Intelligent Transportation Systems

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1 INTRODUCTION

In many countries of the world, the problems of crashes and congestion associated with ground transportation have reached unsupportable levels. In the traditionally "developed" nations of the world, there is no longer the space or land to continually build new roadways to deal with the congestion problem. Similar strictures are placed upon developing nations who are also experiencing an explosive growth in the number of vehicles on their roads. If information superhighways are important to sustained growth and development, how much more so are physical highways that carry people, goods, and vital services? The result of these trends is that we have overcrowded and dangerous highways upon which vehicles travel at progressively slower speeds as the transportation infrastructure spirals downward in decline. What can be done about this problem? The answer in many regions of the world is to turn to innovative and advanced technologies to solve the problems of congestion and safety. Across the globe this endeavor has had several labels: in Europe it has been referred to as Transportation Telematics; in Japan Advanced Transportation; but the phrase used here is the consensus term used in the United States — Intelligent Transportation Systems (ITS). The National ITS Program Plan (1995) refers to its function as follows:

> ITS applies a broad range advanced and emerging technologies to the needs of our surface transportation system, drawing from such fields as information processing, communications, control, and electronics. Effectively integrated and deployed ITS technologies could lead to significant improvements in safety. Mobility, accessibility, and productivity.

The reasoning behind ITS is clear. If technology can find ever more efficient ways to pack an increasing number of vehicles safely on to existing roadways, then politicians and administrators can avoid the unwelcome and unworkable alternative of ever more road-building programs. ITS seeks to accomplish this goal through the identification of user services which have been bundled according to specific domains (see Table 1). Many of these services are building blocks that can be combined for deployment in a number of different ways. For example, ITS provides an excellent opportunity to improve the dissemination of real-time weather information (RWIS) to the travelling public but also to decision-makers routing aircraft, ground commercial

TABLE 1
Identified Bundles and Associate User Services

Bundle	User Services
Travel and transportation management	En-route driver information
	Route guidance
	Traveler services information
	Traffic control
	Incident management
	Emissions test and mitigation
Travel demand management	Demand management and operation
	Pre-trip travel information
	Ride matching and reservations
Public transportation operations	Public transportation management
	En-route transit information
	Personalized public transit
	Public travel safety
Electronic payment	Electronic payment services
Commercial vehicle operations	Commercial vehicle electronic clearance
	Automated roadside safety Inspection
	On-board safety monitoring
	Vehicle administrative processes
	Hazardous material incident reports
	Freight mobility
Emergency management	Emergency notification and security
	Emergency vehicle management
Advanced vehicle control and safety systems	Longitudinal collision avoidance
	Lateral collision avoidance
	Intersection collision avoidance
	Vision enhancement and crash avoidance
	Safety readiness
	Pre-crash restraint deployment
	Automated highway system

Source: From the National ITS Program Plan (1995) transport, or emergency management. Such services can be expected to change over time as different supportive technologies mature and different forms of inter-modal linkage are developed.

In addition to these user services, if innovative technologies, such as telecommuting, can replace the need for physical travel, it is possible that the problem of congestion may be solved. In the near term this is unlikely. In the United States in the two decades between 1977 and 1997, the amount of drivable road increased by 2% while the number of registered vehicles increased by 50% and the number of journeys increased by an incredible 70%. Clearly, the demand is increasing and there is at present no obvious indication of any decline. Not unnaturally, administrators turn to those who created the roadways to solve the contemporary problems and since these individuals have largely been trained in the engineering sciences it is again unsurprising that they themselves turn to their parent discipline for solutions.

2 ENGINEERING SOLUTIONS TO ADVANCED TRANSPORTATION

The marriage of engineering solutions with advanced technologies could not seem a more natural one. Since the problem is essentially one of controlling a large number of vehicles on a relatively small amount of roadway, the obvious solution is to concentrate a greater number of vehicles into a smaller space. However, there is a barrier to this which is the unpredictability associated with human drivers. Therefore, from an engineering perspective, it would appear best to circumvent this unpredictable component and to generate automatic control over all vehicles. In the US, this effort was labeled the Automated Highway System or AHS. AHS was certainly well-intentioned and in some ways, there were signs that such a system could be successful. After all, when a complete system can be regulated, automated vehicles do quite well. For example, there are many shuttles which run at airports in the United States with no driver aboard and they perform to a tolerable level of success. What defeated the general idea of fully automated vehicles was the same stumbling block which has retarded progress in the area of Artificial Intelligence (AI), namely the conundrum of *context*. Where the problem of concern can be bounded, then computer-mediated systems do very well. For example, in the airport shuttle case, all stops and their locations are known. It is certain that there will be no other traffic on the line, etc. Similarly, in chess, AI programs have been successful since they are able to survey a bounded space of possibilities (despite the apparent enormity of that space of potential moves to us humans as individual chess players). Unfortunately, real-world problems are not so easily bounded in that same formal way. Thus, to be successful, automated vehicle systems would have to possess a wealth of "world" knowledge which appears so facile to human performers yet so difficult for their machine surrogate.

If we are unable to have a completely automated system the engineering argument ran, then let us develop a limited "world" in which some automated vehicles could operate. This was the idea behind levels of automation that could use "automated" lanes as used in the automated highway demonstration. To gain entry into this privileged world, the vehicle would have to undergo an electronic "check" to ensure that it had sufficient "intelligence" to operate within such a world. This conception seemed feasible, especially since many congested urban areas had already begun to construct or designate high occupancy vehicle (HOV) lanes in initial attempts to increase passenger-to-vehicle ratios. In order to maximize the effect of such automated lanes, the concept of "platooning" was adopted in which a group of vehicles, all travelling at the same uniform velocity, joined together in close proximity (essentially 1–2 feet apart from bumper to bumper). The technical feasibility of platooning was shown in several impressive demonstrations. However, some major problems have beset the platooning version of automated transportation. First, there is the problem of entry into automated lanes when large platoons can suddenly appear and the choice of entering the lane is at the discretion of the individual driver. Second, there is the problem of assembling platoons as they travel along well in excess of 60–70 mph. Third, there is the problem of egress from platoons or platoon dispersal as all cars reach their downtown destination at one time. This is not to say that such problems are insuperable, and indeed much progress was made on these issues culminating in a series of demonstrations of automated vehicle control in California in 1997, as had been mandated in the original Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991.

Despite these successes, however, it became apparent that fully automated vehicles were not the way that Intelligent Transportation Systems (ITS) were heading. Rather than one single reason, there were a collection of influences which militated against such developments. There were questions of infrastructure. For example, if vehicle were to be guided by magnetic strips in the road, who was responsible for laying and maintaining these strips? What would happen in the event of a crash if these failed? Would car manufacturers construct vehicles that needed such external forms of support to operate efficiently and would the costs of these added features be supported by buyers in the market? In addition, how would automated and non-automated vehicles be integrated on the roadway and how would such dedicated lanes serve all road users? This is not to say that such problems of legislation, infrastructure, and responsibility — like those of a more technical nature — could not have been overcome. Rather, it is that ITS chose a different direction for progress and the vital conception in this new thrust is human-centered transportation.

3 HUMAN-CENTERED TRANSPORTATION

In actuality, human-centered transportation is an initiative of the US Government that extends well beyond ground transport to include aviation, marine, and space operations. Human-centered approaches to ground transportation can vary widely, depending upon what the specific institution or agency means by the term. In ITS, human-centered approaches have been founded upon user-services of which 29 were indicated in the 1995 ITS plan (see Table 1), while some others have since begun to emerge. The purpose of ITS is to deliver these services. This is not what we mean by human-centered approaches in human factors and ergonomics (see Barfield and Dingus 1998). Our vision concerns itself with user-centered interactions with technical systems in which the human provides both the intention (either at the stage of design or at the stage of operation) and the control. Thus users in the ITS realm are largely passive consumers to be satisfied whereas in the human factors realm they are self-intention beings to be designed for. Despite this difference, I shall deal with users in the latter sense, and thus will focus largely on users as drivers of vehicles that are envisaged as including many advanced technical systems in the near future. A first question is how to structure a brief review of such a vast and growing area of research and applications? Here, I have decided to use response time as the defining characteristic. In so doing, I shall focus on some forms of current technology, mostly those in the vehicle, while necessarily giving less attention to other innovations, such as those being implemented in advanced traffic management centers. In general, the three categories I shall deal with are (1) communications, (2) navigation, and (3) collision-avoidance.

3.1 COMMUNICATIONS TECHNOLOGIES

The first forms of advanced in-vehicle systems to penetrate the mass market have essentially to do with communication. In this, the cellular phone is pre-eminent. Cellular phones first appeared in the US in 1983 and were installed in vehicles closely thereafter. Although still somewhat rare in rural areas, it is difficult to drive down a major road of any urban region of the US without seeing someone telephoning from their car. Although there may be some users for whom a phone is a vital piece of operational equipment (e.g. emergency services), most car phones are discretionary technology which it may be useful to have, but not impossible to live without. A natural question that has surfaced is whether it is safe to drive and phone at the same time. It turns out that this question is not simple to answer (Goodman *et al.* 1999; Hancock and Scallen 1998) and the National Highway Transportation Safety Administration (NHTSA) has recently conducted an extensive study of just this issue. In Japan, a breakdown of accidents involving car phone use reveals that 42% occurred when the driver was answering the phone, 31% took place when the driver was dialing and 16% resulted when the driver was simply conversing on the phone. However, as Hancock and Scallen (1998) noted, the simple act of phoning and driving together may in themselves, not be dangerous, rather it is the context in which such actions are performed that cause them to be more or less safe activities. In view of this contextual dependency, the present safety effect of cellular phone use on driving is still largely to be determined.

Now that we have a communications channel into the vehicle there is, in principle, nothing to stop the whole of the electronic world being introduced into the driving environment. Already it is possible to receive fax and email. There are also plans for an auto-PC in which the car can become a travelling office accessing the World Wide Web and unlimited electronic information, all while travelling at 70 mph down a crowded freeway. There are already great concerns over drivers reading newspapers, applying make-up, shaving, and the like while driving. This concern must surely grow if distractions such as email, TV, and video games are placed in everyday vehicles. Many such commercial products are already being installed and operated. How and where limitations are put upon these in-vehicle systems appears, at this time of writing, yet to be determined. Of course, we can all think of ways of locking drivers out from use while the vehicle is in motion; however, for some services such communication capabilities are vital. Cellular communications have already given rise to mayday and automatic collision notification systems (e.g. OnStar, RESCU, etc.) and promise several other critical advances such as emergency notification upon airbag deployment, route assistance, real-time traffic data, and stolen vehicle recovery. What can and what should be available for operation while the vehicle is in motion is clearly a human factors question and one which many of our community is now investigating.

3.2 NAVIGATION TECHNOLOGIES

If mobile phones are among the first advanced electronic systems to enter the vehicle, map navigation systems are fast following. Global positioning technologies (e.g. GPS) enable the immediate and accurate positioning of the vehicle, which can be immediately displayed on an electronic map. Some professionals, such as taxi drivers and delivery personnel, are in constant need of direction from their origin to a destination with which they are not familiar, and there is an advantage for emergency services to have information upon locations to which they are being summoned. However, is there such a strong demand from the ordinary driver? We know that the vast majority of driven miles occur on routes with which the driver is intimately familiar. Further, we know that with the increasing use of cars for commuting there is a slow but clear decrease in car use as a source of recreation. Therefore, we must ask, what advantage is it to the regular driver to possess such a capability as in-car, dynamic map-navigation systems? The answer to this seems to be bound up in the question as to how much the average driver would be willing to pay for this as a vehicle option. As of the present the answer does not seem to be a lot.

Manufacturers of such systems point to some forthcoming additional advantages. For example, when linked to information broadcast from central traffic management centers (TMCs), map systems can also display congestion. With this information drivers can choose to re-route themselves or request that the navigation system does this for them and provide a more efficient route. In saving the driver time, such systems may save the driver more money than their cost and so prove sound investments. However, this assumes that there are always viable alternative routes, but in many urban areas this simply is not so. Often, there may be only one or two routes possible between, say, downtown and a given suburban region and, if one way is blocked, virtually all drivers on the road are aware of the alternative. The optimistic advertising scenario of the powerful vehicle roaring though empty urban backstreets is likely to be misleading and counter-productive. Further, since many current map systems are downloaded from large-scale military or civilian sources, such as the USGA, they provide birds' eye views of areas from a perspective vertically above the area of interest. In reality however, individuals do not navigate well using this perspective, but are much better at landmark recognition from the viewpoint of the human eye. Thus, turn-by-turn advisory systems are more closely allied to actual driver navigation behavior, and a number of these have begun to come to market. Perhaps integration of such understanding of human preferences and behavior will facilitate market penetration.

From a safety standpoint, navigation systems have the potential for causing significant driver distraction or increased workload. In Japan, where 12% of all new passenger vehicles come equipped with such systems, they resulted in one fatality and 93 injuries in the first half of 1998. The majority of these accidents (73%) occurred while drivers were looking at the navigation systems. This is not surprising given that driver inattention is a primary or contributing factor in a majority of all crashes in the US — even without such in-vehicle navigation systems. Thus, the challenge for designers and manufacturers is to make these devices safe and easy to operate. For example, the seemingly simple issue of deciding when to present turn instructions depends not only on the timing of the route instruction, but also on the traffic conditions and road geometry. On a positive note, standards and design guidelines are being developed for limiting access to input information to navigation systems while the vehicle is moving, as well as ensuring message uniformity prioritization of functions for in-vehicle messages.

3.3 Collision-Warning and Collision-Avoidance Systems

While congestion is certainly a significant economic problem, it is the improvement of safety that stands out as the main goal of ITS. In the US alone, vehicle crashes take the lives of 42 000 people per year and millions more are injured. Adding together both the direct and indirect costs of vehicle accidents, the financial detriment alone runs into the hundreds of billions of dollars. However, road traffic accidents do more than this. Figures show that young people are far more likely to die as a result of road traffic crashes than from any other cause. Thus, road traffic accidents rob individuals, families, and society of more useful years of life than any other source of societal harm. Given this, there is a strong moral and financial impetus for us to seek ways in which technology can successfully reduce the accident toll. ITS collision warning and avoidance services promise this increased safety and efficiency through computer-based decision and automation in the form of driver assistance or warning systems. These devices are expected to reduce both the occurrence and the severity of crashes, as well as property damage losses and crash-caused traffic delays that lead to lost work, wages, or productivity. The National Highway Traffic Safety Administration estimates that over 1 178 000 crashes could be avoided if only three systems — rear-end, lane change/merge, and road departure systems — are implemented (NHTSA 1996). To help achieve commercialization of effective collision warning and avoidance systems, NHTSA has undertaken a program of research to develop safety-based performance specifications for a number of these systems, including those for preventing rear-end, road departure, lane change and merge, and backing crashes. The automotive industry envisions such collision warning/avoidance safety services will be available within the next five to ten years.

Although collision-warning and collision-avoidance are terms that are used synonymously, there is an important distinction. Collision-warning systems are used to focus the driver's attention upon a source of threat and thus provide advanced notice of an impending collision. Collision-avoidance systems initiate some form of active intervention by the system to circumvent imminent collision.

We deal first with collision-avoidance systems. Drivers have finite capabilities and among these are restrictions upon the time it takes them to perceive and respond to stimulation in the environment. For changes that can be anticipated, humans respond relatively quickly, but their responses can be quite slow for unexpected changes. In addition, there are some events which occur with such a short latency that even the most attentive and skillful individual is unable to respond, and these are the conditions in which engineering solutions must step to the forefront. For example, an incursion into the path of progress of the driver some 250 milliseconds into the future (the equivalent of a child stepping out, from between two parked cars, 11 feet in front of a vehicle travelling at 30mph), is not amenable to significant driver response. In this case, a purely automated system could be responsible for engaging in evasive action such as swerving and/or immediate application of full braking. More complicated questions are raised when the driver and the automated system have to work together to achieve the goal of collision-avoidance. Many human factors questions are immediately evident (see Hancock *et al.* 1996). Who has control? How and when is control passed from one entity (the driver) to the other (the automation)? How and when is that control returned? Should automation ever usurp the driver's right of control? Under what circumstances might this be envisaged?

Collision-warning systems, unlike collision-avoidance systems, provide information further in advance of incipient collision. One obvious question is how far? The further off in time and space that warning about a potential collision is given, the greater the propensity for false alarms. Even with virtually flawless detection systems, there is a significant false alarm problem anyway since the probability of collision on the road is actually so low (Parasuraman *et al.* 1997). In addition, how are we to warn drivers? Is a four-dimensional auditory warning, necessarily competing for visual attentional resources, the best form of localization? How are we to calibrate different systems to different drivers' styles? Another concern is that drivers may compensate for each of the safety improvements afforded by collision-warning and avoidance technologies to gain what they perceive as the best advantage for themselves. Overreliance on these systems may therefore lead drivers to assume additional risks and compromise any gains in safety. Drivers with forward collision- warning or night-vision systems, for example, may have a tendency to drive faster or exercise less caution than they otherwise would under degraded conditions. Product standardization and consistency is also paramount among safety critical warning systems. All these and a multitude of other questions have yet to be resolved as we endeavor to assist drivers in a task which, we must recognize, they do very well on a day-by-day basis anyway. These are part of the future challenges of ITS.

4 SUMMARY

Intelligent transportation systems using human-centered views are currently being built and implemented. However, progress in this area is moving so rapidly that it is likely that by the time this work is published some, if not all, of the developments described in this article will be either outdated or obsolete. While there have been significant and sincere attempts to bring human factors and ergonomics professionals into the development of standards, guidelines, and many specific designs, it is clear that not all such burgeoning technologies are likely to have benefited from human factors input; unfortunately, in a litigation-laden society, there will be many opportunities for forensic human factors professionals to comment and speculate upon the impact of designs of varying utility. If, however, we have contributed to the reduction of crash frequency and can demonstrate that human-centered approaches are effective in the protection of pedestrians, drivers, and passengers, we will have made a contribution that our students and followers can take into the future.

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