indicate that

> "The data obtained from an experiment involving several levels of one or more factors are analyzed by the technique of analysis of variance. This technique enables us to break down the variance of the measured variable into the portions caused by the several factors, varied singly or in combination, and a portion caused by experimental error. More precisely, analysis of variance consists of (1) partitioning of the total sum of squares of deviations from the mean into two or more component sums of squares, each of which is associated with a particular factor or with experimental error, and (2) a parallel partitioning of the total number of degrees of freedom."

The assumptions of the analysis of variance (ANOVA) technique is that the dependent variable populations have the same variance and are normally distributed (Littell and others 1991). This section tests and ensures that the dependent variables were normally distributed.

As described earlier, many of the variables that were collected as part of the field operational test were counts of an action (i.e., frequency) during a particular drive.

For example, the number of times a driver "set" the cruise control from the beginning to the end of a 10 km trip. It is not surprising that someone driving a 100-km trip may press the cruise control SET button many more times than someone driving a 10-km trip. Consequently, in order to overcome this potential bias, trips were normalized using the relevant portion of the trip length. For example measures that were recorded for the entire trip were normalized using the entire trip length, while measures that were associated with cruise control usage were normalized with respect to the length of the trip during which the cruise control was activated. As shown in Table 3- 6, this normalizing of the data helped reduce the skewness of the data and increase the likelihood the data was normally distributed. The test for normality shown is the Shapiro-Wilk statistic, which produces a score ranging from 0 to 1. The closer the score is to 1, the more likely the data is normally distributed.

The distinction between normality and non-normality of data and what should be done in the case non-normality exists are two controversial issues. Some researchers, on the one hand, believe that the ANOVA technique is robust and can be used with data that do not conform to normality. On the other hand, other researchers believe that non-parametric techniques should be used whenever there is a question of normality. Research has shown that data that do not conform to normality due to skewness and/or outliers can cause an ANOVA to report more type 1 and type 2 errors (Ott, 1989). Conover (1980) recommends use of ANOVA on raw data and ranked data in experimental designs where no non-parametric test exists. The results from the two analyses are compared. If the results are nearly identical then the parametric test is valid. If the rank transformed analysis indicates substantially different results than the parametric test, then the ranked data analysis should be used. As a result, an approach using both an ANOVA on the normalized data and an ANOVA on rank-transformed data was adopted. Ranking of data was only conducted when the Shapiro-Wilk test was less than 0.85.

Figure 3-11 through Figure 3-13 illustrate graphically how the normalization and ranking of data can be utilized to achieve a normal distribution for the "Coast" variable. The normality test increased from 0.40 to 0.62 by normalizing the data with respect to the trip length (Coast versus CoastP). Ranking the CoastP data increased the normality test from 0.62 to 0.92 (CoastP versus RCoastP).

Table 3- 6 Descriptive and Normality Statistics for Dependent Variables

Variables	Mean	Std	Skewness	Kurtosis	W:Normal
Distance	34.66	33.22	2.11	4.31	0.71
Rank of Distance	133.50	76.92	0.00	-1.20	0.93
Engage	0.49	0.23	-0.23	-0.73	0.95
ICCOn	1.33	0.73	3.13	13.21	0.52
ICCOnP	6.64	5.08	1.80	6.25	0.86
Set	2.01	2.16	4.01	19.58	0.54
SetP	8.81	8.27	2.91	13.84	0.77
Rank of SetP	133.50	76.92	0.00	-1.2	0.93
Coast	4.31	9.32	6.94	60.43	0.40
CoastP	15.67	22.26	3.10	10.65	0.62
Rank of CoastP	133.50	76.92	0.00	-1.20	0.92
Resume	1.55	2.04	2.09	6.04	0.75
ResumeP	6.53	9.34	2.45	8.81	0.73
Rank of ResumeP	133.50	74.08	0.25	-1.45	0.82
Accel	5.47	9.80	5.70	43.25	0.51
Accelp	22.58	30.88	3.03	14.64	0.71
Rank of Accelp	133.5	76.69	0.03	-1.25	0.90
Brake	30.12	17.01	1.29	1.57	0.88
BrakeP	129.89	80.33	1.34	3.96	0.92
Cancel	0.49	1.22	3.44	13.64	0.48
CancelP	1.73	4.34	3.63	16.93	0.48
Rank of CancelP	133.5	55.58	1.45	0.2	0.53
CCBi	1.15	1.29	1.57	3.11	0.79
CCBiP	5.07	5.87	1.27	1.28	0.82
Rank of CCBiP	133.50	74.97	0.18	-1.42	0.84
CCNe	0.67	1.06	2.12	5.43	0.67
CCNeP	2.56	4.68	2.37	5.81	0.62
Rank of CCNeP	133.50	68.22	0.64	-1.32	0.70

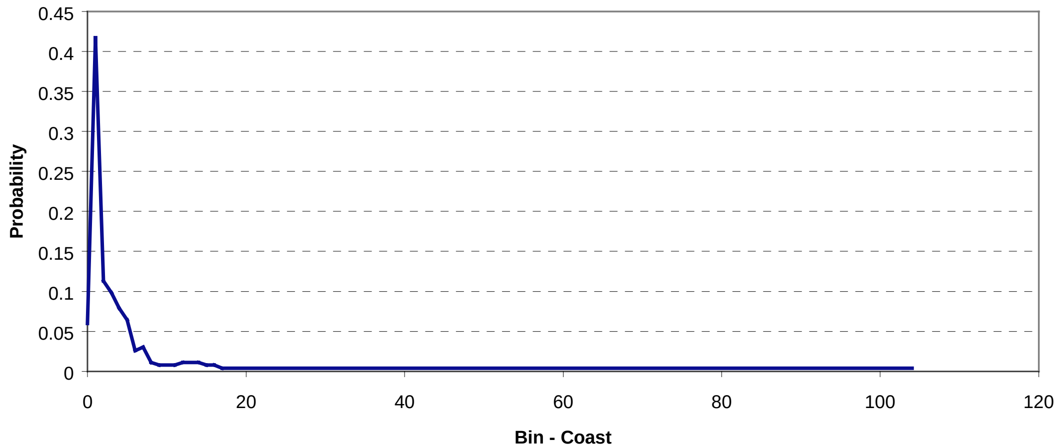

Figure 3- 10 Probability Distribution of Variable "Coast"

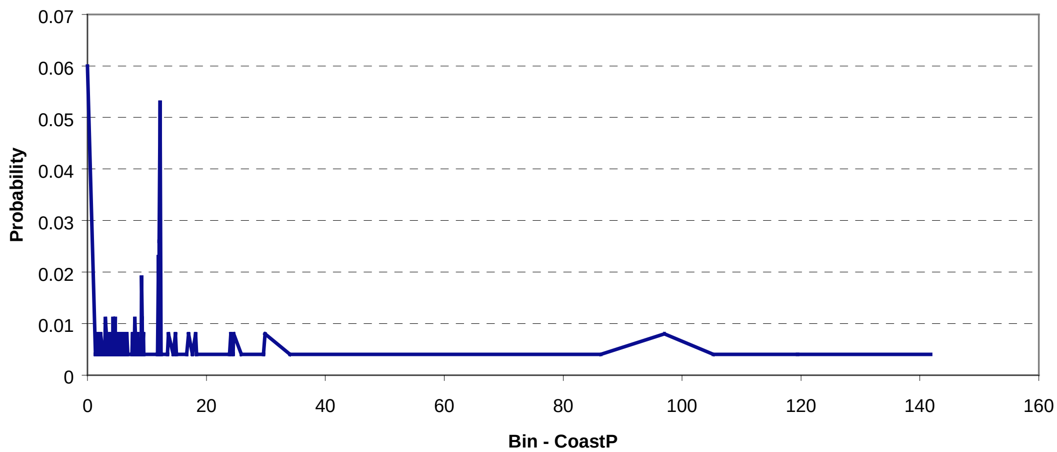

Figure 3- 11 Probability Distribution of Variable "CoastP"

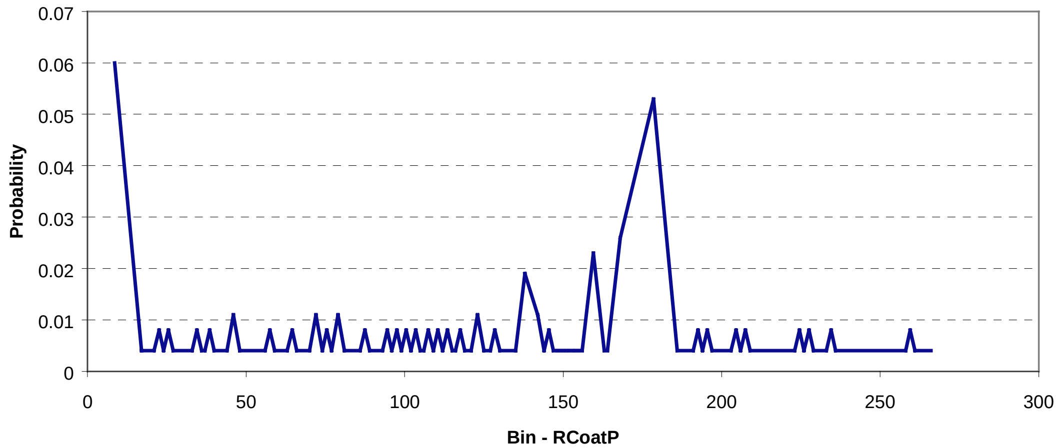

Figure 3- 12 Probability Distribution of Variable "RCoastP"

3.3.3 ANOVA Results

In order to conduct an analysis of variance (ANOVA) the number of observations for each factor must be equal. If they are not equal general linear models (GLM) can be utilized. The approach that was adopted in this study was to compute the mean measure for each set and ICCEnable combination in order to ensure that the number of observations were equal. Adding an "m" to the variable name denotes these mean variables (e.g. CoastP is denoted as MCoastP). Because it was not clear which variable explained more of the error ("set" or "driver"), a separate ANOVA was conducted using the "driver" variable as one of the factors in the ANOVA instead of the "set" variable. Although the "set" variable explained more of the error, the two ANOVA's produced identical findings, as will be discussed later.

The ANOVA's were also conducted on ranked dependent variables that scored less than 0.85 in the normality test. With few exceptions, both the parametric analyses and the non-parametric analyses reported similar findings. In all cases, the results for the parametric tests are reported and discussed. The non-parametric results will be discussed for the cases where they differ from the parametric analysis.

A two-way type of ANOVA was conducted on each variable using the similar trip set number (Variable = Set) and a flag indicating whether the trip was CCC or ICC (Variable = ICCEnbl) as the independent variables, as demonstrated in Table 3-7. The interaction of trip set and type of control (ICCEnbl×Trip) was computed separately in order to ensure that it was fine to evaluate the type of control across the different sets. Specifically, an insignificant interaction term means that it is possible to compare ICCEnbl averaged over all sets (Litell, 1991). Fortunately, in each of ANOVA's that were conducted the interaction term was insignificant.

This 60×2 factorial design was balanced with 60 observations (sets) for each type of control (ICC versus CCC). The primary reason for including "set" in the model was to partition variance due to the difference in like trip sets out of the error term and to increase the probability of finding a main effect for the type of cruise control (ICCEnbl). Although all the variables used in this analysis indicated a significant main effect for "set", the result is both unsurprising and uninteresting. As described earlier, the variable "set" could involve a different driver, a different origin, a different destination, and/or a different time-of-day for the trip. Noteworthy, is the fact that the "set" variable explained more of the error than did the driver variable as demonstrated by comparing the squared sum of errors (SS) explained by "set" (in Table 3-8) to that for "driver" (in Table 3-9). Because the findings for both ANOVA's are consistent, only the results for the "set" ANOVA are quoted (Table 3-8). The results of both analyses are presented in Appendices (B) and (C).

Table 3-8 demonstrates that the like trip set had a significant impact on the average trip length, however, there does not appear to be any statistical difference in the trip length between ICC and CCC. Consequently, there is no evidence that ICC resulted in a change in the routing behavior in such a way that the trip length was altered.

Figure 3-15 illustrates how the percentage distance during which the cruise control system was engaged varied within and across sets for CCC and ICC types of control.

One important thing to note is that the ICC type of control involved more usage than the CCC type of control. Specifically, CCC was utilized for 40 percent of the trip length on average while ICC was utilized 55 percent of the trip length on average, as demonstrated in Table 3-2.

Table 3-8 demonstrates that this observed difference was statistically significant (p=0.0001). It is not clear, at this point, if drivers used ICC more because they liked it more than CCC or due to the novelty of the system.

Given that drivers used ICC more than CCC, the next step was to investigate how different they used the two systems. The first test was to investigate if the ON button was used more. Figure 3-16 illustrates how the number of times the "ON" button was pressed per 100 kilometers. There appear to be more presses associated with ICC compared to CCC. Table 3-5 demonstrates a slightly higher usage of the "ON" button for ICC versus CCC control (6.8 versus 6.3 button presses/100 kilometers). However, the use of the ON button did not appear to be statistically different for CCC and ICC type of control, as demonstrated in Table 3-8.

Figure 3-17 through Figure 3-21 demonstrate how usage of the cruise control buttons varied within and across similar trip sets for CCC and ICC types of control. Table 3-5 demonstrates that the number of SET and RESUME button presses were slightly higher for ICC versus CCC type of control (9.2 versus 8.2 and 6.9 versus 5.9). In addition, the number of ACCEL button presses was much higher for the ICC versus CCC type of control (27.2 versus 15.3). The number of CANCEL button presses was lower for ICC versus CCC type of control (1.6 versus 2.0). The following sections will investigate if any of these observed differences are statistically significant.
As was the case with the ON button, the SET button was used more for ICC versus CCC (9.2 versus 8.2 times per 100 km), however, this difference was not statistically significant (p=0.4017), as demonstrated in Table 3-8.

Increasing the vehicle speed after it has been initially set, can be accomplished by pressing the ACCEL button and releasing it at the desired speed, tapping the ACCEL button to increase incrementally, or pressing the accelerator until obtaining the desired speed and repressing the SET button. There was no statistically significant difference in the use of the ACCEL button between ICC and CCC, as demonstrated in Table 3-8 (p=0.7974).

In order to decrease the originally set speed on the cruise control, drivers can either press the COAST button and release it when the desired speed has been obtained or deactivate the system and press the SET button when the desired speed has been obtained. The ANOVA did not show a significant effect for this variable, as demonstrated in Table 3-8. However, the ANOVA of ranks indicated that drivers were significantly more likely to use the COAST button when using conventional cruise control (p=0.0003). Since this main effect was not found for the non-ranked ANOVA, its significance should be interpreted cautiously. This finding is consistent with the function of the ICC system. Given that the ICC system reduces the vehicle speed when it closes in on an object this finding indicates that the system appeared to work as intended.

In order to deactivate the cruise control while keeping the set speed in memory, the driver has the choice to either tap the brake pedal or press the CANCEL button. The results indicate that although the CCC involved more usage of the CANCEL button compared to ICC (2.0 versus 1.6 presses per 100 km), this difference was not statistically significant (p=0.4979), as demonstrated in Table 3-8.

When drivers want to reactivate the cruise control after hitting the CANCEL button or touching the brake, all they need to do is to press the RESUME button. Given that the use of CANCEL button was not statistically different between CCC and ICC, it is not surprising that there was no significant difference in re-activating the cruise control (ICC = 6.9 and CCC = 5.9, p=0.2498).

Figure 3-22 and Table 3-5 illustrate how the use of brakes varied within and across similar trip sets for CCC and ICC types of control. Noteworthy, is the fact that drivers used their brakes more (BrakeP=144.9 versus 120.4 times per 100 km) for trips that involved CCC while they used their brakes less while the cruise control was activated (CCBiP=3.8 versus 5.8 brake interventions per 100 km) relative to ICC. However, both measures are statistically insignificant.

Finally, there was some concern that drivers of ICC would be more likely to be in an accident or a near miss type of situation than drivers using CCC. This analysis showed no significant difference (p=0.3483) for "near encounters" when using ICC (mean = 2.6) compared to CCC (mean = 2.5), as demonstrated in Table 3-8. A "near encounter" was defined as the use of a deceleration greater than 0.05g when the time headway was less than or equal to 0.3 seconds.

Table 3- 7 ANOVA Variables and Degrees of Freedom

Variable	Degrees of Freedom
ICCEnbl	1
Set	59
Error	59

Table 3- 8 ANOVA Results Using "Set" as a Factor

Variable	Like Trip Set		ICC Flag	
	Sum of Squares	Pr > F	Sum of Squares	Pr > F
Mdist	106712.442	0.0001	0.054	0.9180
MRDist	574071302	0.0001	71.281	0.4756
Mengage	3.778	0.0001	0.318	0.0001
MICCOnP	3954887.702	0.5576	5352.002	0.7825
MRICCOnP	557683.937	0.0001	7530.927	0.0201
MSetP	2944923.689	0.5384	36524.731	0.4017
MRSetP	480891.025	0.0001	5469.670	0.0746
McoastP	2962551.999	0.5268	71826.494	0.2406
MRCoastP	456095.609	0.0001	29306.685	0.0003
MresumP	72805.971	0.0267	1003.130	0.2498
MRResumP	381477.643	0.0002	2169.430	0.3583
MaccelP	290568.666	0.0001	79.234	0.7974
MRAccelP	461962.088	0.0001	779.547	0.4979
MCanclP	51485.210	0.0001	0.70426759	0.9615
MRCanclP	219899.207	0.0007	184.214	0.7350
MbrakeP	529514.232	0.0001	1511.507	0.2069
MCCBiP	23492.326	0.1143	250.415	0.3569
MCCNeP	1135152.577	0.5221	17445.193	0.3483
MRCCNeP	270363.391	0.0117	873.669	0.5584

Table 3- 9 ANOVA Results Using "Driver" as a Factor

Variable	Driver		ICC Flag	
	Sum of Squares	Pr > F	Sum of Squares	Pr > F
Mdist	55869.170	0.0001	5.676	0.5319
MRDist	295089.947	0.0001	19.578	0.5195
MEngage	2.108	0.0001	0.228	0.0001
MICCOnP	2901590.058	0.5364	39262.158	0.4963
MRICCOnP	326289.037	0.0001	4815.810	0.0273
MSetP	2663286.619	0.5171	72596.734	0.3319
MRSetP	280274.862	0.0001	1475.242	0.2900
McoastP	2666591.120	0.5027	119944.377	0.2119
MRCoastP	293562.442	0.0001	20393.956	0.0011
MresumP	54692.593	0.0849	287.694	0.5868
MRResumP	230145.834	0.0007	232.016	0.7430
MaccelP	190757.681	0.0001	895.205	0.3704
MRAccelP	239788.162	0.0001	1011.545	0.4327
MCanclP	49157.131	0.0005	99.468	0.6381
MRCanclP	139285.866	0.0016	97.251	0.7945
MbrakeP	288046.667	0.0001	593.177	0.4180
MCCBiP	8768.711	0.0186	8.146	0.7961
MCCNeP	70177.597	0.5507	1539.410	0.3901
MRCCNeP	150716.008	0.0019	212.433	0.7136

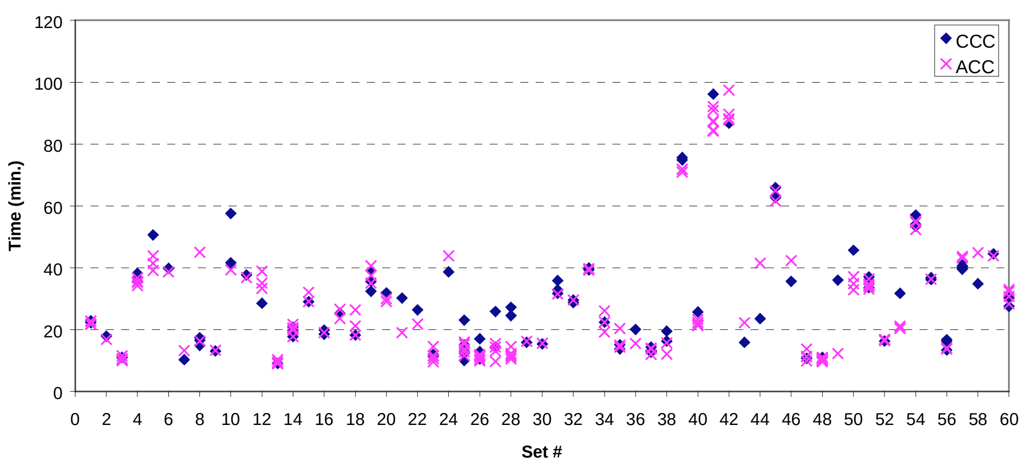

Figure 3- 13 Variation in Trip Time for Like Trip Sets

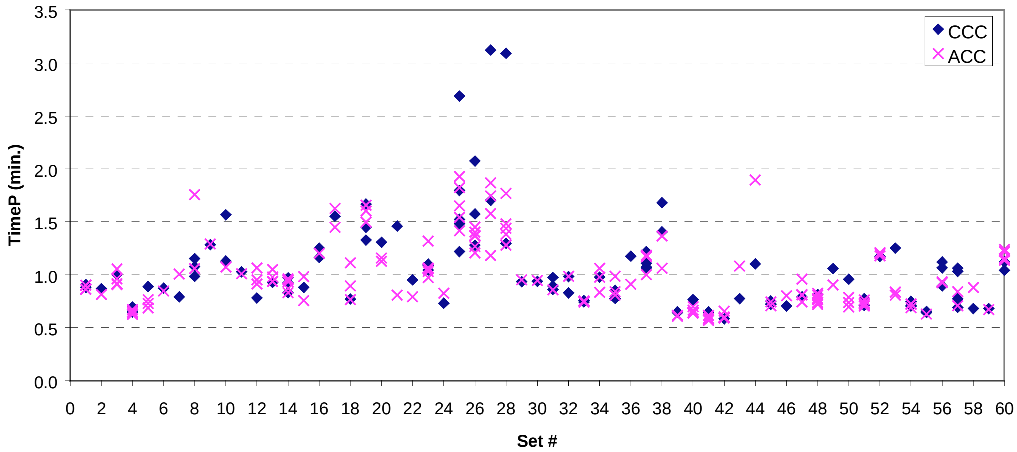

Figure 3- 14 Variation in "TimeP" as a Function of Set Number

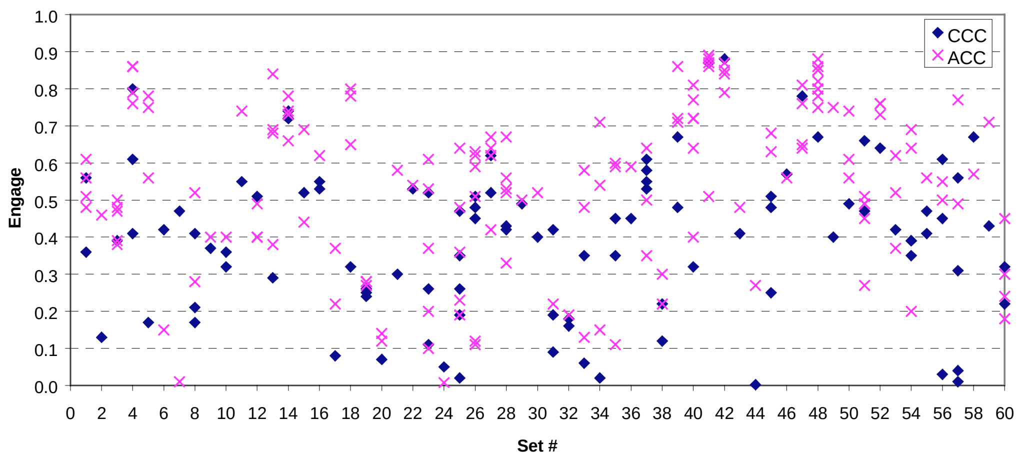

Figure 3- 15 Variation in "Engage" as a Function of Set Number

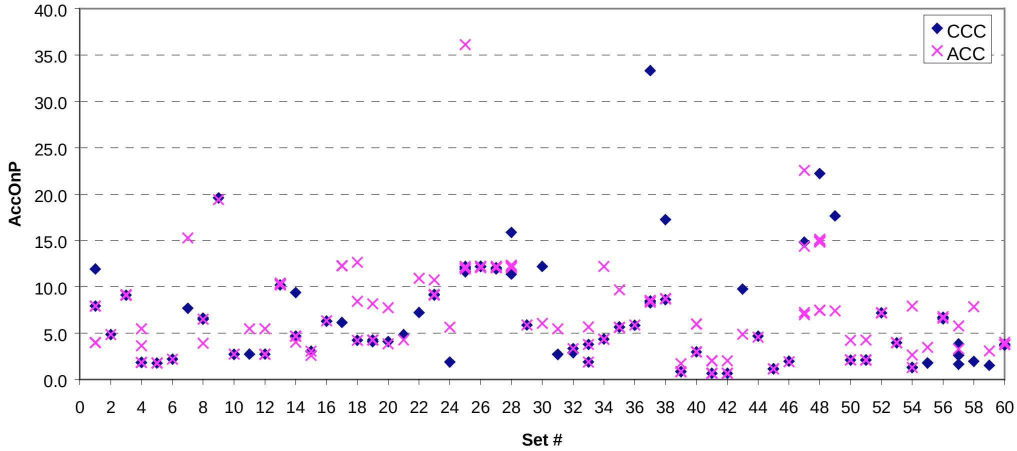

Figure 3- 16 Variation in "AccOnP" as a Function of Set Number

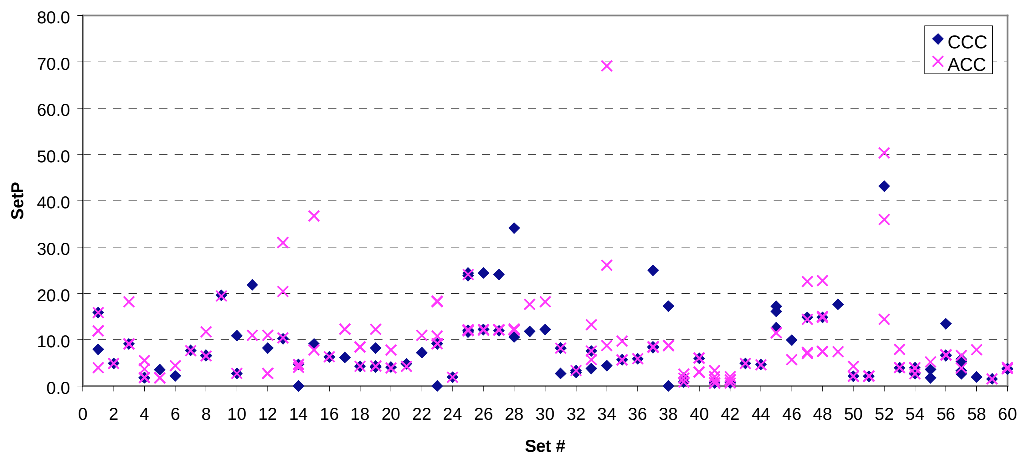

Figure 3- 17 Variation in "SetP" as a Function of Set Number

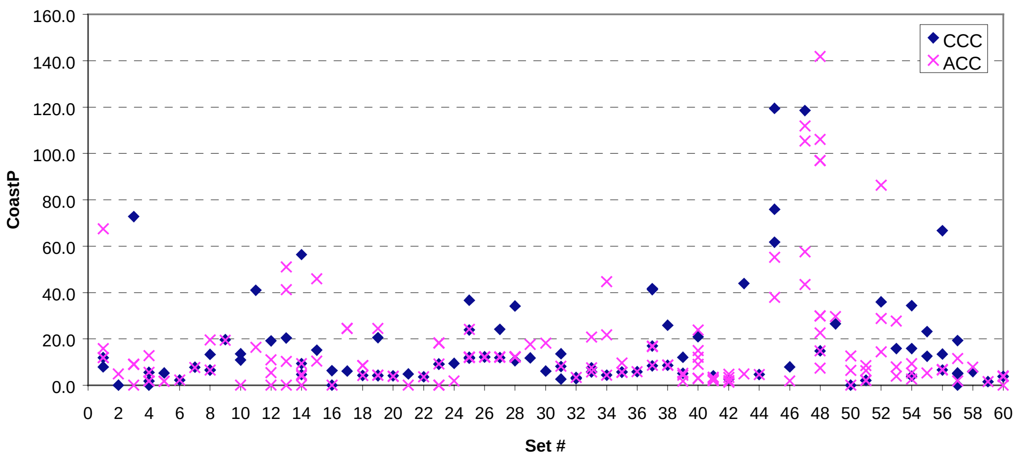

Figure 3- 18 Variation in "CoastP" as a Function of Set Number

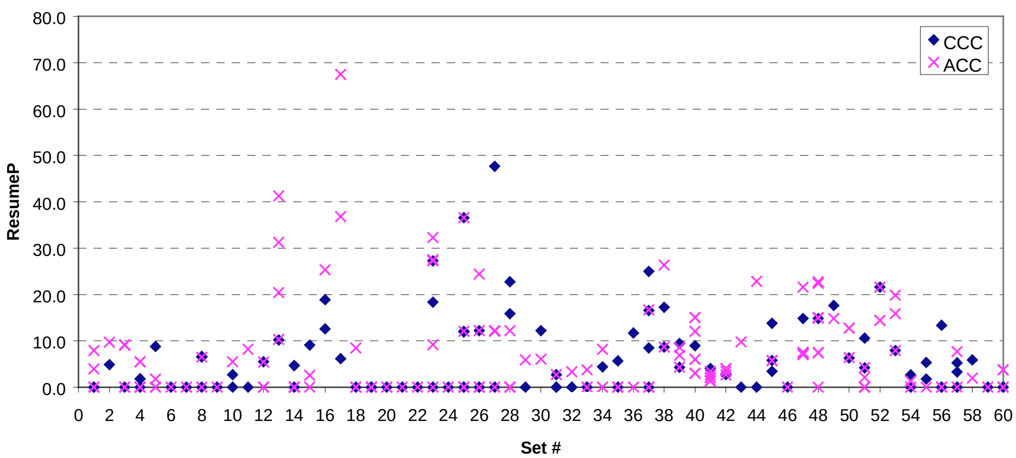

Figure 3- 19 Variation in "ResumeP" as a Function of Set Number

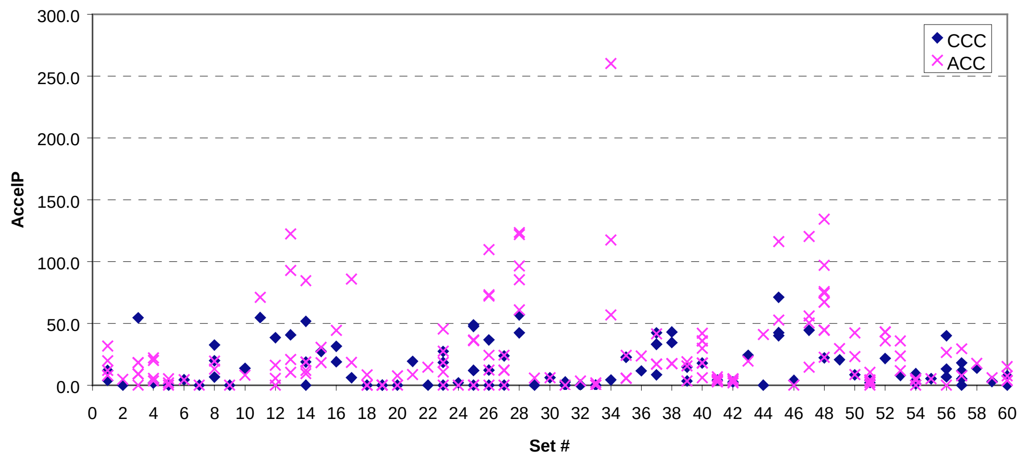

Figure 3- 20 Variation in "AccelP" as a Function of Set Number

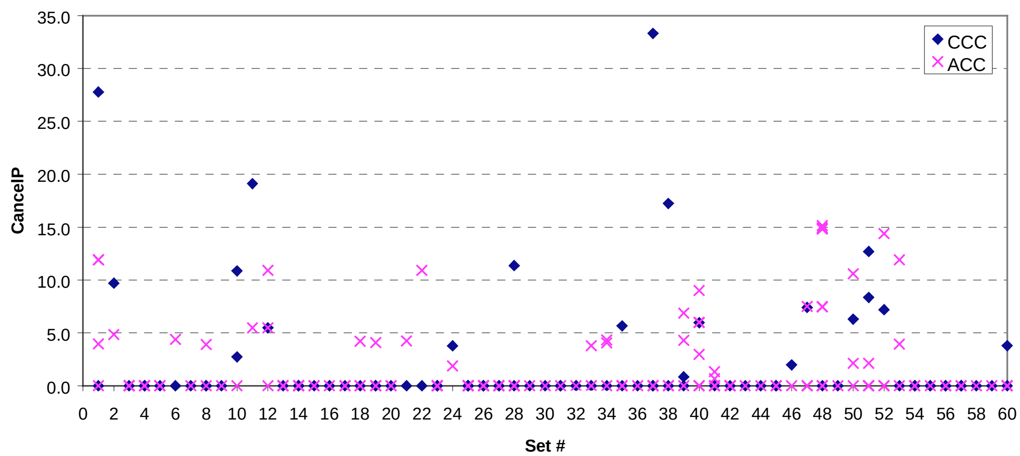

Figure 3- 21 Variation in "CancelP" as a Function of Set Number

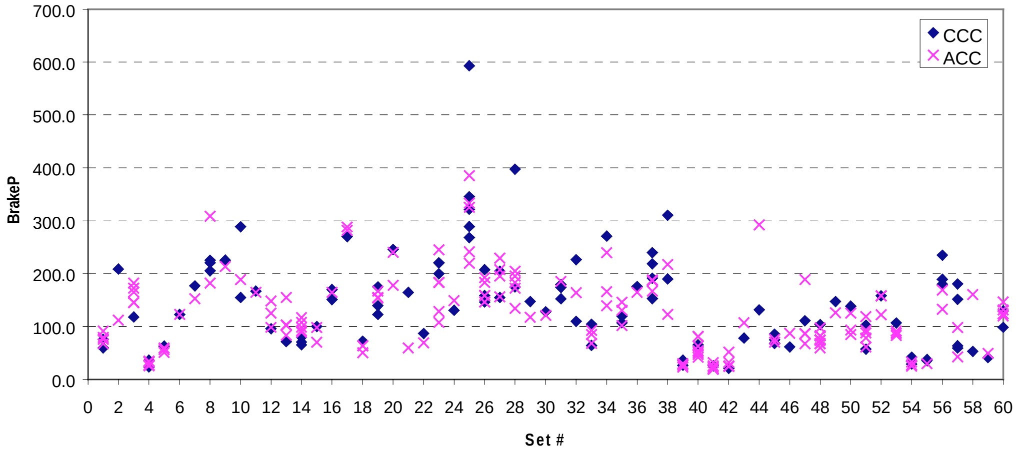

Figure 3- 22 Variation in "BrakeP" as a Function of Set Number

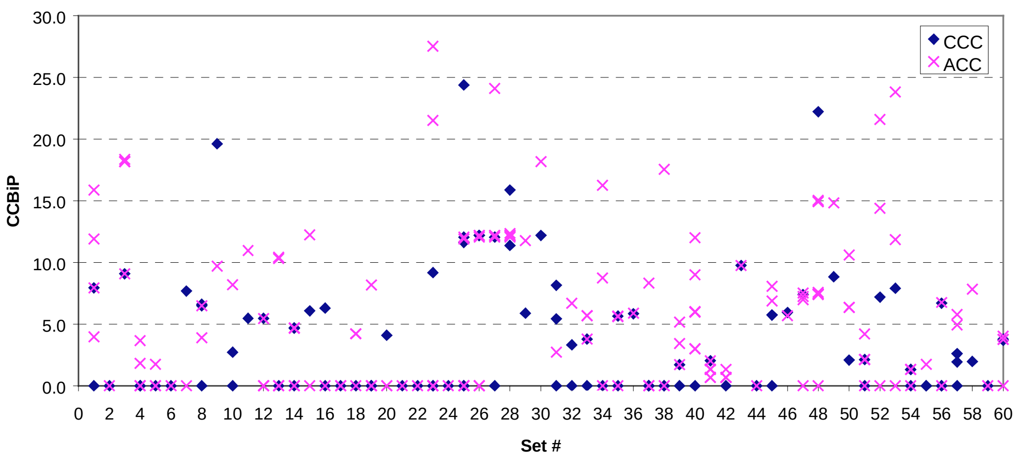

Figure 3- 23 Variation in "CCBiP" as a Function of Set Number

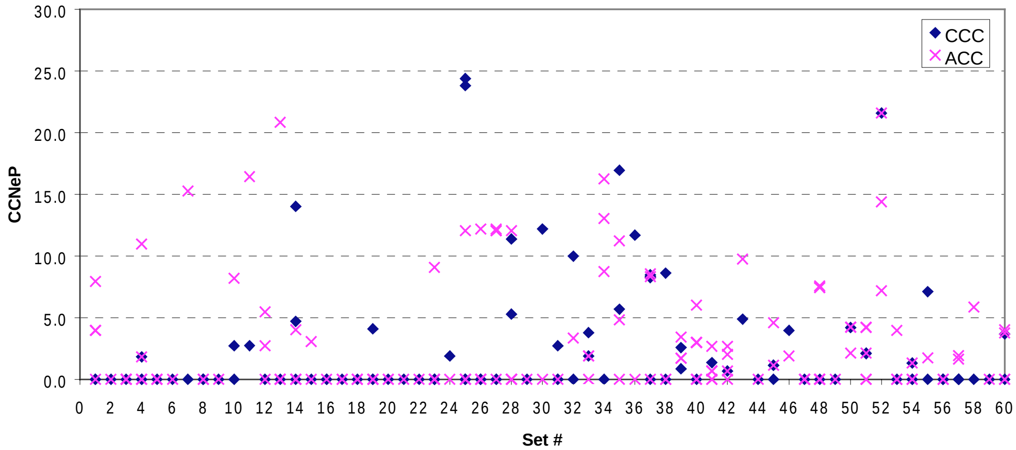

Figure 3- 24 Variation in "CCNeP" as a Function of Set Number

3.4 Conclusions and Recommendations

Based on the like trip analysis, the following conclusions were drawn:

1. Intelligent Cruise Control was utilized more along similar trips than conventional cruise control (55 versus 40 percent usage).
2. There was no difference in usage of the ON and SET buttons between ICC and CCC.
3. ICC resulted in a higher usage of the ACCEL button and a lower usage of the COAST button compared to CCC (ACCEL button used 27.2 versus 15.3 time per 100 km, while COAST button used 15.3 versus 16.3 times per 100 km).
4. There was no statistical difference in the use of the CANCEL and RESUME buttons between ICC and CCC.
5. The number of brake interventions while ICC was engaged was higher than CCC (5.8 versus 3.8 times per 100 km).
6. There was no difference in the number of near encounters for ICC and CCC.

The following are recommended:

1. Further analysis of similar trips conducted at the micro-level in order to isolate the effects of cruise control.
2. Further investigation for differences in car-following behavior between ICC and CCC.

The recommendations suggested above are addressed in the succeeding chapter.