Title
Towards a Technology Assessment of Highway Navigation and Route Guidance

Author
Kanafani, Adib

Publication Date
1987-12-01

Institute of Transportation Studies
University of California, Berkeley

PROGRAM ON ADVANCED TECHNOLOGY
FOR THE HIGHWAY

Towards a Technology Assessment of Highway Navigation and Route Guidance

Adib Kanafani

PATH Working Paper UCB-ITS-PWP-87-6

December 1987

TOWARDS A TECHNOLOGY ASSESSMENT OF AUTOMATED HIGHWAY NAVIGATION AND ROUTE GUIDANCE

Introduction

The search for automobile navigation and route guidance technology is as old as the automobile itself. Over the long history of this process, various systems have been developed ranging from the now primitive Jones Live Map to the advanced systems available today such as AL1 Scout or Etak.[1] Countless assessments have been made of this technology over its long pathway. It would therefore seem redundant to attempt a "preliminary" technology assessment as this late stage. But this is done for a good reason. Wootton, [1985], one of the pioneers in this area concluded:

> "...one is bound to wonder why the system as developed has not already appeared in every driver's car. The answer is quite simple. The cost of developing the system is high: the cost of coding maps is even higher; the market is not willing to pay a high price; there is a multitude of different systems appearing to confuse the market place."

One can also add to Wootton's reasons another fundamental one, and that is that the benefit-cost relationships of such systems have never been ascertained adequately. There is no definitive evidence on whether navigation and route guidance systems will or will not generate the benefits that will make them worthwhile.

With this in mind, this paper is intended as a first look at the required assessment of technology. It is preliminary in the sense that it attempts to identify the issues and to identify some aspects of technology assessment that are needed to deal with them. It's aim is to raise some of the fundamental questions that arise in connection with the evaluation of this technology, and to suggest some further work for dealing with them. A more extensive research plan for looking at the various aspects of automobile navigation is to be found in Gosling [1988].

---

[1] See: Technology Options for Highway Transportation Operations, Conference Proceedings, UCB-ITS-P-87-l.June 1987.

Background

As mentioned above, the interest in automobile navigation is not a new phenomenon. Early designs, were aimed principally at aiding drivers in navigating across intercity road networks. The goal was to provide a convenient alternative to handling road maps. However, the improvement in road signing, and in the science of cartography probably eliminated the need for vehicle navigation aids and it was not until much later that other concerns rekindled the interest in route navigation and guidance. This current interest is motivated by a number of factors, of which the following two are perhaps the most important.

One is that drivers in general seem to choose routes in a less than optimal way due to their lack of knowledge about the network available to them. Most of the work in this area has been done in England, where most researchers appear to estimate that excess travel times and distances of the order of 5-8% could be saved if motorists knew and followed the shortest paths, (Robb, 1987). The objective therefore is to aid the driver in identifying and following the shortest path rather than to aid in the reading and use of road maps per se. Estimates of savings that can be achieved with this type of navigation aid have been based on savings in vehicle operating costs (fuel, etc.,) and travel time. One such estimate, by Jeffreys (1985), suggests that savings in Great Britain could reach about $1.2 billion annually, if everyone were to know and follow shortest paths.

The other main motivation for the current interest in aiding navigation is to achieve a better utilization of existing, limited network capacities. The idea here is that by guiding vehicles with known origins and destinations to routes that avoid congestion, one might be able to optimize the distribution of flows on network links. Much less work has been done on this aspect of route guidance and consequently little is known about its impacts or the potential benefits it would generate. However, the theoretical literature on route assignment is rich with models of vehicle routing and could be easily brought to bear on addressing the question of potential benefits.

Current Technology

In a rather extensive review Robb [1987] describes the wide variety of route guidance systems available at the present time. Robb identifies both automated and non-automated systems, referring to road signs, maps, and broadcast information as non-automated; and to electronic route guidance systems, and to in-car and out-of-car navigation systems as automated.

An important distinction in **Robb's** taxonomy is that between route navigation and route guidance, and it is interesting to note that both automated and non-automated systems can perform both functions. This distinction is worthy of some further exploration since it plays an important role in defining possible paths for technology development. Before doing this, however, we need to adopt some definitions of terms, as follows:

Navigation Aids This refers to giving the driver information regarding the physical shape of the roadway network. It can be associated with location finding so that a driver can see where on the network the origin and destination of the trip are. Navigation aids, even in their most rudimentary form of simple maps, sometimes give values of some performance measures such as travel time or distance; but there is no attempt to suggest a route to be followed.

Route Guidance In this case the driver is given information that suggest a route to be followed to the destination, or in fact suggests the route directly. This suggestion can be on the basis of minimum distance path, or the minimum travel time path depending on current network traffic conditions, thus incorporating measures of performance into the route guidance process. Some route guidance can also be based on avoiding routes that are not compatible with the type of traffic in question, such as guiding trucks away from residential streets during night hours.

Route Control This goes a step beyond guidance, and instead of suggesting a route to the driver, determines the route and instructs the driver to follow it. This of course requires some control mechanism such as automated vehicle monitoring, (AVM). At the present time there are no systems that do route control as defined here, but it a conceivable future technology, particularly *in* an automated highway environment: or in environments where AVM is to be implemented for purposes such as pricing.

Although one would be jumping ahead at this point to outline the paths that these technologies might follow on the way to implementation: it is nonetheless easy to see that the three levels implied by these definitions represent a very likely ordering. The technology of navigation is clearly needed, and would have to be imbedded in route guidance systems; and that of route guidance is a very likely basis for route control systems. Nor is this set of definitions exhaustive of the possibilities of technology in this regards. There are indeed a number of other functions and configurations that can be conceived. Such as route planning and management.

The technology currently exists for automated navigation and route guidance in many forms. Non-automated navigation and guidance have existed for many years in the forms of maps, road signs, radio broadcasts, and customized "route planning" maps. As mentioned earlier, mechanized navigation devices have been in existence for decades. As for route control, it is interesting to note that non-automated systems are the only ones in existence today. These include control of circulation into automobile restricted zones of central business districts (eg. Singapore,). They also include ramp metering schemes and other rather conventional systems that restrict or control vehicle routing.

The distinction between automated and non-automated systems is important for the purposes of this discussion. BY automated systems we mean those that integrate communications and control functions into a computer based scheme in which information is acquired, processed, and then used to develop guidance or other information that is also electronically communicated to the drivers. The ultimate purpose of automation would be to permit the handling of the large amounts of data that would be needed to process and transmit guidance, navigation, or control information to individual cars with specific origin-destination strings. Automation would also be necessary if the systems used are to have the capability of on-line assessment of network conditions and of real-time revision of routing information.

This distinction is of course not universal. For example the existing technology of road signs that convey traffic condition information and suggest routings may be considered automated in the sense that it uses communication systems and does convey information to drivers electronically, indeed, it may also be computer based. However, these signs are rather primitive when compared with the concept of individualized car-specific route guidance information, and with the on-line capability of monitoring network conditions and re-computing optimal routings. Our interest here is in these advanced concepts for which we adopt the characterization "automated".

There exist currently a number of automated navigation and route guidance systems. However this is not true of route control systems, for none exist today that can be considered automated. Furthermore, the current technology of route guidance, while positioned to provide the driver with online traffic information and updated optimal routing guidance does not in fact do so yet. At most, the systems available today will advise the driver of the minimum path to the destination and will update that if the vehicle deviates from the path. Network conditions remain static and are typically based on free-flow or other predetermined network conditions. Table 1 identifies some of the more commonly known automated navigation and route guidance systems that exist today.

Table 1 Navigation and Route Guidance Systems

Navisation	Route Guidance
ETAK Navigator	Siemens AL1
HONDA Gyrocator	Miti CACS
FORD Tripmonitor	Blaupunkt/Bosch EVA
JNPA Amtics	TRRL AUTOGUIDE

Again we are limiting the list and the subsequent discussion to systems that are characterized as automated. In the area of route navigation there exist map service systems that border on that definition. For example the British system called ROUTES provides a computerized map service that gives a driver a customized map showing preferred routes for a desired journey. These systems can be accessed via computer services such as Viewdata systems, but they still involve the use of a hard copy map printout taken along in the car. There appear to be no systems at the present time that would permit accessing the mapping system directly from an onboard device in the car. Consequently these systems are really no more that advanced means of providing services that have in the past been performed manually by organizations such as the AAA in the US or the AA in the United Kingdom, as well as many car rental companies.

Naviaation Systems: Three of the navigation systems listed in Table 1 are generically similar:the ETAK, Honda and Ford systems. They incorporate map information with a location finding device and present the combined information on some sort of an on-board video display unit. The ETAK navigator relies on a flux compass for positioning and on an onboard cassette tape for storing the base map information. As the car proceeds along its path the combined display shows it as a blip in the middle of a scrolling map. Honda's Gyrocator uses a direction sensor together with an odometer to feed information into an onboard computer. The computer plots the car's path on the screen over which a transparent hard copy map must be overlayed. Ford's Tripmonitor relies on satellite communication to position the car and displays it as a moving blip on the onboard screen.

Of these three and some others that are similar to them only the ETAK appears to have been introduced commercially. The system as it is currently configured has limitations such as slow speed and low capacity resulting from the use of audio cassette as a storage medium. Current efforts are underway to upgrade this system and to add a communications feature to it in order to permit it to provide route guidance in addition to navigation.

The fourth system: The Japan National Policy Agency system called AMTICS adds an important feature to the navigation capability. It does that by introducing the online, updated traffic condition information automatically into each car. Thus this system provides a step towards the automated route guidance system. While AMTICS does not suggest routes as such, it does provide sufficient information about traffic conditions in the network to aid the drivers in selecting the routes they deem appropriate. The system is planned for an experimental trial during 1988.

Route Guidance Systems:

The route guidance systems listed in Table 1 differ from one another in significant ways. First there are the on-board systems such as Blaupunkt/Bosch's EVA and Philip's CARIN; and the roadside systems such as ALI, CACS and AUTOGUIDE. Then with the roadside systems there are two groups differing by the means of communication between roadway and vehicle.: one groups, including CACS and AUTOGUIDE use the buried loop as the communications means; and the other including AL1 uses radio beacons installed at signalized intersections.

Of the roadway based systems the AL1 has recently emerged as the leading candidate technology. The ALI(Autofahrer-Lankungs und Informations Systems) has become the focus of the joint European program Prometheus. Developed by Siemens, this system involves the use of radio beacon devices installed in conjunction with traffic light installations at signalized intersections.- These devices communicate with on-board units obtaining information about a car's location and desired destination, and returning information about minimum path routing. The information is updated each time a car passes one of the intersections equipped with a beacon device. Route guidance information is displayed on-board via a video display that shows intersection lane configurations and suggested turns. No map of the whole area is displayed.

The AL1 system appears to have two advantages. One is that the radio beacon devices are relatively inexpensive to install: and in association with the on-board devices have a large information storage capacity. The other is that these same devices can be used as monitors receiving information about traffic flow that would permit an updating of routing strategies. They can, by being connected with the traffic light system, be linked to central traffic management computers and hence can allow the system to take advantage of area-wide traffic management capabilities. The disadvantage of this system, as with all roadway based systems, is that it requires an investment in public infrastructure. By placing some of the intelligence of the system in the roadway, the vehicle become dependent on its location and can only take advantage of route guidance within the environment of the intelligent roadway. Whereas in systems, such as EVA, where the intelligence is totally within the vehicle route guidance can become easily more ubiquitous and will depend only on the ability to add information to the on-board storage in order to extend the reach of the service.

The other roadway based systems listed in the Table 1 include the British system AUTOGUIDE and the Japanses CACS System (Comprehensive Automobile Traffic Control). Autoguide appears to have been integrated within the framework of Prometheus together with ALI. The Japanese CACS system differs in that it uses buried loop detectors to perform the functions of communications carried out by the beacons of ALI. Depending on the nature of the city involved, and its street network, this system may or may not have the cost advantage for the investment in infrastructure. Otherwise, the two are quite similar generically.

A Taxonomy of Potential Benefits

A thorough technology assessment of auto-navigation and route guidance requires a detailed estimation of user and system benefits. There are different types of benefits that can be associated with this technology. Some are likely to be more important than other. Some are easy to assess, and other are virtually impossible to estimate in advance. The following taxonomy of benefits is intended to help focus the analytic and experimental work that would need to be undertaken for benefit estimation.

First, there are user benefits. These include the reduction in unnecessary travel resulting from the inefficient use of the transportation network. This inefficient use results from the lack of adequate knowledge about the network, or about its general conditions. This class of benefits can be accrued largely by navigation and do not necessarily require route guidance, although they would probably be enhanced by it. The magnitude of these benefits is very hard to assess. However, as mentioned earlier, some work done in the UK suggests that the amount of unnecessary travel resulting from not using best routes is of the order of 6-8%. It should be recognized however that these results do not refer to rush hour urban traffic of the commuting type, for which the figures can be expected to be lower.

In this category one can also identify the simple benefit that acrute from giving information to persons unfamiliar with the area within which they are traveling. These include out-of-area visitors, tourists, and the like. While it is hard to quantify such benefits, it is possible for, say, car rental agencies to offer cars equipped with navigators and to charge a higher premium for those. Market response to such an option can soon determine whether or not it is a feasible proposition.

The next level of user benefits is that achieved by the avoidance of congestion, unexpected bottlenecks, or roadway incidents. This would require a technology of route guidance that has the capability for monitoring road conditions and suggesting alternate routes around congestion. These benefits are likely to be more substantial in congested urban areas and under conditions where dense networks do offer alternate routes around bottlenecks.

A second class of benefits are those that accrue to what might be referred to as institutional users. These include delivery vans, police and emergency vehicles, post office vehicles and the like. A route guidance system could generate substantial benefits if it were possible to use it in such a way as to optimize the routing of such vehicles. One can think of benefits from optimal routing of emergency vehicles to incident sites; or the optimal routing of pick-up and delivery vehicles. Indeed, one can expect that users such as collection distribution fleet operators may be the first in line as markets for automated route guidance systems. Because of the rather formal and organized nature of this user group, the estimation of potential benefits poses no insurmountable conceptual difficulties.

The third class of benefits refers to system, as distinct from user benefits. Firstly one can think of the use of route guidance for the optimization of the use of congested freeway corridors by redirecting entry and exit as is done with ramp metering. This can directly be extended to think about the optimization of the of the overall network, particularly in an urban context. The magnitude of these benefits is going to be strongly dependent on the structure of the network in question. Some networks are such that there are no realistic alternatives to congested corridors (such as bridges and tunnels). These are likely to gain less from route guidance than systems that do not have such natural bottlenecks. The benefits are also strongly dependent on the capabilities of the system used. For instance, a system that has a dynamic updating capability so that it can respond on-line to changes in traffic conditions and promptly reflect them in its route strategies will yield larger benefits than one that does not update often.

The estimation of this last class of benefits is going to be extremely difficult. There is little that can be done short of actual experimentation to understand driver response and compliance with suggested routings and actual benefits gained from such compliance. Many of the problems faced in the calculus of benefit analysis will also be faced here such as the issue of accumulation of a large number of small time savings, and the conversion of time values and so forth. However, experimentation to least understand the behavior of the system and to assess the compliance issue is likely to be quite beneficial.

Finally, one can identify a fourth class of benefits that could derive from using automated guidance systems in the more complex environment of route control, pricing and overall travel planning. While these systems are rather advanced and require much more thinking at this point; it can be said that some are likely to have potential benefits that could exceed those already identified. For example, if the automated route guidance system can be adapted for use in trip planning **in time** rather than in space only, then significant savings in congestion can be achieved; since congestion is caused as much by the temporal as by the spatial concentration of traffic and since we may find that there is more temporal flexibility in traffic demands rather spatial.

Major Issues of Technology Assessment

Considerable research would be necessary in order to under-take a thorough technology assessment of automated navigation and route guidance. Such an assessment would be essential from the public policy point of view, particularly if the systems envisaged involved significant public investments in road infrastructure, navigation, or communication systems. On the other hand, it is conceivable that a wholly automobile based navigation and route guidance system be developed by an automobile manufacturer in the private sector and marketed on the basis of its attractiveness to consumers. Indeed, we may find that route navigators may become commercially available options on automobiles within a rather short time, and long before any all embracing technology assessment is completed and a consensus reached regarding the technology.

Nonetheless, there are a number of issues that must be looked into within the context of technology assessment, and they will require research. As mentioned above, Gosling [1988] has outlined a research program aimed at this. What the following paragraphs aim to do is to highlight some of the more important issues regarding the development of this technology.

Measurement of Benefits The magnitude and distribution of benefits from automated navigation and route guidance is going to depend largely on the technology used and the type of service it provides. Much less benefits are to be expected from simple navigation aids than from route guidance or from automated online network updating systems. The benefits will also depend strongly on how some of these technologies are used. For example, the extent to which route guidance can benefit the overall network by redistributing congestion and avoiding links with high marginal costs will depend on the degree to which drivers will in fact follow the suggested routes given them by the system. In some cases, these routes may not be the optimal routes from the individual driver's perspective and drivers familiar with the system may not wish to follow them.

The benefits will also depend on the existence of options for routing traffic around congested links. This is likely to be highly dependent on network structure and will vary signifi-cantly from one area to another. Even within the same area, the benefits from route guidance that can accrue from routing traffic around areas with incidents will depend on the location of these incidence.

Consequently it would appear that research that deals with estimating the magnitude of the benefits from route guidance will have to be quite specific and microscopic in nature. It would seem that a major experimental effort, coupled with in depth simulations of selected urban areas would be necessary to at least get a start on benefit assessment.

Figures currently available that suggest a saving of 5-10% of vehicle miles due to navigation aids do not shed much light on this question. For one, they were based on experiments in the UK and in environments that are quite dissimilar to the congested urban commute corridors where most of the traffic problems are.

Equity and Economic Efficiency If route guidance systems are used to balance network flows by routing traffic, then an important issue of equity arises. The strategy of network optimization typically involves moving some people away from their preferred or optimal routing in order to achieve the system goal. The benefits for those who use the links relieved by this redistribution are clearly larger than the losses to those diverted from their optimal routes; but the equity issue remains. The public policy implication of this, from the points of view of public acceptance and economic efficiency should be assessed.

Related to this is the issue of economic efficiency. In assessing the feasibility of automated route guidance systems one must explore the possible cost recovery schemes that can be used. There are numerous goals that drive the cost recovery schemes: some can be used to maximize efficiency, others to achieve an equitable distribution of costs and benefits. The automated system in place may lend itself very well to vehicle identification and pricing, but the proper application of a pricing scheme will remain dependent on an adequate way of measuring benefits and costs, at both the user and the system levels.

Liability While not as serious as in the case of the automated highways, the issue of liability nonetheless is serious and must be dealt with. This issue has been known to inhibit many technological developments, and it can do so in this case. Tort liability can arise here if a driver, guided by the system to a specific route should encounter a serious mishap. This could be an accident, or an excessively long delay with serious consequences, for example. If the system is totally vehicle based, then the liability issue is rather well defined and is between the driver and the manufacturer. However, if the system is partially based on infrastructure built into the highway system and operated by a public agency, then there would be a public liability issue that would be quite difficult to deal with. An assessment of the technology of automated route guidance and navigation must clearly resolve this issue.

Public Acceptance The capability for automated navigation and route guidance would certainly an attract proposition if it were reasonably priced. As an added option in today's car or' truck, this can have a fairly substantial market. The limitations to market acceptance will be a result of the cost to the user vis a vis the nature of the service provided. This is a question for market studies. However, another serious limitation to public acceptance may be the response of "nonusers". The issue here is that of the "redistribution of congestion". If the route guidance system is to optimize network flows, then it will probably do so by reallocating some congestion from links with high marginal costs to ones with lower costs. In the case of freeway corridors this may mean the redirection of traffic from congested freeways to parallel local streets; a redirection most likely to be opposed by the local neighborhoods. An important issue of technology assessment related to this is the analysis of the possible impacts that traffic redistribution may cause. It may be well to optimize the flow on urban freeway systems by reallocating traffic, but the impacts of this diversion on local non-freeway links will require mitigation.

Another issue of public acceptance has to do with the possibilities that exist within the technology. Particularly, one is concerned with issues related to the potential use of these systems for vehicle identification, flow control, and pricing. Whether these are likely pathways for the technology will depend to a large extent on public acceptance of the whole concept of automated control.

Summary

From recent developments in navigation and route guidance it would appear that the technology has reached an advanced stage, and has in fact been delivered on the market in some forms. Little is now known about the potential gains that automated route guidance and navigation can offer for the relief of congestion. Yet, it does also appear that some form of this technology may in fact become available on the market and at prices that might make it quite attractive, if only for the occasional convenience it offers the driver.

If this technology is to require significant infrastructural commitments on the part of public agencies then a thorough technology assessment must be conducted in order to guide public policy. It seems most likely that route guidance will have to be partly based on roadway as well as vehicle installations, particularly if it is to have the feature of on-line updating of traffic conditions and the capability to reroute traffic around bottlenecks. The required technology assessment will be rather broad and would have to touch on many technical as well as non-technical issues. The following are a suggested first step toward such an assessment.

Given the little knowledge available about driver response and potential user benefits, it would seems that as a first step toward such an assessment an experimental effort must be undertaken in order to measure driver response and network behavior and to evaluate the technical requirements and limitations. Such an experimental effort would have to be preceded by a thorough simulation study in order to help design the experimental framework. Ultimately, since system performance is going to be network dependent, one would expect that at least the simulations, and in some cases the experiments would have to be done for different environments.

Second a thorough economic analysis must be undertaken in order to clarify the economic efficiency and the cost effectiveness implications of this technology. Based on the results of the first studies dealing with the measurement of benefits, such an economic analysis would look at the issues of cost-benefit, equity and efficiency. It will also have to address the financing and cost recovery issues explicitly.

Thirdly, policy analyses are needed to look at the issues of liability, and public acceptance mentioned above.

The pathway of development of automated navigation and route guidance is far from clear. Technology assessment may clarify some of the desirable developments. But market trends will also indicate which way the development will go. Currently, it would appear that navigation aids may become a desired features in automobiles, and if marketed cheaply and hence widely may provide the strongest force for the further development of route guidance and more advanced features that are yet to be invented.

Reference

Robb M. C. (1987) "Route Information Systems for Motorists" Transport Reviews Vol. 7, No. 3. pp. 259-275.

Gosling, G.D. (1988) "A Research Agenda for Plan for Highway Vehicle Navigation Technology", ITS Working Paper UCB-ITS-PWP-87-1. 47pp.

Wootton, J. (1985) "The Design of Route Guidance Systems", IEEE Digest No. 1985/11.

Nakashita, H. and Okamoto, H. and Kawabata, T. "Advanced Mobile Traffic Information and Communication System (AMTICS). Paper presented at the Transportation Research Board Meeting, Jan 1988.15pp.

Institute of Transportation Studies,"Technology Options for Highway Transportation Operations" Conference Proceedings UCB-ITS-P-87-1. June 1987. 192pp.