Development of Human Factors Guidelines for Advanced Traveler Information Systems and Commercial Vehicle Operations: The Effects of Inaccurate Traffic Information on Driver Behavior and Acceptance of an Advanced In-Vehicle Traveler Information System

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Foreword

This report is one of a series reports produced as part of a contract designed to develop precise, detailed human factors design guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). The contractual effort consists of three phases: analytic, empirical, and integration. This report is a product of the empirical phase. The empirical phase will also address topics such as: ATIS function transition, display channels, multi–modality displays, CVO driver fatigue, display formats and workload, and head–up displays. Among the analytic topics discussed in the series are functional description of ATIS/CVO, comparable systems analysis, task analysis of ATIS/CVO functions, alternate systems analysis, identification and exploration of driver acceptance, and definition and prioritization of research studies.

This study is part of the empirical phase of this ATIS/CVO guidelines development effort and is one of a series of investigations designed to provide supporting rationale for the in–vehicle design guidelines. The research reported in this document investigated the effects of varying information accuracy regarding traffic conditions, in both familiar and unfamiliar traffic networks, on driver performance, use and acceptance of in–vehicle information systems.

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A. George Ostensen, Director
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The document type of resource materials. How reliable must traffic information be for motorists to trust and accept such advice? This study provides data to aid the designer of Advanced Traveler Information Systems (ATIS) in selecting an appropriate level of system accuracy. The Battelle Route Guidance Simulator was used to study: (1) the effects of information accuracy, and (2) familiarity of the driving environment on objective and subjective indices of driver performance and opinion. The simulator provided real-time information and traffic video. Information was either 100 percent, 71 percent, or 43 percent accurate. Drivers experienced either Seattle and its environs or an artificial setting that was topologically matched to Seattle. Results showed that while 100 percent accurate information yielded best driver performance and subjective opinion, information that was 71 percent accurate was still accepted and used. But information that was 43 percent accurate produced powerful decrements in performance and opinion. Simulated ATIS information was not used as effectively in the familiar Seattle setting. Driver trust decreased with inaccurate information but recovered, although not always fully, with subsequent accurate information.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ATIS Advanced Traveler Information Systems

ITS Intelligent Transportation Systems

RGS Route Guidance Simulator

T-SC Trust Minus Self-Confidence

EXECUTIVE SUMMARY

How reliable must traffic information be for motorists to trust and accept such advice? People are slow to accept and use new technology, even when the technology works reliably (Kantowitz, Becker, & Barlow, 1993). Can an in–vehicle Advanced Traveler Information System (ATIS) presenting real–time traffic information be commercially successful when some of the information it presents is incorrect?

A route guidance system is a driver decision aid that uses knowledge about a traffic network to provide advice that facilitates travel between an origin and a destination. There are many possible algorithms and heuristics to provide such support. A simple static algorithm may only calculate the path providing the shortest distance. More sophisticated heuristics might take travel times into account based upon historical data. The most powerful systems use real–time communication between the vehicle and a traffic information center to provide frequent updates on travel times and network bottlenecks. Route guidance systems can plot travel routings for the driver and some can update them if traffic conditions change or if the driver diverts from the plotted path. Thus, it is important for the system designer to be able to estimate the conditions that will maximize the probability that a driver will trust and follow ATIS suggestions.

The basic issue of the effects of traffic information reliability was first studied by Kantowitz, Kantowitz, and Hanowski (1994) using the Battelle Route Guidance Simulator (RGS), a part–task simulator that provides the driver with continuous real–time information and traffic reports. This is an improvement in methodology over earlier simulator studies that used discrete traffic images either projected from slides (Allen et al., 1991) or on a small computer (Bonsall, 1994). When traffic information was 100 percent accurate, drivers were able to reduce penalty costs associated with non–optimal route selection relative to an unreliable condition with 77 percent accurate information. However, drivers continued to use the simulated ATIS even when the system was unreliable. In this first experiment, a real existing traffic network, Seattle and its environs, was simulated. The present experiment extends and replicates these results by using three levels of information accuracy and two traffic networks.

The RGS was used to study: (1) the effects of information accuracy, and (2) familiarity of the driving environment. The simulator provided real–time traffic information and traffic video. Traffic information was either 100 percent, 71 percent, or 43 percent accurate. Drivers experienced either Seattle and its environs or an artificial setting that was topologically matched to Seattle. A total of 48 drivers was tested.

Three objective dependent variables were studied:

- Penalty cost—the amount charged drivers when they either encountered heavy traffic or selected a non–optimal route.
- Convergence—the agreement between the route selected and a baseline route drawn by the drivers prior to beginning their simulated journey.
- System query frequency—the number of times traffic information was requested.

Five subjective measures were studied:

- Trust—the degree of confidence the driver had with the system.
- Self–confidence––the degree of confidence the driver had on his own.
- Trust minus self–confidence—a measure that indicates acceptance of automation.
- Traffic expectations—what the driver expected traffic density to be on a link.
- Estimated link travel times—how long the driver thought it would take to complete a link.

Results showed for several dependent variables (e.g., penalty cost, trust, trust minus self–confidence) that while 100 percent accurate information yields best driver performance and subjective opinion, information that is 71 percent accurate remains acceptable and useful. Drivers are willing to tolerate some error in a simulated ATIS. However, when information accuracy drops to 43 percent, driver performance and opinion suffer. Thus, information accuracy above 71 percent is recommended to system designers. Future research is needed to evaluate information accuracy between 44 percent and 70 percent.

Drivers did not use simulated ATIS accurate information as effectively in the familiar setting as in the unfamiliar setting. Inaccurate traffic information was more harmful in the familiar setting. These results may imply that commercial success for in–vehicle ATIS will be easier to accomplish in unfamiliar settings, e.g., for use in rental vehicles for visitors, than in one's home city. Because drivers have greater self–confidence in familiar settings, they are more critical of ATIS advice and hold to a higher standard of user acceptability when they know the area geography. Thus, to achieve user acceptance, in–vehicle systems intended for purchase by a driver in a private passenger vehicle will likely have to meet higher standards than systems intended for commercial use.

Driver trust was decreased by inaccurate traffic information but recovered when accurate information was received. However, the more likely that information was inaccurate, the less the recovery. For the 43 percent accuracy condition, trust minus self–confidence became negative, implying that drivers would prefer their own solutions to those offered by the simulated ATIS device. So, although drivers do not demand perfect traffic information, high degrees of inaccuracy will cause drivers to ignore system advice, especially in familiar settings.

CHAPTER 1. INTRODUCTION

How reliable must traffic information be for motorists to trust and accept such advice? People are slow to accept and use new technology, even when the technology works reliably (Kantowitz, Becker, & Barlow, 1993). Can an in–vehicle Advanced Traveler Information System (ATIS) presenting real–time traffic information be commercially successful when some of the information it presents is incorrect?

Noise is inherent in most large systems and highway networks often suffer perturbations. Congestion, delays, and accidents can sometimes make traffic information provided to motorists unreliable when it is received inside the vehicle. Drivers may therefore discount, or even ignore, such information, just as alarm signals can fail to produce behavior intended by the system designer (Sorkin, 1988). In some domains, a single bad experience is sufficient to prevent people from using a machine or service. For example, few people continue to feed coins into a defective vending machine or parking meter. Empirical data are badly needed to help the highway engineer select a level of system reliability and accuracy that will maintain the driver's acceptance and use of route guidance information. The goal of this research is to provide data to aid the ATIS designer in designating an appropriate level of system reliability that will be accepted by drivers and help to achieve the goals of Intelligent Transportation Systems (ITS), e.g., reducing traffic congestion (IVHS America, 1992).

ROUTE GUIDANCE

A route guidance system is a driver decision aid that uses knowledge about a traffic network to provide advice that facilitates travel between an origin and a destination. There are many possible algorithms and heuristics to provide such support. A simple static algorithm may only calculate the path providing the shortest distance. More sophisticated heuristics might take travel times into account based upon historical data. The most powerful systems use real–time communication between the vehicle and a traffic information center to provide frequent updates on travel times and network bottlenecks. Route guidance systems can plot travel routings for the driver and some can update them if traffic conditions change or if the driver diverts from the plotted path. Thus, it is important for the system designer to be able to estimate the conditions that will maximize the probability that a driver will trust and follow ATIS suggestions.

Part–task simulators are an effective tool for studying how operators interact with large systems in general (Kantowitz, 1988) and route guidance systems in particular (Bonsall, 1994). Bonsall and Parry (1991) used a simulated artificial traffic network to investigate the quality of advice defined as the ratio of the minimum time to reach a destination by means of the advised route to the minimum time by any route. They found that user acceptance declined with decreasing quality of advice in an unfamiliar network. As familiarity with the network increased, drivers were less likely to accept advice from the system. However, Allen, et al., (1991) found that familiarity did not affect route choice behavior. These researchers used a real traffic network, as opposed to the artificial network created by Bonsall and Parry (1991). Allen et al. (1991) explained their results by speculating that perhaps both familiar and unfamiliar driver populations may have been more similar than intended in that all drivers may have been unfamiliar with the environs of the Garden Grove Freeway in southern California. Thus, these two experiments yielded conflicting results about the effects of familiarity on driver choice. Since a comparison of these two experiments confounds familiarity with real vs. artificial traffic networks, additional research is required. The present experiment compares a familiar real traffic network with an unfamiliar artificial network that has been carefully matched to the topography of the real network.

Furthermore, the independent variable of familiarity was not operationally defined identically in both experiments. For Bonsall and Parry (1991), familiarity referred to learning the artificial network through repeated trials. For Allen et al. (1991), familiarity referred to the driver's mental conception of an existing real traffic network prior to the experiment proper. The present experiment also examines effects of repetition using a balanced experimental design. This design permits evaluation of both familiarity in the sense of a driver's mental model of a locale as well as in the sense of learning through repeated trials.

The basic issue of the effects of traffic information reliability was first studied by Kantowitz, Kantowitz, and Hanowski (1994) using the Battelle Route Guidance Simulator (RGS), a part–task simulator that provides the driver with continuous real–time information and traffic reports. This is an improvement in methodology over earlier simulator studies that used discrete traffic images either projected from slides (Allen et al., 1991) or on a small computer (Bonsall, 1994). When traffic information was 100 percent accurate, drivers were able to reduce penalty costs associated with non–optimal route selection relative to an unreliable condition with 77 percent accurate information. However, drivers continued to use the simulated ATIS even when the system was unreliable. In this first experiment, a real existing traffic network, Seattle and its environs, was simulated. The present experiment extends and replicates these results by using three levels of information accuracy and two traffic networks.

TRUST

In a formal sense, the driver's decision about accepting the advice of an automated route guidance system is very similar to the dynamic allocation of function decision made by an operator controlling some industrial process (Kantowitz & Sorkin, 1987). In both cases, the system operator either lets the automation make the decision or manually makes the decision. The operator's subjective feelings about trust in the automated system play an important role in the dynamic allocation of function decision (Lee & Moray, 1991); indeed, a quantitative model of operator trust has been developed for process control. Additional research using this model (Lee & Moray, 1994) has shown that better predictions of operator behavior are made when subjective self–confidence is also taken into account. In general, when trust exceeds self–confidence, operators accept automated control. Conversely, when self–confidence exceeds trust, operators use manual control. The present study measures both operator trust and self–confidence to determine if these two factors are related to driver acceptance of traffic information. Several hypotheses may be formed using these subjective measures. For example, trust should decrease when ATIS reliability decreases. Furthermore, if self–confidence decreases in an unfamiliar setting while trust in the ATIS remains constant, drivers should be more willing to accept ATIS advice in the unfamiliar setting. Of course, since these subjective measures are correlational, inferences about causality must be made with great caution, if at all. It can be difficult to determine if operators make a decision because they trust the automation or if they trust the automation because they made a decision to use it.

CHAPTER 2. METHOD

SUBJECTS

Subjects were 24 males and 24 females, ranging from 18 to 35 years of age, recruited from the University of Washington and the surrounding community. Each was paid $5.00 per hour, plus a cash bonus. Prospective participants were administered a screening questionnaire by telephone to ensure that all had a driver's license, were familiar with driving in the Seattle area, and drove at least twice per week. To determine subjects' driving experience, data were collected on the following: years lived in Seattle (mean = 10.8), years driven in Seattle (mean = 4.8), total miles driven annually (mean = 9,219).

APPARATUS

Driver behavior was investigated using the RGS which consisted of two linked Intel 486 computer systems and two video displays (see figure 1). One monitor provided drivers with a real-time windshield view of the traffic scene from the driver's perspective. Additional information displayed on this monitor below the windshield included: (1) speed of the vehicle, (2) queried information (both written on the video screen and "spoken" by a DecTalk system), (3) other traffic information (always extraneous to the chosen route), (4) current time, (5) goal time, (6) bonus amount, and (7) current location (street location written on the screen). The second computer, equipped with a touch screen input device, displayed a computer-generated map of the traffic network. A moving dot indicated the current location of the simulated vehicle. Drivers used the touch screen to select route options from the displayed map and to query the system about the traffic congestion on any route segment ("link"). System queries for traffic congestion information could be done at any time and querying a link was required prior to traversing it. When a link was chosen, the appropriate video was displayed in real time on the first monitor.

Videotaped traffic scenes of the various routes from Westlake Center in downtown Seattle to Bellevue Square Mall were used for Seattle, the familiar network. The unfamiliar network, "New City," was created by combining video clips of streets and highways throughout Northwest Washington. The "New City" map was rotated 90 degrees in relation to the Seattle map. All video clips were digitized and stored on hard disk. The traffic network structures for both familiar and unfamiliar cities were identical (i.e., 31 links were used for each scenario, with each link varying in length from one to several streets). Thus, the topography was identical for both familiar and unfamiliar networks (see figures 2 and 3). Thirty-three different routes were possible on a variety of roads, including congested city streets, four-lane State roads, and Interstates in an urban setting. Completing a route required traversing seven links, regardless of the path chosen. The present methodology is an improvement over previous research (Kantowitz et al., 1994) where inaccurate information was path dependent on a trial by trial basis and hence not directly controlled by the experimenter. In this experiment, information accuracy was controlled independent of the path selected.

Figure 1. Battelle Route Guidance Simultor.

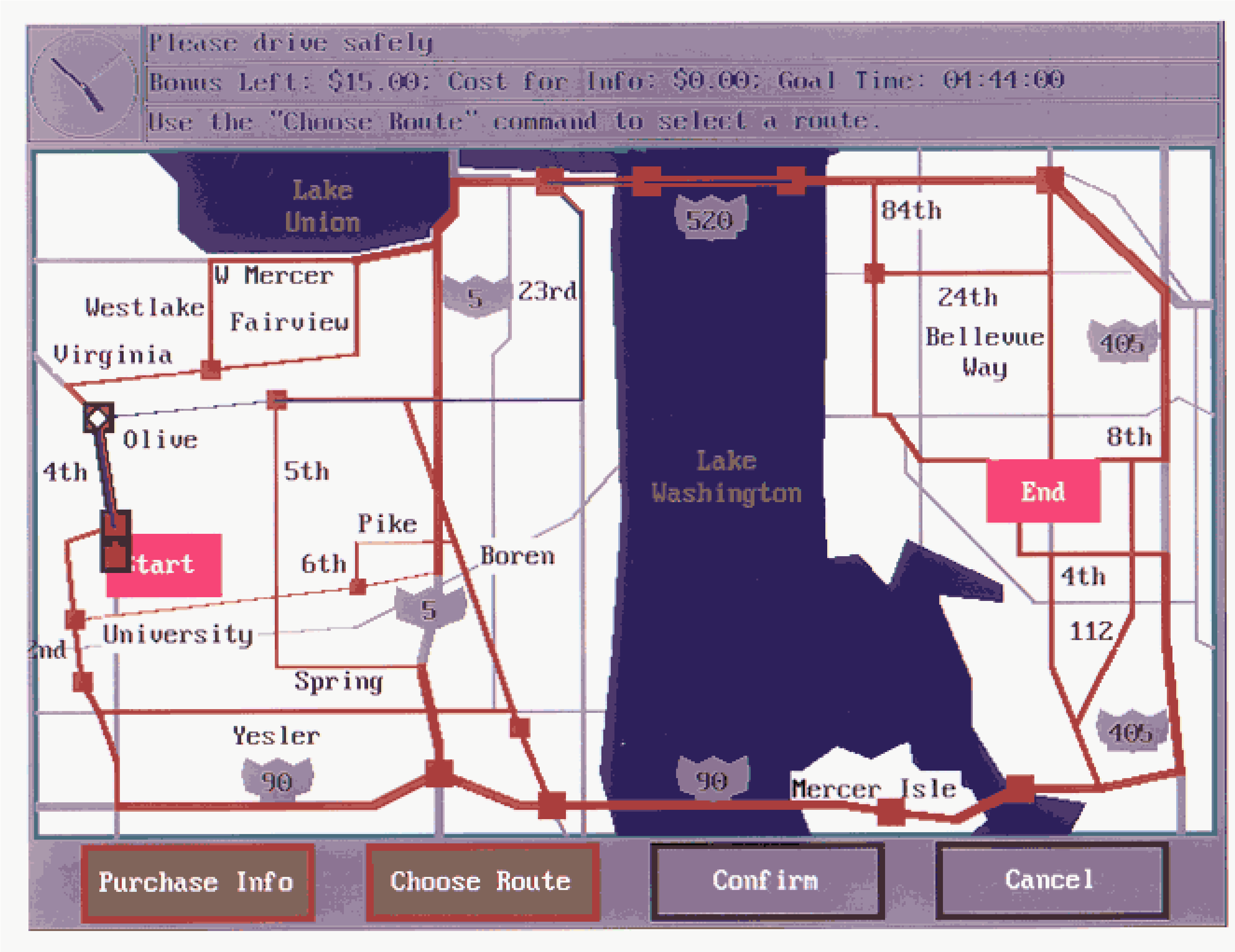

Figure 2a. Topography of familiar network

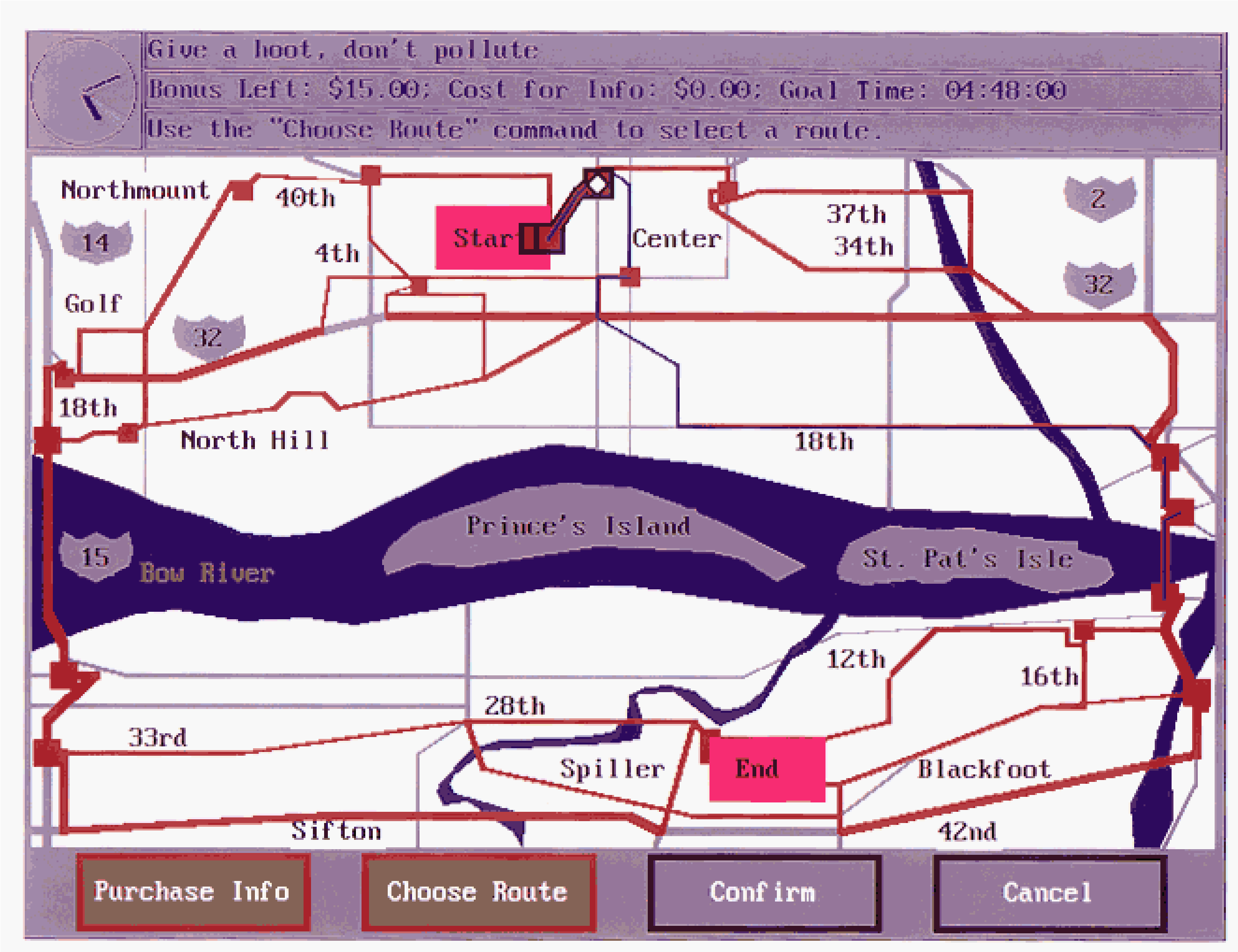

Figure 2b. Topography of unfamiliar network

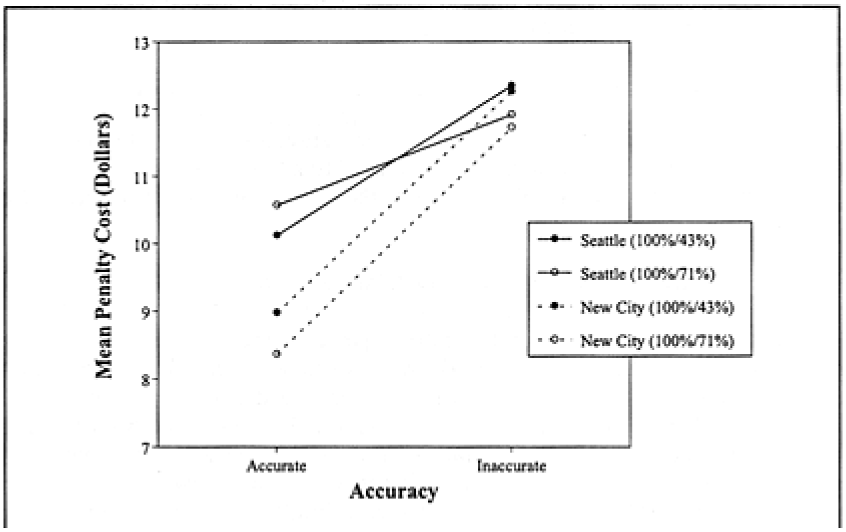

Figure 3. Mean penalty costs as a function of Accuracy.

Although most of the links had "light" traffic, several had "heavy" traffic as defined in terms of *level–of–service* (Transportation Research Board, 1992). Light traffic, *Level–of–Service* A, represents a free flow of traffic where individual drivers are unaffected by others present in the traffic stream. Heavy traffic is defined as *Level–of–Service E* or *Level–of–Service F*. *Level–of–Service E* occurs when operating conditions are at or near capacity level and all speeds are reduced to a low, relatively uniform value, and *Level–of–Service F* occurs when operations within a traffic queue are characterized by unstable stop–and–go traffic.

EXPERIMENTAL DESIGN

A balanced design was used with Order as a between–subjects variable. All subjects experienced four trials with information always being 100 percent accurate for the first two trials and inaccurate (either both trials 71 percent or both 43 percent) for Trials 3 and 4. Half of the subjects were tested on Order 1 (Seattle [F]–New City [U]–U–F) and half on Order 2 (U–F–F–U).

The two independent variables of major interest were traffic network familiarity and information accuracy. Network familiarity, a within–subject variable, had two levels: (1) Familiar (Seattle), and (2) Unfamiliar (New City). Information accuracy, a between–subjects variable, also had two levels: (1) 71 percent accurate, and (2) 43 percent accurate. In addition, all subjects experienced 100 percent accurate information for the first two simulated trips. Inaccurate information was either harmful, (e.g., traffic on link reported to be light, but was actually heavy) or harmless, (e.g., traffic was reported to be heavy, but was actually light). Table 1 shows the ordinal position of links for which inaccurate information was presented.

Table 1. Distribution of inaccurate link information for Trials 3 and 4.

Link Ordinal Position	Information Accuracy	
	71%	43%
1		
2	*	*
3		
4		*
5		*
6	*	*
7		

* Inaccurate Information Given

PROCEDURES

Drivers had an opportunity to practice using the simulator to become familiar with its operation, after which they began the first of the four trials. Prior to each trial, drivers marked on a paper map the route that they would normally take in the familiar city and the route they thought they might take in the unfamiliar city. Outlining their preferred route served to both orient the drivers to the traffic network and acted as a baseline for measuring convergence: the extent to which drivers followed their baseline route.

The driver's goal was to reach the destination as quickly as possible by choosing links with the least amount of traffic and shortest travel time. This combination of links represented the optimal route. Drivers began each of the four trials with a $15.00 potential "bonus." The bonus provided an incentive for drivers to use the ATIS. A penalty cost ranging from $.05 to $2.14 was assessed for each non–optimal link selected. This penalty cost was proportional to the time lost relative to the optimal path. An additional penalty cost equaling half of the remaining bonus was assessed for each heavy–traffic link encountered. Deductions from the bonus served to simulate the negative consequences associated with deviations from the optimal route and hitting heavy traffic.

To complete a route from origin to destination, drivers traversed seven links. Prior to traversing a link, drivers were required to query the ATIS for traffic congestion information for that link. The system would not allow drivers to traverse a link until congestion information pertaining to that link had been obtained. Drivers were not required to obtain a link's congestion information immediately preceding that link's selection. Rather, this information could be obtained at any time during the route as long as it was prior to traversing that link. Drivers were allowed to query the system for congestion information at any point during the route, and as often as desired. Unlike previous research (Kantowitz, et al., 1994), traffic information was provided without any monetary cost.

Drivers made their way from origin to destination by querying the system for traffic congestion information, selecting links, and watching the driving scene. In selecting links, drivers were not allowed to choose more than one link in advance of their current link. For example, drivers currently on the second link could select the third link, but not the fourth link. Link four could not be selected until the driver had completely traversed link two and had begun to traverse link three. It was believed that drivers would be more apt to recall the traffic congestion information pertaining to a given link if the time between obtaining the information and traversing the link was minimized. This aspect is important since questions pertaining to system trust, self–confidence, and expectations were given at the end of each link. Drivers responded to these questions by recalling the system's traffic congestion information for a link and comparing it to the traffic conditions they saw while traversing that link.

To help prevent unintentional link selections, drivers were required to confirm each link choice. A confirm button, located on the touch–screen, was pushed after a driver was satisfied with a link selection. Once a link had been selected and confirmed, the driver could not change his/her decision.

Subjective data were collected by questionnaires, administered prior to, and during, the course of the experiment. Prior to the experiment, individuals interested in participating were given a series of questions over the telephone to determine their eligibility. Only prospective participants who met the following criteria were allowed to participate: (1) had a valid driver's license, (2) were familiar with driving in Seattle, (3) drove at least once per week, and (4) had not driven in Calgary, Canada. The reason for the fourth criteria, had not driven in Calgary, was that the traffic network of the unfamiliar city was similar to that in Calgary. Suitable participants who met the four eligibility criteria were given a second telephone questionnaire to determine their driver demographic characteristics. Examples of the content of these questions included: (1) years lived in Seattle, (2) years driven in Seattle, and (3) number of miles driven annually.

During the course of the route, drivers were given brief inter–link questionnaires that consisted of four questions. These questions pertained to (1) trust, (2) self–confidence, and (3) traffic expectations when using the ATIS, and (4) estimated travel time. The three questions that pertained to trust, self–confidence, and traffic expectations were presented on scales ranging from 0 (Does Not Apply) to 100 (Strongly Applies). Drivers responded to the question about travel time by providing an estimate in minutes and seconds. The set of four questions was given to drivers upon completion of each link. In other words, questionnaires were administered between links (i.e., "inter–link"). Though not recorded, the time to complete a questionnaire was typically less than 10 seconds. Since there were seven links from origin to destination, and drivers had four trips, each driver answered a total of 28 inter–link questionnaires.

CHAPTER 3. RESULTS

OBJECTIVE VARIABLES

Three objective dependent variables are reported: penalty cost, convergence relative to the baseline route, and system query frequency. Figure 4 shows mean penalty costs were lower when traffic information was accurate, $F(1,44) = 108$, MS e= 2.89, $p < 0.001$. This result is consistent with previous research (Kantowitz, et al., 1994) and shows the greater benefit of using the simulated ATIS when it was accurate. Penalty costs were higher in the familiar Seattle network, $F(1,44) = 15.5$, MSe = 2.54, $p < 0.001$, suggesting that drivers were more likely to follow ATIS advice in an unfamiliar setting. When traffic information was 100 percent accurate, penalty costs were higher in the familiar setting ($10.34) than in the unfamiliar setting ($8.67), $t(44) = 4.02$, $p < 0.01$. The interaction shown in figure 4 between Accuracy and Familiarity while significant, $F(1,44) = 6.81$, MSe = 4.15, $p < 0.02$, is unimportant; the less rapid rise in cost for the familiar setting is probably a ceiling effect (Kantowitz, Roediger, & Elmes, 1994, p. 335) due to a maximum penalty of $13.00 on any one trial. Penalty costs were reduced on Trial 2 ($9.20) versus Trial 1 ($9.80), $t(44) = 2.34$, $p < 0.02$, showing that repetition allowed drivers to use the simulated ATIS more effectively.

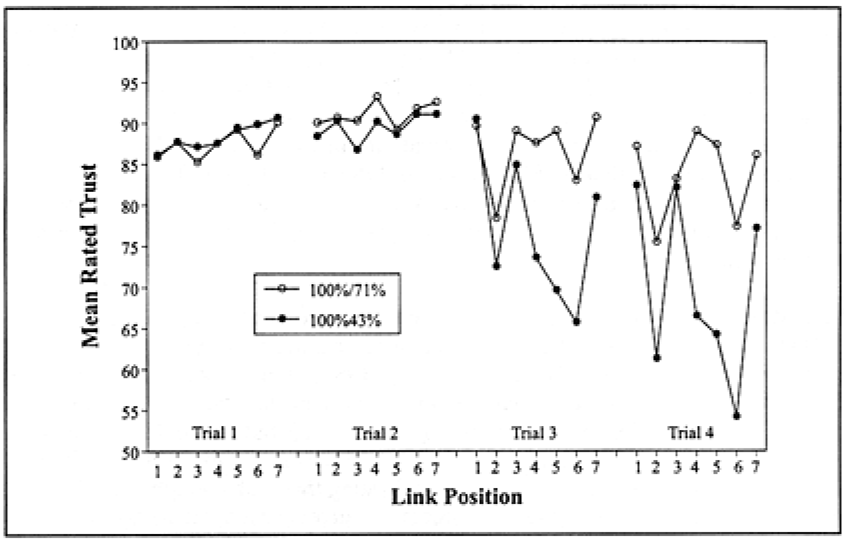

Figure 4. Mean rated interlink trust as a function of Information Accuracy and Link Position

The higher penalty costs for the familiar network cannot be explained by a lower frequency of queries. Query frequency did not differ between Seattle (32.3) and New City (29.8), $F(1,44) = 3.95$, MSe = 75.9, $p > 0.05$. Thus, although the same amount of traffic information was received in the familiar setting, it was not used effectively. Perhaps drivers rely more upon their internal mental representations of traffic density in a familiar setting and so tend to discount external information or possibly create a mental weighted average of old internal representation and new external information. However, more queries were made when information was Inaccurate (34.8) than when Accurate (27.3), $F(1,44) = 34.7$, MSe = 79.1, $p < 0.001$. This seems to be a reasonable strategy for drivers: when the world has greater uncertainty, drivers seek more information to resolve that uncertainty.

A convergence score of 100 percent indicates that a driver perfectly followed his or her preferred route marked on a paper map at the start of the experiment; a score of 0 percent indicates no common links between the paper map and the route chosen on the RGS. Convergence was higher when information was Accurate (64.6 percent) than when Inaccurate (47.5 percent), $F(1,44) = 11.8$, MSe = 1192, $p < 0.001$. This agrees with previous results (Kantowitz, et al., 1994), showing that drivers are less likely to diverge from preplanned routes when traffic information is accurate. However, a significant three–way interaction, Order X Accuracy X Familiarity, $F(1,44) = 9.03$, MSe = 811, $p < 0.005$, revealed the importance of the first city encountered on Trial 1. Drivers who started with New City had greater differences in Convergence between Accurate and Inaccurate conditions than did drivers who first encountered the Seattle map. These drivers in Order 1 had higher convergence scores for Accurate information, and lower scores for Inaccurate information, than did drivers first encountering New City. Convergence was lower on Trials 1 and 4 (but equal on Trials 2 and 3) for Seattle (48.2 percent) than for New City (66.7 percent). Since the topographies of Seattle and New City were identical, this interaction can be interpreted as consistent with the result that drivers exhibited greater self–confidence in familiar environs.

SUBJECTIVE MEASURES

Five subjective dependent variables were analyzed: trust, self–confidence, trust minus self–confidence (T–SC), traffic expectations, and estimated link travel times. All F–ratios involving the Link Position independent variable used the Greenhouse–Geiser correction for repeated measures.

Figure 5 shows mean rated trust as a function of Link Position and Information Accuracy. Trust was higher when information was accurate, $F(1,44) = 31.6$, MSe = 1031, $p < 0.001$. When information was inaccurate, trust was higher for the 71 percent condition than for the 43 percent condition, $F(1,44) = 5.02$, MSe = 2539, $p < 0.03$. While there was a significant effect of Link Position, $F(6, 264) = 11.9$, MSe = 240, $p < 0.001$, this effect was due to the inaccurate information on Trials 3 and 4 rather than the accurate information on the first two trials, $F(6,264) = 6.17$, MSe = 139, $p < 0.001$. When inaccurate information was presented, trust recovered on subsequent links when accurate information was presented. Figure 6 shows mean rated trust as a function of network familiarity and information accuracy. While there was no main effect of familiarity, $F(1,44) < 1.0$, the interaction shown in figure 6 reveals that 43 percent—accurate information decreases trust more than 71 percent—accurate information in both settings, $F(1,44) = 5.01$, MSe = 630, $p < 0.03$.

Trust did not differ according to type of inaccurate information: Harmless (71.3) versus Harmful (68.8), $t(1338) = 1.89$, $p > 0.05$. While this differs from earlier results (Kantowitz, et al., 1994), we believe the present results are more definitive. In the previous experiment, type of inaccurate information depended upon the path taken and was based upon a small number of observations. This experiment controlled the type of inaccurate information (table 1).

Rated self–confidence was higher in Familiar (76.6) versus Unfamiliar (71.7) settings, $F(1,44) = 6.92$, MSe = 1196, $p < 0.02$.

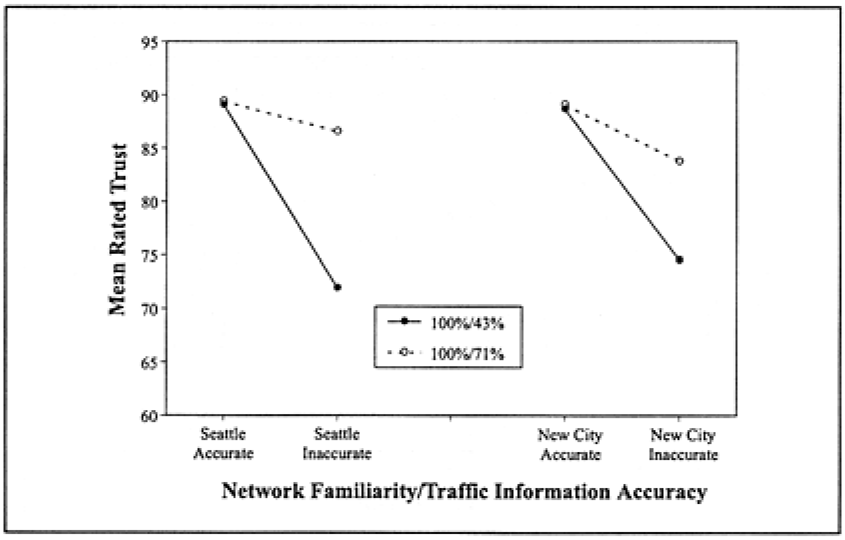

Figure 5. Mean rated trust in the RGS as a function of Accuracy-Group, Network Familiarity, and Traffic Information Accuracy.

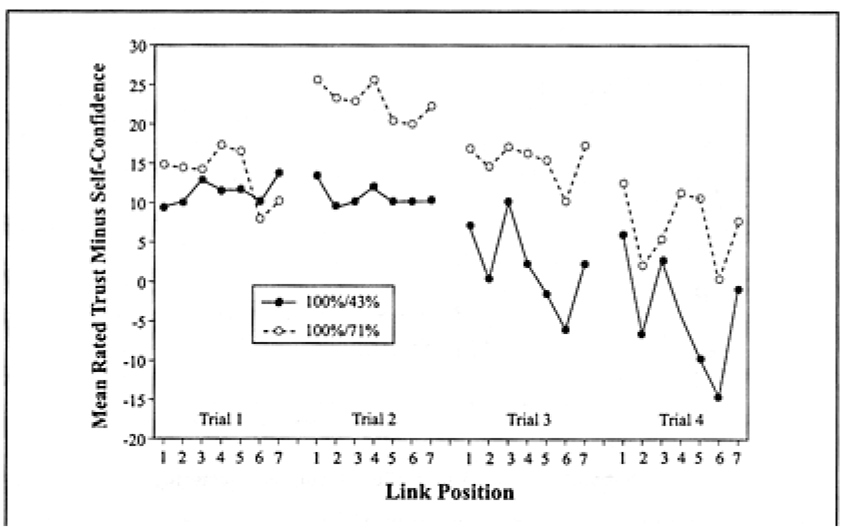

Figure 6. Mean Rated trust minus self-confidence as a function of Accuracy-Group and Link Position.

Figure 7 shows T–SC as a function of Link Position and Information Accuracy. Results are similar to those in figure 5. T–SC was higher when information was accurate, $F(1,44) = 26.6$, MSe = 1135, $p < 0.001$. When information was inaccurate, T–SC was higher for the 71 percent condition than for the 43 percent condition, $F(1,44) = 5.97$, MSe = 5209, $p < 0.02$. While there was a significant effect of link position, $F(6,264) = 11.2$, MSe = 196, $p < 0.001$, this effect was due to inaccurate information on Trials 3 and 4, $F(6,264) = 3.15$, MSe = 170, $p < 0.02$. Note that T–SC became negative on the last two trials for the 43 percent accuracy condition. Figure 8 shows T–SC as a function of network familiarity and information accuracy. Unlike figure 6, there was a main effect of familiarity, $F(1,44) = 6.10$, MSe = 1229, $p < 0.02$, with T–SC being higher for the unfamiliar setting. Also unlike figure 6, there was no interaction between variables, $F(1,44) < 1.0$. Note that T–SC becomes negative only for the familiar setting with inaccurate information.

In general, T–SC scores are not as well behaved as either of their two components considered in isolation. This is a well–documented problem with difference scores from empirical data (Cronbach & Furby, 1970; Bittner, Carter, & Kennedy, 1986). For example, the divergence on Trial 2 of the two Information Accuracy groups was unexpected and inconsistent with results for the Trust dependent variable in isolation (figure 5). Similarly, Trust for the 100 percent/71 percent group does not show the continuing decline over Trials found for T–SC. While it might be tempting to interpret this decline in figure 7 as indicating that with enough trials T–SC will eventually become negative even for the 100 percent/71 percent group, the decline of the T–SC scores could also reflect methodological issues associated with difference scores. Since any in–vehicle ATIS will provide the driver with far more than four trials, it would be prudent to replicate this experiment over several days to investigate a variety of learning and practice effects.

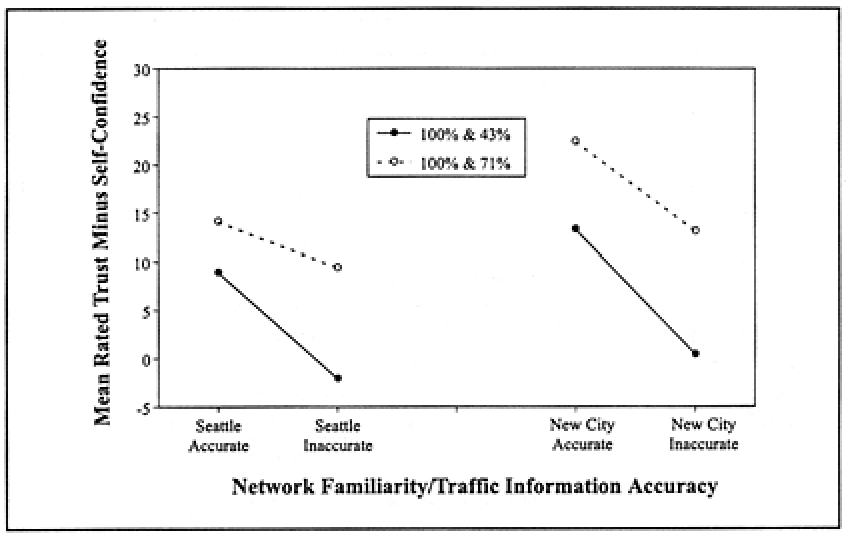

Figure 7. Trust minus self-confidence as a function of Accuracy-Group, Network Familiarity, and Traffic Information Accuracy.

Figure 8 shows rated traffic expectations as a function of information accuracy. Expectations were better met when information was accurate, $F(1,44) = 14.9$, MSe = 1037, $p < 0.001$. The interaction shown in figure 8 reveals that inaccurate information did not alter expectations when information was 71 percent accurate, but expectations were not met when information was only 43 percent accurate, $F(1,44) = 11.5$, MSe = 1037, $p < 0.001$. Mean estimated link travel time was greater for Familiar (2.50 minutes) versus Unfamiliar (2.20) settings, $F(1,44) = 19.6$, MSe = 1.7, $p < 0.001$. Accuracy of information did not influence estimated travel time, $F(1,44) < 1.0$.

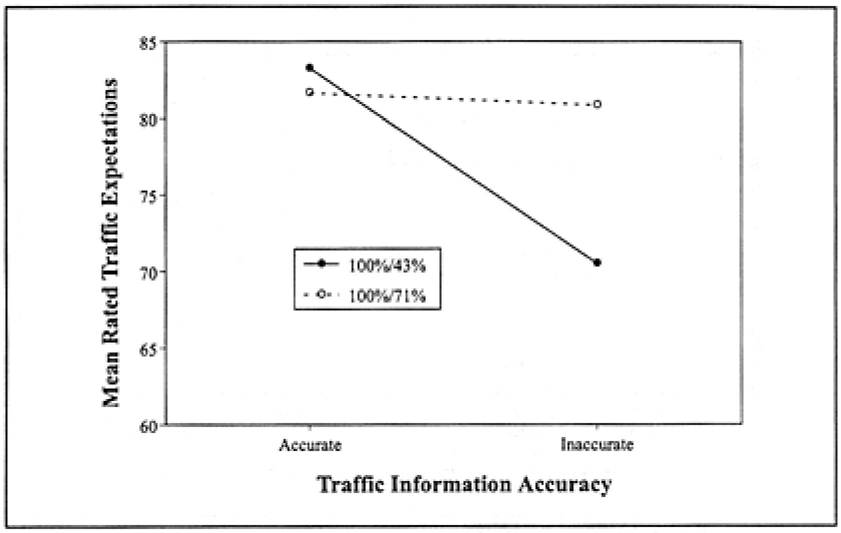

Figure 8. Mean rated expectations as a function of Accuracy-Group and Traffic Information Accuracy.

CHAPTER 4. DISCUSSION

The goal of this experiment was to provide an initial answer to two questions asked by ATIS designers:

(1) How reliable must traffic information be for motorists to trust and use it?

(2) How does the familiarity of the setting influence trust and use of unreliable traffic information?

Results showed for several dependent variables (e.g., penalty cost, trust, trust minus self–confidence) that while 100 percent accurate information yields best driver performance and subjective opinion, information that is 71 percent accurate remains acceptable and useful. Drivers are willing to tolerate some error in a simulated ATIS. However, when information accuracy drops to 43 percent, driver performance and opinion suffer. Thus, information accuracy above 71 percent is recommended to system designers. Future research is needed to evaluate information accuracy between 44 percent and 70 percent.

Drivers did not use simulated ATIS accurate information as effectively in the familiar setting as in the unfamiliar setting. Inaccurate traffic information was more harmful in the familiar setting. These results may imply that commercial success for in–vehicle ATIS will be easier to accomplish in unfamiliar settings, e.g., for use in rental vehicles for visitors, than in one's home city. Because drivers have greater self–confidence in familiar settings, they are more critical of ATIS advice and hold to a higher standard of user acceptability when they know the area geography. Thus, to achieve user acceptance, in–vehicle systems intended for purchase by a driver in a private passenger vehicle will likely have to meet higher standards than systems intended for commercial use.

Driver trust was decreased by inaccurate traffic information but recovered when accurate information was received. However, the more likely that information was inaccurate, the less the recovery. For the 43 percent accuracy condition, T–SC became negative, implying that drivers would prefer their own solutions to those offered by the simulated ATIS device. So, although drivers do not demand perfect traffic information, high degrees of inaccuracy will cause drivers to ignore system advice, especially in familiar settings.

It is interesting to compare present results with those of Bonsall and Parry (1991) and Allen et al. (1991) summarized in the Introduction. When familiarity is defined as knowledge of a local geography, we found that familiarity was harmful since penalty costs were higher; Allen et al. (1991) found no effect of familiarity. When familiarity is defined as learning over repeated trials, we found no decrement in driver trust over the first two repeated trials. However, penalty cost did decrease on the second trial. This conflicts with results of Bonsall and Parry who found drivers less likely to accept advice over repeated trials. Note that experiments using artificial networks to some extent necessarily confound familiarity with the traffic network and familiarity with the simulated ATIS device, since the network is learned by using the new device. While artificial networks can be useful microworlds for the ergonomics researcher, we believe that they are most useful when topographically matched to a real network as in this study.

Finally, we also note that this experiment manipulated information reliability in only one of several ways that might be meaningful to drivers. In this experiment, accuracy was based upon level of service. Drivers judged whether the actual level of service on a particular traffic link matched their expectations based upon information provided by the simulated ATIS. Other traffic dimensions may be equally salient for drivers. For example, Janssen and Van der Horst (1993) presented drivers in a simulator with length of congestion in kilometers, delays relative to normal travel times in minutes, and travel times in minutes. Reliability was manipulated by altering the variability of these estimates. They found that travel time information was most resistant to degradations in reliability. So the present results may not generalize to all of the possible formats and types of information traffic engineers can offer to drivers.

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