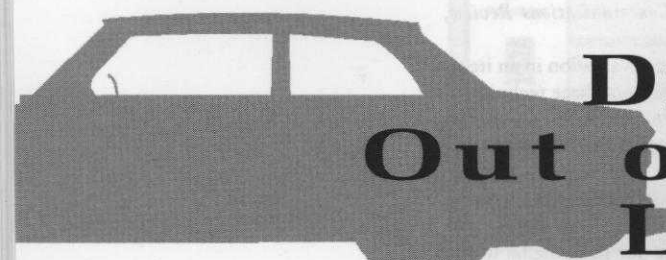


Driver Out of the Loop?

Examining issues of driver control and driving safety vs. efficiency in a fully automated transportation system.

BY JAY L. BRAND

A RATIONALE FOR THE inclusion of either safety or efficiency as a legitimate goal in any transportation system might seem to be a given at first thought, because each offers such obvious advantages. Guaranteeing safety minimizes accidents and their accompanying costs; efficiency minimizes numerous transportation complexities such as traffic congestion. Although most currently proposed implementations of automated vehicular transportation systems (AVTS; intelligent vehicle/highway systems [IVHS] and advanced traveler information systems [ATIS] represent related technologies), emphasize both safety and efficiency, few of these proposals include a detailed analysis of the features of current transportation systems – many of them safety-related – that contribute to their inefficiency. Analysis reveals that in several fundamental ways, the goals of safety and efficiency are pragmatically at odds, because under autonomous vehicular control conditions, many actions by drivers to maximize safety also compromise efficiency.

A detailed explanation of how and why these goals can be at odds and how a properly designed and implemented AVTS could greatly ameliorate this conflict would benefit the design and development of these transportation systems – systems that will almost certainly characterize the future of vehicle transportation in one form or another. In this article, I propose that implementation of a fully automated transportation system, with braking, steering, and acceleration outside the driver's control, is the optimum solution for many traffic congestion problems. Not surprisingly, such a proposal poses a number of human factors issues, which I attempt to address here.

Safety, Efficiency, and Relief of Congestion

Most current reviews of the various alternatives for intelligent vehicle control systems (e.g., Zetsche, 1995) emphasize safety concerns at the expense of efficiency, though others acknowledge that both goals must be considered (Hancock & Parasuraman, 1992; Sweet, 1991). However, in several respects, the integration of safety and efficiency objectives into the design of intelligent vehicle systems represents a primary design difficulty, perhaps even a conceptual *non sequitur*, at least as far as traffic behavior is concerned. To some extent, safety considerations sacrifice efficiency, and vice versa. One example of why this juggernaut between safety and efficiency exists within current transportation design involves the incentive structure inherent in enforcing compliance with current vehicle traffic regulations.

Incentives from at least two sources exist to ensure that vehicle operators eliminate behaviors that decrease overall safety levels. First, laws that control and regulate traffic have as their primary goal the elimination of driver behaviors that pose a risk to the driver's or others' vehicle(s) and their occupants. Following other vehicles too closely, driving too fast, failing to provide cues before turning or changing lanes, continuing through an intersection monitored by a red traffic signal, changing lanes frequently – all these behaviors would be penalized by current traffic laws. However, some of these behaviors actually become necessary for maintaining efficiency in traffic flow (for example, typically maximum speeds rather than minimum speeds are posted).

Second, insurance companies predict traffic accidents based on actuarial incidence of "risky" behaviors, such as those just outlined, and base insurance rates on those predictions. No allowances or advantages accrue for "efficient" driver behavior – especially in light of the fact that such behavior can increase the probability of an accident, most often because other drivers' behavior is biased toward safety at the expense of efficiency. The well-known adage, "Drive defensively!" summarizes this bias.

The incentive system provided by traffic regulations and insurance policy represents one reason that safety concerns typically eclipse efficiency considerations in transportation. It could be argued that both the context for the operation of a particular human-machine system and its expected output or goal behavior figure prominently in the evaluation of its efficiency. In the present transportation context, what are the comparative consequences for an error of omission (e.g., failing to accelerate as soon as it becomes possible when a red traffic signal turns green) and an error of commission (e.g., changing lanes when one's vehicle is moving too slowly to join traffic in that lane)? Is there a speed-accuracy tradeoff for this system, such that as speed of operation increases, errors of both commission and omission will increase? What types of displays could be designed to reduce these kinds of errors?

Analysis of some typical features of traffic behavior in urban areas reveals how the goals of safety and efficiency can be fundamentally opposed. If the relief of traffic congestion constitutes a primary objective of implementing an AVTS, then a concern with "optimal" system behavior (output) becomes centrally important. Many suggestions for more environment-operator-vehicle integration and automation in vehicle transportation have not included the relief of traffic congestion as a system goal (e.g., Generic Intelligent Driver Support, or GIDS; Michon, 1993). Rather, the concern has been with how to supply the driver or passenger(s) with more information that is potentially useful for his or her commute – for example, flexible, dynamic presentation of geographical information (compare Hancock, Dewing, & Parasuraman, 1993).

However, numerous social scientists and urban planners have noted a tremendous increase in traffic congestion in large metropolitan areas throughout the 1970s and 1980s (e.g., Shefer, 1994), which has resulted in a variety of significant societal costs (Seow & Lim, 1993). Because of increasing financial and political obstacles, new roadway construction is not feasible as a long-term solution to this congestion (Arnott & Small, 1994).

Fully Automated Transportation Systems

In addition to the technologies currently featured in discussions of AVTS, fully automated braking, steering, and acceleration capability might prove necessary to ensure the relief of traffic congestion. Such designs could be termed *fully automated transportation systems* (FATS). This version of an intelligent vehicle/highway system could be reified in many ways, but a description of three central user-oriented design functions can delimit what will certainly be a controversial proposal, whatever its final form (compare Arnott & Small, 1994; Stix, 1995).

First, users of an FATS system would need conveniently scheduled and located vehicles (that is, constantly available). Current public transportation systems, such as rail transit and buses, though energy- and time-efficient, still cannot fulfill the temporal demands or location specificity required by many commuters. Thus, ideally, system vehicles would be individually owned and operated, as they are currently.

Second, users need a system that minimizes commute times, at least comparable to current automobile traffic (an FATS could easily exceed individually controlled vehicles in this regard for reasons described later).

Third, this system should be user-friendly, involving easily learned and managed human-machine interfaces for individual vehicle operation. Presumably, in an FATS, the interface would at least be used to establish initial location and destination, although the former information could easily be supplied by on-board sensors making use of geographical databases, either internally or externally represented.

Informed by these considerations, what other areas of concern can be addressed by the human factors/ergonomics community to ensure that an FATS will achieve political and societal feasibility?

The psychological impact of an FATS – along with potential individual differences in this regard – has yet to be fully determined. Undoubtedly there will be objections about lack of control over the transportation process. Presumably, steering, acceleration, and perhaps changing gears (shifting) for some individuals represent

Many actions by drivers to maximize safety also compromise efficiency.

the joys of driving, whereas braking or avoidance maneuvers could represent negatives (although individual differences would need to inform these generalizations). Current models of driver behavior emphasize safety rather than efficiency (e.g., Ranney, 1994), and, as mentioned earlier, if system goals include the elimination of traffic congestion, maximizing individual vehicle efficiency will be key. To this end, an FATS will be necessary to maximize the goals of efficiency while maintaining high safety standards.

Undoubtedly there will be objections about lack of control over the transportation process.

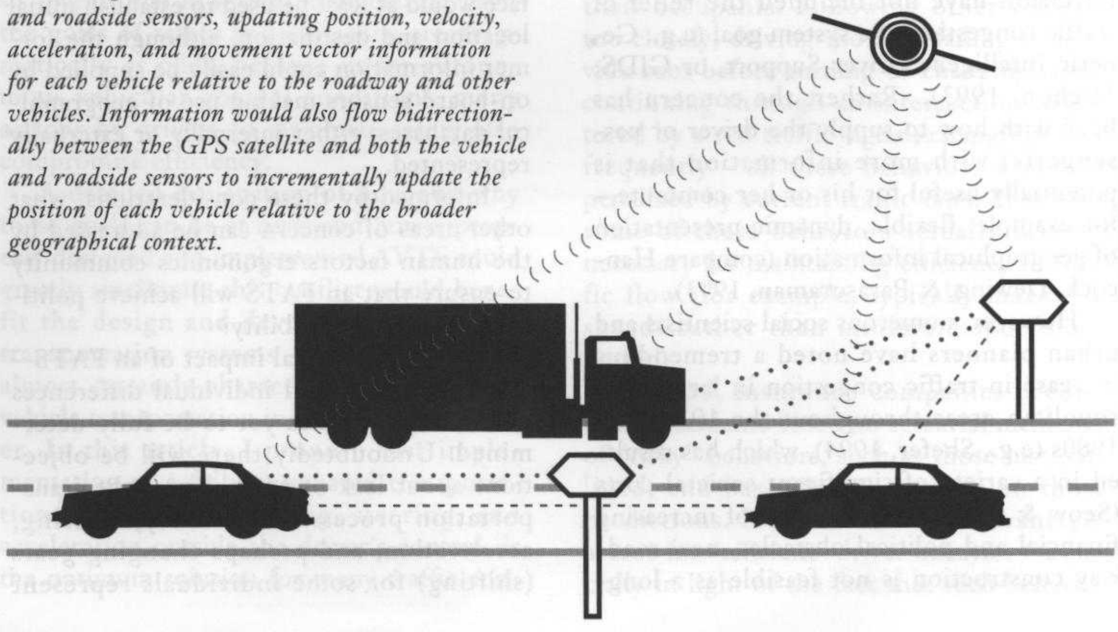
Advantages of an FATS

Motorists tend to be too cautious when responding to vehicle brake lights, resulting in the familiar traffic congestion "wave" (Arnott & Small, 1994; Holvenstot, 1994). This wavelike back-propagation of aggregated "safety" can actually stall traffic, especially as maximum roadway capacity is approached. An FATS would eliminate this emergent property of individually controlled vehicles, significantly reducing traffic congestion in urban areas. Short of implementing an FATS, displaying deceleration rate information in the vehicle brake lights might increase drivers' efficiency in responding to vehicles in front. Currently, brake lights give only binary information: Vehicles are either stopping or not. This maximizes safety at the expense of efficiency, although perhaps for good reason. Additionally, the processing demands placed on drivers if brake lights were to carry deceleration rate information could prove excessive (compare Shinar, 1995; Zeitlin, 1995).

Safe drivers always slow for brake lights with plenty of room between their car and the one immediately in front, regardless of that driver's behavior. Therefore, most drivers react only to one vehicle rather than to the dynamics of the entire line of traffic, and they decelerate well before efficiency would require it. ("Efficient" in this case could mean that braking would not begin until necessary to stop completely perhaps 15–20 cm behind the car in front, at perhaps 90% of braking capacity.)

A line of efficient drivers, by contrast, would each calculate necessary distances for each vehicle in front to stop and then integrate these calculations across the number of vehicles (assuming their optimal behavior) in deciding when to begin slowing, which enables them to stop inches from the vehicle in front. If all drivers in a line of vehicles behaved this way, there would be very little delay in slowing traffic reaching an intersection. Even more important, on accelerating or leaving an intersection, all vehicles would begin to move simultaneously, allowing the gap between vehicles to grow gradually. Demonstrating these FATS advantages and designing human-system

One concept of the fully automated transportation system: Information flows bidirectionally between and among vehicles, as well as between vehicles and roadside sensors, updating position, velocity, acceleration, and movement vector information for each vehicle relative to the roadway and other vehicles. Information would also flow bidirectionally between the GPS satellite and both the vehicle and roadside sensors to incrementally update the position of each vehicle relative to the broader geographical context.



interfaces that will entice commuters to use them constitute fundamental human factors/ergonomics challenges.

Another related consideration involves dynamic "preprogramming" of one's vehicle location after coming to a complete stop, such as at a traffic signal. If, after the driver plans this location and begins to brake at precisely the right time to stop, a vehicle from an adjacent lane moves in front of him, it will be very difficult to avoid a collision. An FATS would eliminate such situations and thus address certain safety concerns in addition to increasing traffic flow efficiency.

Still another common hazardous condition in large metropolitan areas involves competitive merging: Two lines of traffic use the same merging lane: one line to exit off, and one line to merge onto the freeway. Essentially the psychological context for each driver approaching such merging lanes involves the prisoner's dilemma: Should I benefit myself at the expense of the other driver ("prisoner") right now, or should we both cooperate to mutual benefit in the long run (Brams, 1993)? By accelerating, by this analogy, one benefits oneself at the other motorist's expense but also at the expense of efficiency for all the vehicles coming from both directions. However, if each pair of motorists could decide simultaneously who will decelerate and who will accelerate, a tremendous boost in efficiency could be realized. As traffic approaches maximum road capacity, the strategy of alternating vehicles becomes most efficient.

One solution to this problem would be to let an FATS dynamically specify acceleration and deceleration curves for every vehicle involved in competitive merging situations. This might be accomplished by comparing data from on-board sensor arrays with data from roadway sensor arrays, which could provide a dynamic map of the motion vectors of all the vehicles involved. Merging could thus be accomplished with minimal waste from the inefficiency caused by cautious, so-called safe drivers, who brake when they should accelerate.

Additionally, individual merging drivers often behave suboptimally before and after joining the primary traffic artery. They either join a lane where traffic is moving too fast for their vehicle's speed, necessitating braking in that lane (the congestion wave), or they crowd the first available lane. Consequently, cars already in that lane approaching the merging traffic typically move over, requiring the cars behind them in the new lane(s) to brake (the congestion wave again).

An FATS would eliminate the inefficiency of lane choices for vehicles approaching merging traffic, as well as the inefficiency of the vehicle-lane choices of merging vehicles. Perhaps recent modeling efforts directed toward specifying those aspects of the roadway ahead used by drivers in maintaining position-in-lane and vehicle curvature (Land & Horwood, 1995), combined with information about other vehicles' location and movement vectors, can provide sufficient information for an FATS to orchestrate merging. What type of displays would best inform the vehicle driver of the merging plan?

Finally, the fact that vehicle speeds vary among drivers causes traffic congestion in many ways. One of the most obvious involves drivers in passing lanes (to the left on U.S. roads) driving slower than other vehicles so that several vehicles collect behind them. The lanes immediately to the right and left of this lane are affected as well when vehicles behind the slow driver switch lanes, requiring faster vehicles already in those lanes to brake (once again, the congestion wave).

Additionally, many drivers change speeds considerably – either out of choice, inefficient monitoring of their vehicles' speed, or lack of vehicle power – when the roadway declines or inclines for a distance. Again, an FATS, serving much the same function as existing cruise control devices, would maintain constant speeds for vehicles regardless of the inclination of the roadway, with perhaps faster vehicles occupying the leftmost lanes (in the United States, at any rate). Individual drivers could choose how fast to "drive," and this information would determine their vehicles' lane. If it became necessary to switch lanes, vehicles controlled by an FATS would achieve an efficient balance between deceleration and acceleration to match – much more closely than the average driver does now – the speed of the vehicle in front.

Most drivers react only to one vehicle rather than to the dynamics of the entire line of traffic.

Conceptualizing the Design Process

Whether or not the goals of both safety and efficiency can be achieved within one particular implementation of an intelligent

An FATS would maintain constant speeds for vehicles regardless of the inclination of the roadway.

vehicle system remains an open question – though, thankfully, an empirical one. At the very least, such an implementation must rest on optimizing somewhat competing behavioral goals. This implies a trade-off for designers: If safety considerations are maximized, efficiency necessarily must be affected, and vice versa. Thus, the conceptual goal for designers of intelligent vehicle systems will be locating where the curve defining some global measure of decreasing safety meets the curve defining some global measure of increasing efficiency. The challenge facing human factors/ergonomics professionals is to design a user-friendly interface that informs drivers and convinces them the FATS is doing the right thing.

In some ways, implementing an FATS would minimize the necessity for human performance considerations in its design. If primary control of acceleration, steering, and braking for individual vehicles was accomplished via roadway and on-board sensors and controls, without occupant influence, then many fundamental human factors issues would assume much less salience than they do now. Perceptual access to all relevant environmental cues – including visual, proprioceptive, kinesthetic, auditory, and somatosensory – would become secondary because such information represents the primary input to a human occupant's vehicle control decisions and the evaluation of their consequences. Workload evaluation likewise would be somewhat irrelevant in predicting system safety and efficiency; presumably workload represents a psychological variable affecting the human side of human-machine systems.

A useful conceptual framework for evaluating potential design trade-offs in the development of automated transportation systems involves an appreciation of the multiple system levels that would be created. Before a particular design could be constructed, the salient system level being addressed would need to be specified, as well as how different system levels would best be integrated. Should an automated transportation system be designed and evaluated at the national, state, county, city, community or housing-development level, or at the traditional, individual human-machine vehicle level? At each of these levels, a distinct set of environmental inputs and system outputs could be delineated; their consideration would be important for the design and evaluation of such transportation systems.

However, regardless of the eventual answer to such questions, undoubtedly people's ability to interrupt would need to be part of the system design, if only to allow intervention in cases of system malfunction. This interrupt capability would need to reside at the level of individual human-machine vehicle systems. The design of the interrupt interface should involve all of the classic human factors/ergonomics principles:

a. providing adequate preview information in time for appropriate corrective behavior to be initiated and accomplished (Parsons, 1996);
b. stimulus-response compatibility for the layout and function of its controls (McCormick & Sanders, 1987);
c. attentional considerations for the placement of primary and secondary controls (Brand & Orenstein, in press);
d. workload evaluation for the number of displays that would need to be monitored simultaneously and for the number of controls that might need to be manipulated congruently; and
e. adequate perceptual and spatial distinctions among those displays and controls that should not be confused.

Likewise, ergonomics principles involving representative anthropometric dimensions for placement of controls, seat heights, interseat distances, lumbar (and head) support, safety belts, and the size and location of wind screens would retain their current design prominence in an FATS. Ideally, each of these dimensions should be adjustable to accommodate all occupants, although ranges between the 5th and 95th percentiles on all relevant dimensions would be adequate for the majority of users. Again, the control interface(s) for these adjustments should reflect sound human factors/ergonomics principles, as outlined earlier.

Finally, ideally, aesthetic needs should also be addressed (compare Norman, 1992). For example, even though an FATS might retain complete control over steering, braking, and acceleration of individual vehicles, occupants would presumably prefer to visually monitor the passing environment rather than sit in an opaque vehicle compartment. There seems to be no compelling reason that vehicles similar to current automobiles could not represent the primary transportation components of an FATS. Additionally, if occupant control over the vehicle's progress represents a fundamental reinforcement of vehicular transportation, traffic laws could be developed that mandated automatic operation only when congestion approached the maximum capacity of a roadway. Such information could easily be derived from fixed roadway sensors. Specifying when the use of interrupt capabilities is appropriate or not seems to be an area in need of further clarification (see Van Cott, Wiener, Wickens, Blackman, & Sheridan, 1996).

Toward Future Safe and Efficient Driving

In design considerations for intelligent vehicle systems, there are compelling reasons for the implementation of fully automated transportation systems as the best way to ease traffic congestion without additional costly roadway construction. Reducing traffic congestion involves improving traffic flow efficiency rather than the usual emphasis on maximizing safe driver behavior. The inherent irrationality of driver behavior caused by this emphasis on safety at the expense of efficiency renders full automation necessary to ensure the reduction of traffic congestion as a system goal for AVTS.

As I pointed out earlier, if fully automated transportation systems are adopted and implemented, some human factors/ergonomics considerations in their design would thus be obviated. However, the crucial human factors issues of user trust in these systems (compare Jones & Marsh, 1997), usability and utility of the system interface(s) (see Rasmussen, Pejtersen, & Goodstein, 1994), and function allocation among the various system components (Hancock & Scallen, 1996) will no doubt remain critical in determining the ideal form for this new technology.

References

Arnott, R., & Small, K. (1994). The economics of traffic congestion. *American Scientist, 82*, 446–455.

Brams, S. J. (1993). Theory of moves. *American Scientist, 81*, 562–570.

Brand, J. L., & Orenstein, H. B. (in press). Does display configuration influence information sampling performance? *Ergonomics*.

Hancock, P. A., Dewing, W. L., & Parasuraman, R. (1993, April). The human factors of intelligent travel systems. *Ergonomics in Design*, 12–15.

Hancock, P. A., & Parasuraman, R. (1992). Human factors and safety in the design of Intelligent Vehicle-Highway Systems (IVHS). *Journal of Safety Research, 23*, 181–198.

Hancock, P. A., & Scallen, S. F. (1996). The future of function allocation. *Ergonomics in Design, 4*(4), 24–29.

Holvenstot, C. E. (1994). Molecules and motorists. *American Scientist, 82*, 504–505.

Jones, S., & Marsh, S. (1997). Human-computer-human interaction: Trust in CSCW. *SIGCHI Bulletin, 29*, 36–40.

Land, M., & Horwood, J. (1995). Which parts of the road guide steering? *Nature, 377*, 339-340.

Michon, J. A. (Ed.). (1993). *Generic intelligent driver support: A comprehensive report on GIDS*. London: Taylor & Francis.

Norman, D. A. (1992). *Turn signals are the facial expressions of automobiles*. Reading, MA: Addison-Wesley.

Parsons, H. M. (1996, January). A visionary project for drivers. *Ergonomics in Design, 4*, 11–14.

Ranney, T. A. (1994). Models of driving behavior: A review of their evolution. *Accident Analysis and Prevention, 26*, 689–702.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive systems engineering*. New York: Wiley.

Sanders, M. S., & McCormick, E. J. (1987). *Human factors in engineering and design* (6th ed.). New York: McGraw-Hill.

Seow, E., & Lim, E. (1993). Ambulance response time to emergency departments. *Singapore Medical Journal, 34*, 530–532.

Shefer, D. (1994). Congestion, air pollution, and road fatalities in urban areas. *Accident Analysis & Prevention, 26*, 501–509.

Shinar, D. (1995). Field evaluation of an advance brake warning system. *Human Factors, 37*, 746–751.

Stix, G. (1995). Putting the mass back in transit. *Scientific American, 272*, 32–33.

Sweet, R. E. (1991). The Michigan-based program in intelligent vehicle-highway systems at the University of Michigan: An overview. *UMTRI Research Review, 21*, 1–12.

Van Cott, H. P., Wiener, E. L., Wickens, C. D., Blackman, H. S., & Sheridan, T. B. (1996). Smart automation enhances safety: A motion for debate. *Ergonomics in Design, 4*(4), 19–23.

Zeitlin, L. R. (1995). Estimates of driver mental workload: A long-term field trial of two subsidiary tasks. *Human Factors, 37*, 611–621.

Zetsche, D. (1995). The automobile: Clean and customized. *Scientific American, 273*, 102–106.

Jay L. Brand is a human factors psychologist and organizational behavior specialist in Officing Research/Ideation of Haworth, Inc., One Haworth Ctr., MC 2-7B, Holland, MI 49423; jay.brand@haworthinc.com. Interested readers are referred to a recent article published after this article was written, "Automated Highways," J.H. Rillings, Scientific American, *277 (4), 80–85.* EID

Traffic laws could be developed that mandated automatic operation only when congestion approached the maximum capacity of a roadway.