CHAPTER

6

Intelligent Transportation Systems

In the work leading to the first Interstate Surface Transportation Efficiency Act (ISTEA) legislation in 1991, considerable attention was paid to the advanced technologies that collectively define the elements of "intelligent transportation systems" (ITS). The legislation itself contained directives on ITS, up to and including automated highway demonstrations.

Concurrently, work has been progressing on such systems in many countries, and an international dialog was vital for the efficient incorporation of new technologies and systems. *ITS America* became a focal point of this, consistent with the intent of the ISTEA legislation.

The ITS emphasis was based on advances over the past few decades in traffic system surveillance and control projects, variable message signing, signal optimization, and simulation.

Perhaps even more important, the emphasis was put in place at a time of a true revolution in computing and communications. Computational cost was decreasing, computer memory expanding beyond prior concepts, and microprocessors—the heart of the computer—were being integrated into systems ranging from automobiles to dishwashers. At the same time, the availability of a global positioning system (GPS) enabled the use of geographic information systems (GIS) so that individuals could locate themselves rather precisely and do it in terms of defined networks, on a global scale. Wireless communication was also becoming widespread, so that the cell phones have become commonplace. These devices allow travelers to call for assistance, get advisories, report incidents, and be located (within the bounds within which the data base can be used, under existing law).

This explosion in enabling technologies then focused attention on how *transportation systems* could be enhanced, building on past work but taking advantage of new, relatively inexpensive and pervasive technological tools.

In the early years of this new focus, there was much attention to standards-setting by government and *ITS America:* what are the common protocols, interchange formats, and such that should be adopted and used to assure seamless systems?

At the same time, there were major advances in the private sector that acted to preempt the orderly introduction of such standards: cell phone features and technology are driven by an extremely competitive market; commercial vehicle routing systems became a sales feature in a competitive market and are tailored to customer needs by the private sector; locator and emergency assistance became selling points, as did routing systems; traffic advisories based on Internet-based camera networks became features of regional radio, another competitive private sector market. Cell phone networks expanded explosively.

This duality continues to exist. The authors see in it an emerging new paradigm in which (a) the individual has access to information delivered by the private sector and can make more informed decisions that serve personal goals, while (b) the agencies and other units in the public sector that have historically "controlled" the networks become providers of raw information and have less direct control over the network because of the level of information available to the individual travelers, who can continually adapt based on personal goals. At the same time, the public sector can—and has—introduce(d) efficiencies by use of automated toll collection, variable information advisories, enforcement of HOV rules and traffic rules generally (e.g., red light violations are now routinely handled with automated monitoring systems, with tickets sent to the vehicle owner along with the photographic evidence of the violation).

The authors also see as inevitable the pricing of transportation being used to influence the temporal demand pattern to make best use of available capacity, with automated billing and collection an essential part of "congestion pricing." This influence can in turn affect mode choice, because the system users have to make tradeoffs involving convenience, need to travel at given times, and cost.

With the growing concern over security in the face of terrorism, ITS technology will be extremely relevant, and the range of applications — includingcargo and passenger inspixtion — will surely expand.

Following this overview, this chapter is devoted primarily to the range of ITS applications in common use today and their potential.

6.1 The Range of ITS Applications

A fundamental question is: What constitutes an intelligent transportation system application and what does not?

To some, much of what has been done over the past few decades fits the definition and simply has a new name and expanded emphasis — freeway surveillance and control, route advisories, traffic control centers, and so forth. An important distinction, however, is that the longer-term view is that of ITS providing the user with information for decisions, in an environment in which enabling technologies are reaching unprecedented sophistication and availability and in which the public/private sector roles are shifting rather dynamically.

Still, the individual projects and research do seem to sound familiar, although there are new, timely issues such as dynamic routing assignment models and algorithms and a new emphasis on applications in several modes—auto, transit, and freight.

If one were to go over the program of the Annual Meeting of the Transportation Research Board (TRB) over the past few years, one would see papers'on:

- Traffic signal optimization *[1]*, data needs and quality [*2*,*3*], and fuzzy control algorithms *[4]*
- Bus transit [*5*,*6*]
- Dynamic assignment and dynamic routing [7]
- Commercial fleet management [8]
- Trucking [9]
- Specific technical problems [*10*]

Further, one would note a variety of other ITS themes, including Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS), among others.

The *ITS America Annual Meeting and Exposition* is another important forum for ITS applications, as are meetings of the Institute of Transportation Engineers (ITE). Relevant publications for survey articles and technology advertisements include *ITS International* (www.itsinternational.com) and *Traffic Technology International.*

'Most **of** these papers appear in the *Transportation Research Record,* based on the peer reviews conducted by the various TRB committees.

6.2 Network Optimization

Chapter 24 of this text addresses the subject of traffic signal optimization on surface streets; freeway surveillance and control is briefly discussed in Chapter 12. These subjects are central themes in ITS applications, perhaps with greater emphasis placed on communication with the drivers and on the autonomous decisions then made by those drivers.

There has also been a growing emphasis on color-coded maps of the freeway system, available from traffic control centers and used by local TV stations. These graphically depict the trouble spots in the network at any given time.

Some TV and radio stations also depend heavily on a network of "Web-cams" to observe conditions in the network and inform the public. Once this was the domain of the agencies operating the facilities and employing video cameras; it is now relatively common for TV and radio to depend both on these and on privately sponsored "Web-cams.'' Some agencies feature such displays on their Web sites or are used by TV and radio stations on their Web sites.

Given the information flowing to drivers from such systems, by in-vehicle routing systems, and by traffic advisory services (often based on cell phones), an interesting challenge emerges for the transportation professional: how are the drivers going to reroute themselves and how does this affect the network loading and hence travel times?

This challenge can be stated as trying to estimate the actions of drivers based on their current location, the origin-destination that underlies their initial route selection, and their (generally unknown) personal decision rules. Therefore, the technical problems of (a) dynamic traffic reassignment and **(b)** estimation of O/D patterns from observed data take on greater importance and, in fact, blend into the traffic optimization problem.

A related issue is the type of data available from which to estimate the underlying O/D pattern. Some work has assumed that only traffic count observations are available, with turn information. Other work has focused on "probe vehicles" that transmit information from which their exact routing is known. And, of course, with the rather pervasive use of cell phones—and subject to privacy issues related to accessing the data—the route information on many vehicles could be obtained from cell phone locations over time.

This, in turn, raises another issue: who collects and disseminates such information? If it is a private firm, such as the cell phone provider, it is a nontrivial computing task for which compensation would logically be expected. If it is an agency, then the question of access to the private sector's data must be addressed.

There are an emerging set of models and model platforms in which the assignment/routing tools are combined with (or more precisely, generally interface with) the signal optimization tools.

6.3 Sensing Traffic Using Virtual Detectors

The mainstay of traffic detection for decades has been the magnetic sensing of vehicles by a loop installed into the road surface. While this system is relatively reliable, complete intersection coverage is expensive and the desired detail (vehicle classification, extent of queue, speed estimation) is lacking.

To a large extent, the newest tool is a standard or infrared video camera covering an area such as an intersection approach, coupled with software that creates "virtual detectors" that are defined and located by the user, to observe counts at points, occupancy at points or areas (including queue extent), and speeds. Some capability to classify vehicles may also be included.

Using such a tool, the transportation professional can ''locate'' numerous "detectors" essentially by drawing them on top of the intersection image and depending upon the software to process the data. Refer to Figure 6.1 for an illustration of virtual detector placement.

AutoScope® is one of the pioneering video imaging systems; there are now a number of such products in the international ITS community.

The use of infrared imaging allows vehicles to be detected in a variety of weather conditions. The use of sophisticated algorithms based on coverage of the underlying

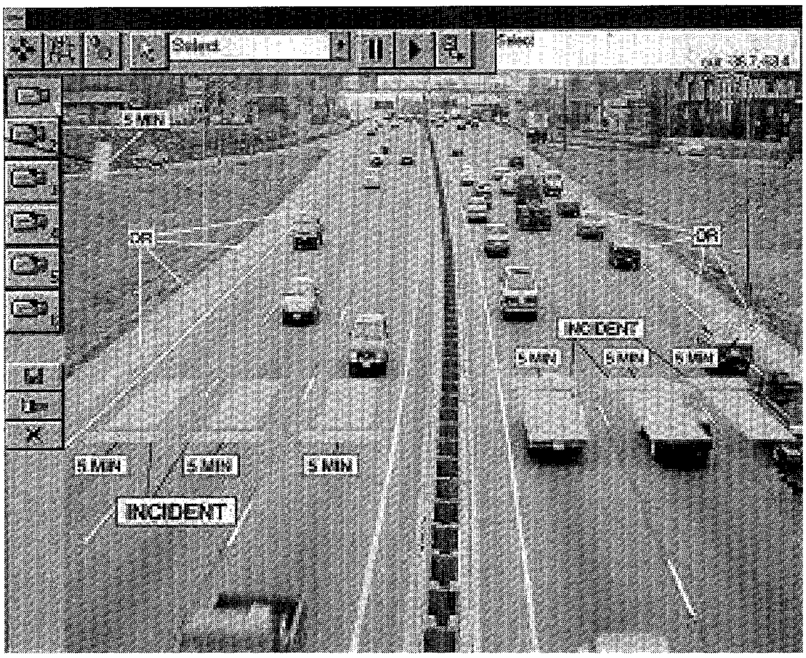

Figure 6.1: Software-Based Virtual Detector (Note: Six user-defined detectors are shown.)

pavement image allows data to be collected from stationary traffic as well as moving traffic.

The literature now shows variants of these concepts, including laser systems for traffic detection as well as a new generation of radar detectors.

6.4 In-Vehicle Routing, and Personal Route Information

Decades ago, a concept for roadside computers that would communicate with drivers and provide routing information was sketched out by the Federal Highway Administration (FHWA). But the relatively high cost and relatively slow speeds of the technology then available made this concept unrealizable.

In recent years, the phenomenal growth in computing speeds and memory, coupled with radical decreases in the associated costs, has made such systems feasible. The implementation is not by roadside computers but rather by systems that use GPS to establish the vehicle's position, access a data base of network travel times (static or dynamic), and compute best routes. Drivers can tailor the computation to their perception of "best"—travel time, distance, etc. In-vehicle displays, accompanied by audio instructions, provide the driver with the detailed routing.

It is now commonplace for new vehicles (particularly high-end) to have such systems as standard or optional equipment. Packages for adding the feature to existing vehicles are also on the market.

Again, the underlying theme is the individual's autonomous decision making, in an information-rich environment. It is the private sector competitive market forces that are driving the evolution of these systems—simply put, they are a selling point.

There are complications, in that there is some literature that suggests such devices may attract the driver's attention for up to 20% of the task time, and thus lead to greater accident potential.

But routing and mapping software is available in a number of formats, both in-vehicle and otherwise. Figure 6.2 illustrates map and route displays on a notebook computer and on a Palm™ personal device.

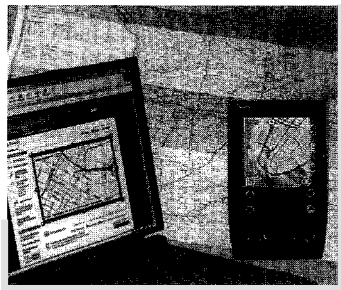

Figure 6.2: Map and Route Information on Two Personal Devices (Source: *ITS International,* Sept–Oct 2001, reprinted with permission (pg. 6 of ITS Profiles insert).)

And most readers are familiar with the map-routing features at Web portals such as Yahoo!@.

6.5 The Smart Car

The authors believe that the commercial market will be a major driver of ITS innovations, simply because market pressures require products that are differentiated, if only in the short term. Anti-lock braking (ALB) was one such feature. In-vehicle route guidance, based on a static or active data base, is another, more recent one. Although not yet integrally a part of the vehicle, cell phones were initially extensively marketed for the personal safety and security they provide to the stranded or lost driver.

Conceptually, the modem car is computer based for such essential features as fuel regulation and efficiency. Sensors add valued features to the car, and some active control mechanisms address specific safety needs. It is easy to envision a car with:

- GPS and on-board communications, including route guidance
- Airbags that inflate at different rates, depending upon the severity of the incident
- Anti-collision sensors that alert drivers to surrounding traffic risks and obstacles while in motion, and to obstacles while backing up
- More efficient transmissions
- Active anti-roll control, particularly for vehicles with a high center of gravity
- Active systems to stabilize vehicles in turns
- Sensors to detect under-inflated tires, and tires that maintain their shape in case of a blowout
- Greater fuel efficiency, with a goal of zero emissions through active control and different fuels

While it might be extreme to state that the car *is* the driver's environment, generations of vehicles have been marketed on that premise.

6.6 Commercial Routing and Delivery

Perhaps routing systems are of even greater importance to trucking and service vehicles. This is a specialty market, with software available that can compute long-haul routing and urban routing and can provide answers that take into account the set of scheduled pickup and delivery points. Dynamic rerouting, as new pickups are added en route, is feasible.

Today, it is commonplace for package delivery services (FedEx, UPS, and others) to offer real-time package tracking to customers on their Web sites. Using bar-code scanning technology and wireless communication, packages are tracked in detail from origin to destination. At the delivery point, the driver uses a computer-based pad to record delivery time and often the receiver's signature. This information is available in virtually real time to the sender.

Clearly, the package delivery services found a differentiating service feature that has rapidly been adopted in a highly competitive industry. What was special a few years ago has now become the expected standard of service.

The same data allows the service providers to obtain a wealth of data on the productivity (and down time) of their vehicles and drivers as well as on the cost of delivery in various areas.

6.7 Electronic Toll Collection

At the time of this writing, it is still appropriate to treat electronic toll collection (ETC) and the "smart card" as distinct topics (next section), but the distinction is blurring as the field advances. The concept of one debit card to be used seamlessly on different transit services and also on toll roads is exceptionally attractive to the public and is evolving rapidly in the United States and elsewhere.

One of the highly visible systems in the United States is the "E-Z Pass" system used in a number of jurisdictions in New York, New Jersey, and, more recently, in Delaware. The great appeal is that one in-vehicle device can be used on many different facilities, with the driver not concerned about which agency operates which facility.

Underlying the tag's popularity is of course the design of special toll lanes that accept only the E-Z Pass and have much smaller queues (if any). Another major feature is discounts for tag users, compared with tolls paid at the standard lanes.

At the time E-Z Pass was introduced, a great concern was whether the public would accept and use the system. In 2001, there were some 2 million E-Z Pass tags in use, and—in order to encourage reasonable speeds through the toll booths—the penalty that was presented for violations was suspension of the right to use E-Z Pass.

When the E-Z Pass system was introduced on the New Jersey Turnpike in 2000, the immediate effect was a 40% usage of the special lanes, thanks, in good part, to the extensive number of users in the region.

In Florida, a tag system known as E-Pass is in use. As of this writing, an extensive operational test of a public/private effort named the "Orlando Regional Alliance for Next Generation Electronic payment Systems" (ORANGES). This system is intended to create a seamless, multimodal electronic payment system that includes toll roads, bus transit riders, and parking services.

There are, in fact, a variety of ETC systems in use or selling planned throughout the world, including projects in Europe, Brazil, Canada, Australia, China, Malaysia, and Thailand.

Three issues and trends have been emerging since the initiation of the ETC systems:

1. Data can be collected from the tags to estimate travel times on sections of road and between toll stations. The same data can be used for noting routing patterns. At the present time, one of the uses of travel-time data is providing the public with estimates of the condition of the system, a benign application. But the potential for using the same tags for speed enforcement exists, although it currently would be viewed as counterproductive in encouraging card use. The ability to establish routings and to know starting times, down to a personal level, also raises questions of privacy, an issue that is a companion to such an information-rich environment.
2. A new generation of toll "stations" is emerging that do not have (or need) the physical infrastructure of existing toll plazas and can sense vehicles at prevailing speeds.
3. The pervasiveness of the tags enables congestion pricing to be considered as technically feasible. Indeed, various discounting options already in effect can lay the groundwork for public acceptance and perhaps enthusiasm for such systems.

6.8 The Smart Card

Systems using "smart cards" have generally implemented seamless travel using a common card on public transportation, thus making the trips easier. In New York City, the MetroCard (perhaps not fully enabled yet as a smart card) allows users free transfers between bus and subway if the transfer is made within a certain time. Other systems use variable pricing with distance and time of day.

As already cited, the ORANGES project is extending the use of smart cards from public transportation to parking and to toll roads.

One should look forward and consider at least three interesting applications of future generations of smart cards:

1. The opportunity to encourage seamless and efficient use of all transportation modes.
2. The ability to introduce variable cost with time of day and with distance, thus moving to a wider use of the "congestion pricing" or "road user cost" concepts.
3. The extensive data base that is being created, and the potential to use that data to obtain both

traffic statistics (volume, speeds, travel times) and O/D estimates for use in:

- Building historical patterns, by season, weather, and other factors
- Observing trends and changes in the historical patterns
- Use in planning, in scheduling, and even in revising transit routes
- Real-time use of the data in traffic advisories and control, as well as in response to incidents

6.9 Congestion Pricing

The general topic of congestion pricing has already been introduced. Indeed, it is a reality in some modest ways (Washington DC metro area) and in major plans for trucking and other road user costing in Europe and elsewhere. Figure 6.3 shows a congestion pricing zone planned in the center of London for implementation in 2003.

The congestion pricing issue in the United States and elsewhere is one charged with political impact, concerns over equity among user groups, and equal or historical access to facilities or routes.

While a good case can be made for the logic and effectiveness of such demand-based pricing, the public policy issues are nontrivial. Indeed, the move to congestion pricing that seems inevitable to the authors will surely focus the public's attention on the underlying role of transportation in their economic and personal lives.

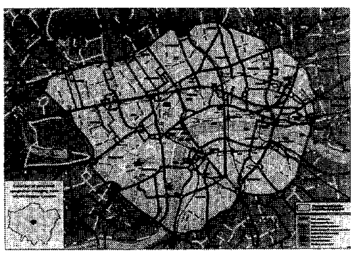

Figure 6.3: Proposed Congestion Pricing Zone in London, England (Source: *Tolltrans, Traffic Technology International Supplement 2001*, pg. ***26***. Used with permission.)

Questions raised over the years on the importance of freight movement to the economy of a region, on the true costs of various modes, and about embedded subsidies will once again draw attention, in a context of (relatively) rapid implementation.

The present text is not the place to define the "right" approach to these issues; that lies in the future. But it is important that transportation professionals recognize the issues that will become increasingly a part of their lives.

6.10 Dynamic Assignment

The traditional transportation planning models focus on assigning traffic to networks in specified time periods, based on historical or forecast traffic loads. They generally assume that the system is fully operational (no incidents), while allowing that some segments may hit their capacity limits. These models also allow for some of the traffic to be assigned outside the design period, if it cannot enter the network.

A far more challenging problem is that of dynamic assignment: traffic exists on the network, and an incident or major event disrupts the capacity of one or more links. How shall travelers reroute themselves, given that they have launched themselves on trips and routings based upon their historical knowledge? Travelers deal with this problem every day and use radio, cell phones, information from variable message signs, and other inputs to make their decisions. The issue with dynamic assignment is: How does one *model* and *anticipate* what people will do and/or advise them on what they should do? To address this requires a new generation of comprehensive models that are not only computationally fast (so as to be of value in real time) but also take into account (1) the planned routings (which in turn are based on the underlying O/D pattern) and (2) the decision rules employed by a range of travelers.

There is extensive and evolving literature on the development and use of such models. References [*11–14*] are only a sampling. For present purposes, suffice it to say that such models are central to providing informed advice and to anticipating the effects of disruptions.

6.11 Triaffic Enforcement

ITS techno'logyprovides considerable opportunitiesto enforce traffic rules and regulations and to thereby enhance safety. Reference was already made to the pros and cons of using travel time data from ETC tags for enforcement.

One area in which technology has been used is the detection ad vehicles that pass red lights. This is a clear safety issue and one that has gained public acceptance and support. The essence of such systems, already in use in many locations, is that a video camera observes both the signal indication and the moving vehicle with sufficient detail to see and recover the license plate. A ticket is then sent to the registered owner for what was done with his or her vehicle, without citing the person for the infraction.

The monitoring of vehicle license plates for the purposes of identifying stolen vehicles, vehicles with outstanding tickets, and those sought for security or police matters is another application that is generating interest in the international community. Of particular interest is use of such systems at border crossings. Another clear application is assigning road-user costs. Other candidate enforcement activities include (1) emissions monitoring and (2) weight in motion, to ascertain axle loads.

6.12 Bus Transit and Paratransit

Bus transit ITS applications include vehicle location systems, signal priority at intersections and on arterials, and electronic toll collection. The value of smart cards has already been noted as an effective tool in enabling use of public transportation. With a growing emphasis on multimodal transportation, the matching of schedules for bus to rail and for bus to bus is also an important item.

Perhaps most fundamental in the emphasis on multimodal transportation is the concept of a *minimally acceptable transit net* to service a corridor or area. A single bus route is likely to lack ridership, for the simple reason that the number of origin-destination pairs that can be served is limited and service frequency is often unattractive. Solutions that depend upon using auto to get to bus transit seem self-defeating, in that people are already in their personal vehicles (although we recognize that some park-n-ride scenarios are valid). But single routes—or even uncoordinated routes—tend to lead to a self-fulfilling prophecy: ridership is low because of limited appeal and value, and low ridership justifies the lack of need.

Therefore, one approach is to use the O/D patterns of the area to define a minimally acceptable transit net, one that can have enough interlocking routes so that the overall service is viable. The transportation adequacy can be first measured against whether such a net exists, and later against whether it attracts riders. The role of ITS in this approach is manifold, ranging from the data base needed to coordinated schedules to seamless travel using smart cards that allow discounted transfers for multibus or multimode trips.

Paratransit is often an alternative or supplement to conventional bus networks, for trip purposes or O/D pairs that cannot be met efficiently with fixed bus routes, even when they are interlocking. ITS technology can enable trips to be combined efficiently, provide variable fares based upon traveler flexibility and trip departure times, and track vans and taxis for availability.

6.13 Emerging Issues

At the risk of being dated by events, the authors suggest that the following issues should be considered in anticipating the future:

1. The emergence of congestion pricing as a priority, given that ITS technologies are creating the enabling infrastructure. Beyond the technological issues, the market, economic, and elasticity issues need in-depth research.
2. The need for high-quality O/D data, and the ability of the cell phone network to provide detailed trip information, will cause major attention to focus on this issue and the related personal privacy issues.
3. An emphasis on models that specifically address the departure-time decisions and mode decisions of the travelers, so that the "demand profile" is not fixed but is subject to traveler knowledge of network loading and travel cost.

Complicating this is that the demand profile changes interactively with the decisions made.

4. The national priority in the United States on antiterrorism and security, and the same priority in the international community, will set priorities for certain inspection and detection technologies and will influence the design of ITS systems.

6.14 Summary

This chapter has in some ways raised more issues than it answers, and it skips some details of specific ITS systems. This is done intentionally, because (1) the field is moving rapidly and any "snapshot" its present state is sure to be dated rapidly, perhaps even by the publication date of the text, and (2) the real issue is for the reader to be prepared to expand his or her view of providing transportation service in a highly competitive market in which computing, communications, and Web services are being used in novel ways.

Furthermore, the evolving roles of private and public sectors—in some ways, structure vis-a-vis market responsiveness—should draw the reader's attention. Today's "right answer" can be swept away by what the enabling technologies make available.

And there is another fundamental issue for the reader to consider: providing transportation information may simply be a selling point for manufacturers of automobiles, other vehicles, computers, personal data assistants tailored to various users (e.g., package delivery services), cell phones, wireless communication devices, and Web services. That is, while valued by the user, the underlying objective is making products that are both more attractive and differentiated (at least in the short term, until the competition copies success). In this view, transportation data and information is not an end in its own right—the traditional view in our profession—but is rather a product enhancement. In addition, competitive private sector forces may provide a data-rich environment for transportation professionals as a by-product of their work, *and at an innovative pace driven by that work and its market.* And this pace far exceeds the traditional pace of public-sector planning and innovation, and the competing value of standardization.

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Problems

6-1. Consider the feasibility of designing a Web site that offers the public the opportunity to have several service providers bid on paratransit trips. Users might indicate that they need to get to the airport by a certain time and have flexibility in travel time duration (or not) and in multiple pickups (or not). The user might also give advance notice of several days or only hours. Service providers would then bid for the particular trip or for a set of trips specified by the user. Consider how to market the service, what options it should provide the user, and why it might (or might not) be attractive to service providers. Write a paper not to exceed 10 pages on such a system.

6-2. Refer to the second-from-last paragraph in this chapter and prepare for (1) a class discussion of this issue and/or (2) a 5- to 10-page paper on this issue, as specified by the course instructor.

6-3. Refer to the last paragraph in this chapter and prepare for (1) a class discussion of this issue and/or (2) a 5- to 10-page paper on this issue, as specified by the course instructor.

6-4. Address the first "emerging issue" listed in Section 6.13, with particular attention to the research needed to advance the state of the art to where it must be to make informed decisions. This may require a literature search and thus be a major course project. But two timelines—the desire for informed congestion pricing implementations and the advance planning/research needed—may be inconsistent.

6-5. Address the second "emerging issue" listed in Section 6.13 of that name, with emphasis on how much data can be obtained and how it can be used in routing and assignment algorithms. At the same time, address the privacy issues and how personal privacy can realistically be assured. Prepare for (1) a class discussion of this issue and/or (2) a 5- to 10-page paper on this issue, as specified by the course instructor.

6-6. Address the third "emerging issue" in Section 6.13, with emphasis on how closely existing advanced models for dynamic assignment truly address the issue. Prepare for (1) a class discussion of this issue and/or (2) a 5- to 10-page paper on this issue, as specified by the course instructor.

6-7. Address the fourth "emerging issue" listed in Section 6.13, with emphasis on the most acute needs in face of the range of threats that must be considered. Take reasonable account of the reality that passive action—detection and then remedy—may be neither wise or cost-effective.