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Experiments in Strategic Level Driver Behavior

Steven E. Underwood

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College of Engineering/Transportation Research Institute
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IVHS Technical Report-90-7

UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE • (313) 936-1066
2901 Baxter Road, Ann Arbor, MI 48109-2150, and

COLLEGE OF ENGINEERING • (313) 764-4333
4112 EECS, Ann Arbor, MI 48109-2122

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Introduction

With the recent advances in communications and microelectronics technologies it may soon become both feasible and economical to transmit current and predicted traffic information to motorists to assist them in their driving tasks Advanced driver information and traffic management systems are being designed to monitor current traffic conditions and to transmit this information to equipped vehicles in real-time so that the drivers can select better routes to their destinations. These systems, such as image-based traffic detection systems, localcast radio systems, in-vehicle navigation systems, and route guidance systems, promise to assist motorists in making more efficient trips under most traffic conditions, including peak-hour congestion and traffic that is blocked by incidents or road maintenance.

A number of forces have combined to accelerate the development of motorist information technologies in industrialized countries and to consequently escalate the need for research into the impacts of these technologies on the road transportation systems. These include (1) the expectation of continued and worsening congestion, (2) the motorists' demand for relief from the stress, delay, and inconvenience caused by congestion and the increasing geographic dispersion of population growth, (3) the declining cost of electronic and communications technologies, (4) the recognition of the possible commercial potential of these systems, and (5) the efforts of industry to compete internationally in this new market for intelligent vehicle-highway systems (Underwood, 1990).

Foremost among the driving forces is the growing traffic congestion facing drivers in most major metropolitan areas. Traffic congestion, once considered to be isolated to the downtown areas of large cities, is becoming more pervasive. Personal vehicle travel is expected to grow 1.3% to 1.7% annually between 1988 and 2020; the automobile will almost certainly remain the dominant form of transport during this period (TRB, 1988). According to Lindley (1989), in 1987 there were over 2 billion vehicle-hours of delay on urban freeways in the United States alone, a 60% increase over the 1984 levels. If urban freeway travel continues to grow at a rate of 2.1 percent per year, there will be 11 billion vehicle-hours of delay in 2005, a 450% increase. Not only is congestion increasing, but the nature of traffic congestion is changing: (1) it has lost its directional bias, and is no longer only associated with routes radiating from central business districts; (2) it is no longer only confined to densely populated portions of metropolitan areas, as commuters redistribute themselves in response to delays; (3) in the most congested areas it has spread in time, so that "rush hour" has lost its meaning. According to recent surveys, traffic congestion is fast becoming the number one public concern among residents of large urban areas (ITE, 1986).

Another force behind the recent surge of activity in intelligent vehicle-highway systems is the continued revolution in microelectronics and communications technologies. Over thirty years have passed since the invention of the integrated circuit and engineers still see no end to the electronic marvels they can generate. The amount of circuitry that can be etched into silicon wafers, of which chips are made, now stands at an equivalence to 10 million transistors; by the year 2000, experts believe the number will surpass 1 billion transistors for the same size wafer. Today's chips perform electronic operations as fast as 4-billionths of a second; a decade from now, speed is likely to increase to one operation every 200-trillionths of a second. Miniaturization of the chip, accompanied by increased speed, has caused the cost of computing power to drop a thousandfold in the last two decades; a trend that is likely to continue or even to accelerate over the next decade. Consequently, the prospects for economical central management of traffic data and on-board computation of routes have never seemed more possible.

Accompanying this increase in computing power is a related decrease in the cost of processing and managing information. The automotive companies and their suppliers are quite aware of this trend and are packing their latest models with more and more computational power. As the company planners look into the future they can see that it will soon be technically feasible to place relatively affordable information systems on-board both commercial and privately-owned vehicles which will enable the motorist to access both static and dynamic information while en route. Public agencies, both at the federal and local levels, are also aware of this trend and envision a possible role for government as a processor and provider of current, real-time traffic information to this new generation of intelligent vehicles. Concerns about international competitiveness in this new niche has ignited research and development efforts in Europe, Japan, and North America.

The potential benefits from real-time motorist information seem obvious; travelers will obtain the most up-to-date traffic information and most efficient directions that technology the can provide. This should in turn result in a more efficient distribution of demand and improved system throughput within the constraints of the given infrastructure. Nevertheless, at this point it is difficult to say how drivers will respond to this real-time information from both an operational and a strategic perspective. From an operational perspective there are questions about the drivers' ability to assimilate this information and respond expeditiously. From a strategic perspective there are questions about changes in motorists trip decisions, including those concerning routes and departure times, and the resulting impact on traffic patterns over time. With the growing prospect of bringing real-time information to a large proportion of drivers, new questions have emerged concerning the impact of traffic information on the individual driver and the road transportation system as a whole. Will motorist information and route guidance indeed reduce travel times for the driver? Will it reduce congestion? What kind of savings can be expected, if any? Will the driver comply with route guidance information? How will the traffic respond to the new informed driver? It would greatly benefit public agencies and private entrepreneurs if these and other similar questions were addressed before embarking on large-scale implementation of these systems. Answers to these questions should provide a basis for more effective system design and marketing strategies as well as fundamental knowledge on the impact of real-time information of driver behavior.

This proposal is directed at addressing these strategic level concerns through simulation-based experimentation on drivers behavior. Laboratory experiments can provide a practical and relatively affordable approach to study the complex behavioral phenomena governing the dynamics of travelers' decisions and their impacts on transportation systems. Experimentation is especially appropriate for research on strategic driver behavior because the interdependence of the drivers' actions result in a game-like structure. When a driver makes a decision to take a specific route at a specific time his decisions are affected by, and in turn affect, similar decisions made by other prospective drivers. My trip may lead to congestion for you, and vice versa. This structure can be simulated to enable experimentation that otherwise would be infeasible in field studies.

Drivers have historically had comparatively few opportunities to engage in strategic level decision processes while in transit. Indeed, they might depart earlier or later, or they might plan a different route in light of expected traffic conditions. Yet they would be unlikely to modify their day-to-day travel patterns unless some drastic and well-publicized event was to take place prior to departure, for example, lane closure along a highway due to roadwork or a major civic event with related traffic impacts. In most cases when a traffic impeding incident would occur, the motorist would be unaware and fall victim to that incident. However, now with the prospect of providing increased real-time information to the driver prior to departure and while en route, there will be expanded opportunities for the drivers to reassess their routine travel and make adaptive modifications in real time. For example, they may heed a real-time warning of delays along their routine route and take a detour, or, if their vehicle is suitably equipped, they may follow a prescribed "optimal" route that has been computed in light of current traffic conditions. There is a large variety of possible in-vehicle traffic messages and there are perhaps even more behavioral responses to this information. As drivers options expand, so do the uncertainties regarding driver behavior. Without controled experimentation it is difficult to know how drivers will respond or to predict their behavior.

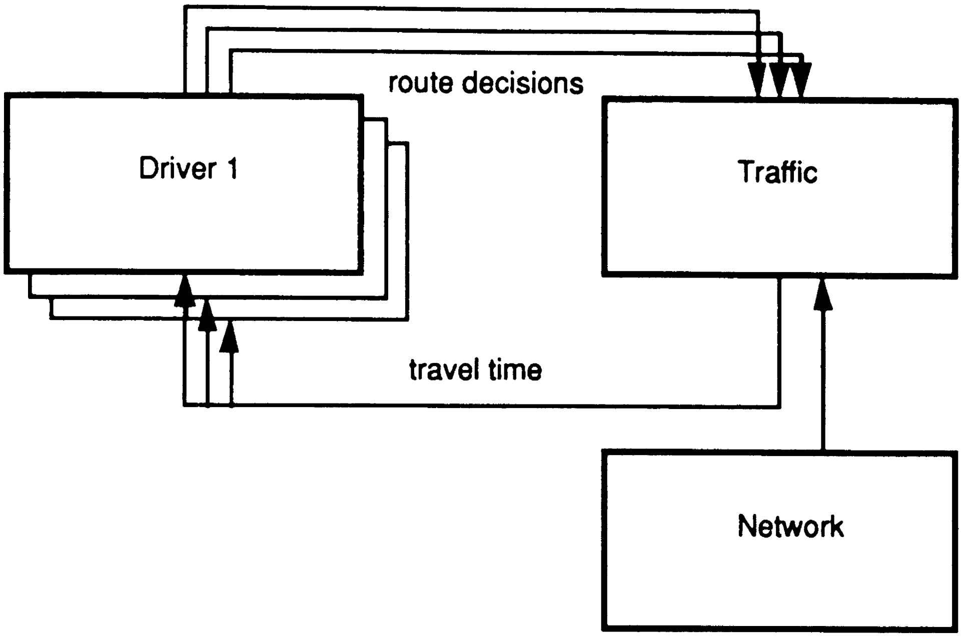
The research proposed here will specifically addresses *strategic* trip making considerations with an emphasis on individual route decisions and their impact on traffic. Strategic considerations are to be distinguished from the more conventional *operational* considerations like display formats, driver tasks, and driver information processing limitations, which are typically addressed in human factors researcher. Table 1 presents a range of strategic and operational considerations which can serve to clarify this distinction. The table is suggestive and does not pretend to be a comprehensive listing of these considerations.

Table 1. Strategic and Operational Considerations in Travel Behavior

Strategic	**Operational**
Canceling the trip	Response times
Linking trips (multiple destinations)	Visibility of in-vehicle displays
Mode of travel	Visibility of traffic signals
Time of departure	Driver workload
Route to destination	Design of controls
Stopping for fuel	Driver skills and proficiency
Speed of travel (aggressiveness)	Malfunctions and reliability
Compliance with traffic regulations	Aesthetics
Compliance with electronic guidance	
Parking location	

Of central concern is the relationships between selected forms of motorist information, the drivers' use of this information, the resulting impact on traffic flows, and the feedback effect on the drivers' behavior. A crucial aspect of this day-to-day route selection process is impact of the individual route selection on collective traffic conditions and the possibility of instability in repeated decision cycles. That is, the route selection process may be seen as a repeated game where every driver is attempting to outsmart the other drivers through their route selection strategy in order to minimize their travel times. It is quite possible that real-time information provided to the drivers may lead to instability in the drivers' individual choices and disequilibrium in the system as a whole. For example, number of people have reported to me that when they hear a broadcast about a traffic jam on a particular stretch of highway they head directly for it, assuming that the other drivers will avoid the area and the roadway will be clear. These drivers have recognized the instability and have employed a counter strategy that may work so long as most drivers continue to heed drivers advisories. The success of a driver's strategy is dependent on the strategies that the other drivers employ. This type of interdependence is depicted in Figure 1 which shows that drivers route decisions, for example, generate a set of traffic conditions, which in turn determines their travel times; each driver's travel times are determined by their own route and the routes selected by the other drivers. Decisions about departure times, mode of travel, parking, and other strategic level decisions exhibit a similar form of interdependence. Given more information and a larger variety of broadcast technologies that may be presented in a range of formats, chances are the driver will have more opportunity for choices and will encounter dilemmas of this nature more often.

Figure 1. Interdependence of Drivers Route Decisions



Research questions

How will drivers and traffic respond to up-to-the-minute traffic information? Limited field tests of advanced driver information systems are being planned for a number of large metropolitan areas around the world. Yet there is little more than speculation as to how these systems will alter driver behavior. Furthermore, it is unlikely that field experimentation will provide much insight into these strategic-level concerns. In particular, field experiments are generally limited to a small number of vehicles at specific test sites (e.g., Pathfinder, TRAVTEK, LISB, Autoguide, AMTICS, RACS), so the impact of the test system on traffic is likely to be negligible. An example of this type of research is the before-and-after evaluation of the INFORM system on Long Island (FHWA). Without having an significant impact on traffic it will be difficult to see the way the interdependent decision processes play out. Moreover, as with most single-time, single-site evaluations it will be difficult to generalize from the results in this study which pertain to a specific form of information that is provided in a specific environment.

Some rudimentary analyses has been conducted to examine the general bounds of the expected impacts, but these have been based on crude assumptions regarding market penetration and drivers' actual response to the proposed systems (Tsuji, et al, 1985; Jones, et al, 1989; Smith & Russam, 1989). More detailed simulation studies have been conducted to determine the impact of route guidance, but these still make mechanistic assumptions regarding driver behavior (e.g., Rakha, et al., 1989;)

Standard simulations and even the more advanced ones take the cognitive element out of the system. Most descriptive traffic models assume that drivers have perfect, though static, information about traffic conditions along alternative routes. Moreover, they assume that drivers minimize travel time by selecting the shortest route. They do not allow for differences in drivers access to information, preferences for route attributes, familiarity with the road system, propensity to comply with instructions, and other attributes that may lead to non-optimal assignment of traffic. Only recently have any models provided for the driver's incremental assessment of traffic conditions to enable revision of routes while in transit. In particular, the most advanced models have the capability of routing vehicles or "packets" of vehicles for improved estimates of traffic flow over user-specified increments of time (Taylor, 1990; Van Aerde & Yagar, 1988). While such models may be sufficient for planning large-scale capital improvements and traffic control operations or estimating improvements from driver information systems, they do not capture the nuances of strategic level driver behavior which may govern individual and collective response to real-time traffic information. They simply do not account for the drivers' decision making processes.

The ability to accurately describe the dynamics of traffic will become more important as real-time traffic information systems evolve toward anticipatory information systems. An effective model-based approach to traffic forecasting will demand a better understanding of drivers' cognitive biases and how they effect drivers' route decisions and drivers' response to traffic information. In anticipation of this need, empirical research is required to describe (1) drivers' individual route decisions and their possible incongruity with optimal choice in a dynamic network setting, (2) the strategic interaction between individual and collective route choices in response to real-time information on traffic conditions, and (3) drivers' propensity to comply with real-time information provided by alternative forms of route guidance systems.

Mahmassani and his colleagues at the University of Texas at Austin have employed experimental traffic simulations to investigate the behavioral mechanisms that might provide an explanation of the variability of departure time and route switching decisions and the interaction between them (Mahmassani & Herman, 1990). Their experiments provided the subjects with either one or two routes to select from and the experimenters varied the amount of information the subjects received before they departed on their trips. The drivers were not given further information while en route to their destinations nor were they allowed to change routes in light of current traffic conditions en route. The authors concluded that there indeed was an interrelationship between route switching and departure time switching decisions. They also noted that the subjects learned to adapt to the prevailing congestion levels by increasing the amount of schedule delay that they would tolerate. The groups with full information had significantly better results in terms of travel time and schedule delay than those with limited information.

In light of Mahmassani's results there are further questions regarding drivers use of information acquired during the trip as opposed to before the trip and alternative types of information that may be provided to the drivers. The type and frequency of information transmitted to the driver provide a wide range of independent variables in this line of research. *Alternative forms of motorist information* might include reports on link times, congested areas, expected delays, recommended routes, recommended links, etc., on driver behavior and traffic. *Types of travel time information* might include historical, current, free speed, and predicted travel times. This information may be transmitted at varying intervals with different effects. Other key independent variables and assumptions that may be considered are listed in appendix 1.

A matrix of treatment conditions can be constructed on the basis of the above questions. This is just another way of stating the questions and looking at the relationships between the questions. The matrix presents the juxtaposition of two information attributes:

1. Type of information presented during the trip:
    - Recommended user-optimal route over the entire network
    - Recommended next link(s), based on user optimal computation,
    - No recommendations
2. Data for route prescriptions:
    - Current travel times
    - Historical travel times
    - Predicted travel times
    - Unloaded travel times (free speeds)

Each box in the matrix is a separate treatment condition. There are then two questions that can be asked about the matrix. Where are the significant differences in outcome measures among these treatment conditions? How can these differences be explained?

Table 2. Information conditions

	Link times	Recommended route	Recommended link
No information	---	---	---
Current travel times			
Historical travel times			
Unloaded travel times			

In addition to these theoretical questions a number of applied question may also be answered by this approach. For example, how sensitive is the drivers' route choice decisions to small variations in trip times? Although this is more of an operational question, researchers may also be interested in the impact of changes in the information format on route choice and the resulting traffic flow.

Appendix 2 has a listing of other controls and independent measures that might be considered. Route guidance updates will be made on a link-by-link basis. Driver feedback at the end of the trip will include total travel time for the trip and how well this compares with other drivers traveling between the same origin and destination.

Dependent measures may include: route characteristics, travel times, compliance with prescriptions, convergence over repeated trials, and driver satisfaction (see appendix 3 for more measures). Participants' behavior in this simulated context may also provide insight about the shape of drivers' utility function for route choices and delays.

The point of these last few words is that an appropriately configured traffic simulation could serve as an ongoing test-bed for a variety of experiments on strategic level driver behavior. A reasonable starting point appears to be questions regarding alternative configurations of advanced driver information systems and their impacts on individual and collective travel times. However, this area of research is new and there is a great deal of room for exploration. A number of alternative research questions are provided in Appendix 1.

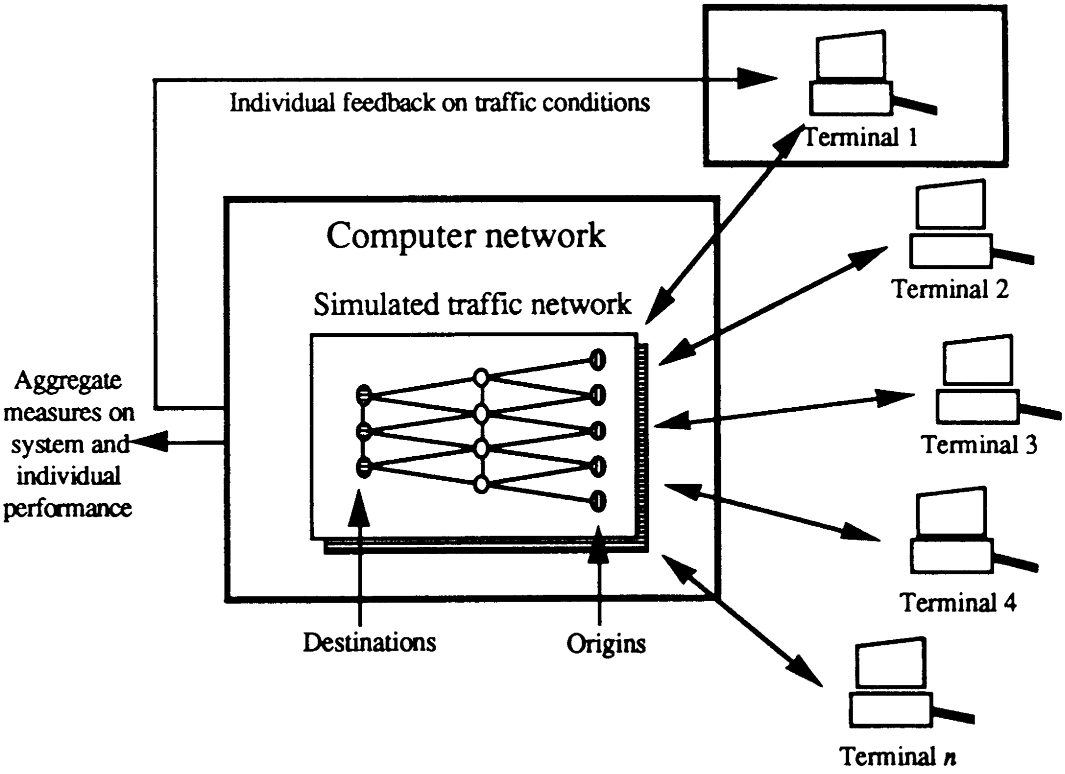
Table 3. Strategic Preferences, Decision and Information Options

Possible Driver Preferences	Strategic Decisions Options	Driver Feedback Options
Waiting time In-vehicle time Neighborhoods Scenery Simplicity (Number of stops) Risk regarding on-time arrival Safety Familiarity Levels of congestion Cost of trip (monetary) Walking time Distance traveled	Canceling the trip Linking trips (multiple destinations) Mode of travel Time of departure Route to destination Stopping for fuel Speed of travel (aggressiveness) Compliance with traffic regulations Compliance with electronic guidance Parking location	Current simulated time Time passed Suggested route Recommended next link Recommended departure times Expected trip duration Expected arrival time Expected variance in trip duration Street type along routed Congestion level

Method

An appealing approach for addressing these issues would be to develop a simple interactive computer simulation where participants, who were connected to the system by a local area network, could "drive" their vehicles from origins to destinations in accordance with simple network constraints. Link time would depend on the number of vehicles. INTEGRATION could serve as the basis for the network model, although something simpler might suffice (Van Aerde & Yagar, 1988). A typical demand pattern could be established and with a large number of participants the links would fill up with drivers over the peak periods. The participants would view different levels of graphic and alphanumeric information in accordance with selected treatment conditions. For example, participants representing typical commuters would be allowed to use a digital map of the area, similar to an ETAK navigator, but they would not receive information on traffic conditions beyond the link that their vehicle resided upon. Participants representing commuters with static route guidance would view the map with their location and would also receive a recommended route, possibly outlined on the map, that they would have the option of following. Other conditions might simulate real-time route guidance, broadcasted advisories, and other forms of motorist traffic information. One cycle of the game would involve completions of all the trips. Multiple cycles could be played to see whether the system would reach equilibrium.

Figure 2. Interactive Computer Simulation of Driver Behavior



The laboratory simulation approach is commonly used to test the behavioral assumptions of game and decision theory (e.g., Underwood, 1989). It has been applied only recently by transportation modelers to estimate behavioral models of traffic (Mahmassani, & Herman, 1990; Mahmassani, Chang, & Herman, 1986). This approach is currently being used in the

United Kingdom to estimate drivers' compliance with Autoguide's arrow-based navigation system (Bonsall, 1990).

An alternative to the fully-mechanized network-based interactive simulation would be to devise a scheme whereby the participants would interact with a standard "off the shelf" simulation of traffic. The participants would make incremental choices at each intersection in response to current information on traffic conditions and the researcher would input the route choices into the simulation to derive the travel times. The exercise would be ongoing because the participants would only make portions of a single trip during each class period. In between class periods the experimenter will update the network traffic to reflect the impacts of the participants' route selections. This type of scheme would avoid the problem of designing an interactive interface for the exercise. The experimental procedure is summarized as follows:

1. The experimenter supplies each participant with initial information and instructions. This includes:
    - Instructions to maximize the value of the trip (most likely by minimizing travel time).
    - Instructions that they will select a limited number of links toward their destination every day for a specified duration or until they reach their destination.
    - Origin and destination information for their trip.
    - Departure time (if required in this experiment).
    - Network geometry and traffic regulations.
    - Historical traffic conditions on the network (in most cases)
2. At time t_n, all participants indicate the links that they would take to progress toward their destination during the specified time period. This information is given to the experimenter. The participants are done for the day.
3. Before the next meeting of the participants the experimenter enters the route selections into the INTEGRATION microscopic traffic simulation model, which assigns the vehicles to the selected paths and generates current traffic statistics including travel times and volumes on each link.
4. The participants meet again at a later date. They are given selected traffic statistics and possibly prescriptions regarding their selection of route links for the next portion of the trip. For example, they may receive information on the current duration of the trip or the level of congestion on the immediate link. Depending on the experiment they may also receive prescriptive information like link or route recommendations. With this information the participants are asked to make their next route decisions. This returns them to step 2. The participants continue through these steps until they complete their trips.

The duration of the exercise will be determined by the size of the network, the frequency of the information updates, and the number of trips that the participants will make. For example, if a typical path from origin to destination covers 20 links, each link can be traversed in approximately one minute, and the traffic updates occur every five minutes, then a trip will take four moves over a four day period of time.

The number of participants will depend on the size of the network. The exercise must be designed so that realistic traffic impedances respond to realistic traffic volumes. The exercise must also be sensitive to the number of participants taking the shortest routes. If all the participants take a route at the same time it must lead to congestion and slower individual and collective trip times.

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Appendix 1

Research Questions Regarding Strategic Level Decisions

Question 1: Will network traffic result in form of dynamic equilibrium after repeated trials in the no-information condition? How many trials will it take equilibrium to emerge? What is the pattern of traffic over time? What factors determine the evolution toward equilibrium? How sensitive is traffic to these variables and assumptions? How does the behavioral equilibrium compare to current equilibrium traffic assignment solutions? What are possible explanations for any discrepancy? (Note: This experiment will provide a control condition for comparison with traffic patterns that emerge when drivers receive various forms of real-time information. This is unlikely to be identical to the static approximations to traffic assignment so it may serve as a better baseline comparison than purely simulated traffic.).

Hypothesis 1: The dynamic behavioral equilibrium pattern will be more geographically and temporally dispersed than the static optimal equilibrium pattern.

Question 2: How will individual and collective traffic measures change in response to providing *current* travel times to the drivers? How do the individual routes differ from those produced in the no-information condition? Under what conditions does this information lead to improvements or regressions in performance? Does this condition result in an equilibrium traffic flow? What kinds of instability results from this condition?

Hypothesis 2: Real-time information on current traffic conditions will lead to instability in the drivers' route choices and the collective distribution of traffic. Instability may be prevalent when all drivers receive periodic information on current traffic conditions and all drivers receive the same information.

Question 3: How will individual and collective traffic measures change in response to providing updates on predicted travel times to the drivers? How do the individual routes differ from those produced in the previous conditions? Under what conditions does this information lead to improvements or regressions in performance? Does this condition result in an equilibrium traffic flow? What kinds of instability results from this condition?

Hypothesis 3: Predictive travel times will lead to greater stability and faster equilibrium than current travel times.

Question 4: How will individual and collective traffic measures respond to prescriptive information provided to the drivers? How will they respond to recommended routes? How will they respond to recommended next links?

Hypothesis 4: Individual trips and collective traffic will be most efficient when equipped drivers are given user-optimal routes based on predicted travel times.

Appendix 2

Possible Independent Measures, Controls, and Assumptions

- Type of information presented before and during the trip: (these may also be combined)
    - Travel times (or vehicle speeds) only (in map format)
    - Congested areas, road maintenance, etc. (in map format)
    - Recommended route over entire network
    - Recommended next link
    - Recommended departure times
    - Expected trip durations
    - Expected arrival time
    - Expected variance in trip duration
    - Street type along routes (residential, arterial, freeway, etc.)
- Types of travel time information for route prescriptions:
    - Current travel times
    - Predicted travel times
    - Historical travel times
    - Unloaded travel times (free speeds)
    - Distance
    - Other: (e.g., drivers' stated preferences)
- Basis for route prescriptions:
    - User optimal
    - System optimal
    - Heuristic combination of user and system optimal
- Type of feedback presented after completion of the trip:
    - Actual travel time
    - Actual arrival time
    - Comparisons of actual arrival and expected arrival times
    - Time saved due to compliance with diversion recommendation
    - Time saved over average trip times between origin and destination
- Frequency of information updates:
    - Pre-trip information only
    - 20 minute update

    - 10 minute update
    - 5 minute update
    - Link-by-link update
- Percentage of vehicles equipped:
    - 0%
    - 1%
    - 5%
    - 10%
    - 20%
    - 50%
    - 100%
- Traffic conditions
    - Incidents
    - Levels of demand and traffic congestion
- Network characteristics (these can be combined in a number of ways for the appropriate effect)
    - Number of origins and destinations
    - Pattern of demand
    - Number of links and nodes
    - Number or lanes, turn restrictions, etc.
    - Signalization
    - Geometry of dominant alternatives:
        - Availability of alternatives routes
        - Amount of backtracking required (look at greedy selection)
- Subject characteristics: (these can be combined for appropriate tests)
    - Sex
    - Age
    - Experience
    - Personality traits (aggressive vs. passive)

Appendix 3

Dependent Measures

- Travel time in seconds between each O-D pair,
- Variation in vehicle trip time,
- Actual and expected arrival time, also average discrepancy
- Link status (mean volume, mean travel speeds, mean saturation, V/C ratio, ave. travel time, etc.)
- Types of streets taken (residential, arterial, freeway, etc.)
- Stability and convergence of driver behavior to a steady-state over repeated trials (no user switching decisions from day to day),
    - Changes in the recommended route during a single trip
- Evolution toward equilibrium (number of trials
- Compliance with prescriptions (% of drivers that complied completely)
- Divergence with prescriptions (mean % of recommended links followed)
- Discrepancy of actual trip time and prescribed trip time (if divergent)
- Satisfaction:
    - Pre-trip information (including types, data, basis, frequency of update, etc.)
    - During-the-trip information
    - Feedback at completion of trip
    - Overall trip outcome
- Drivers' utility for portions of the trip:
    - Free travel
    - Queue time
    - Diversion time