Agent Based Individual Trafficguidance

Abstract

When working with traffic planning or guidance it is common practice to view the vehicles as a combined mass. From this models are employed to specify the vehicle supply and demand for each region. As the models are complex and the calculations are equally demanding the regions and the detail of the road network is aggregated. As a result the calculations reveal only what the mass of vehicles are doing and not what a single vehicle is doing.

This is the crucial difference to Agent Based Individual Traffic guidance (ABIT). ABIT is based on the fact that information on the destination of each vehicle can be obtained. This information can then be used to provide individual traffic guidance as opposed to the mass information systems of today – dynamic road signs and traffic radio. The goal is to achieve better usage of the road and time.

The main topic of this paper is the current development in both practical and theoretical fields concerning the realization of ABIT.

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August 2006

1 Overview

The objective of this document is to present an overview of highly advanced traffic guidance today and especially what remains until Agent Based Individual Traffic guidance (ABIT) is possible. The essentials of ABIT is briefly covered. Following this the most essential theoretical research is covered. This is supplemented by a section on the practical evolution of the hardware required for ABIT. A concluding section will briefly give my expectations on the future of Pervasive Traffic Intelligence (PTI) in general and ABIT specifically.

2 Agent Based Individual Traffic guidance

The applications of models to traffic modeling and planning have lead to efficient, necessary and qualified decisions. These same models have repeatedly proven the most basic rule of mass car transport today. In 1952 Wardrop [Wardrop, 1952] enunciated Wardrop's first principle: *"Under equilibrium conditions traffic arranges itself in a congested network in such a way that no individual trip maker can reduce his path cost by switching routes."* In traffic this is considered to be the Nash equilibrium. In other words, the perceived utility or cost of each route is the same under congestion. It is important to note that this does not mean that all routes take the same time, only that all routes are perceived equal *to the drivers*. Personal preferences may make one driver choose a more beautiful but longer route while another driver chooses a less time consuming route.

Wardrop's second principle is also interesting: *"Under social equilibrium conditions traffic should be arranged in congested networks in such a way that the average (or total) travel cost is minimized."* As [Ortúzar and Willumsen, 2001] illustrates by a simple example the social equilibrium can be 0.5% better in the total travel time than the Nash equilibrium.

In the article [Roughgarden and Tardos, 2002] on selfish routing the authors find that the Nash equilibrium can be far from the social equilibrium. In fact for complicated speed/flow relationships the ratio between the two equilibria is theoretically unbounded.

A most interesting statement also proposed in the article is: *... to match the performance of a centrally controlled network with selfish routing, simply double the capacity of every edge.*

In most cases the drivers choose a route based on the time it takes to traverse it. This is also what most in-car navigation systems and route planning services do. In regular (non-congested) traffic nearly all cars follow the same route from origin to destination. As the traffic flow increases, the speed of a section decreases thus making the preferred route slower. Other routes become attractive and the traffic is diffused into the infrastructure. In this way autonomous vehicle traffic exhibits a form of self balanced sifting.

As exemplified in the previous paper [Wanscher, 2004] on ABIT only redirection of a minor fraction of the vehicles is necessary to obtain the Nash equilibrium.

For most networks there is as mentioned above a better social equilibrium, but this cannot be obtained by the action of any individual driver. To achieve the social equilibrium some cars must choose a worse route in order to make other cars get a sufficiently better route. The situation can be described as a solution space with a local minimum (the Nash equilibrium) and a global minimum (the social equilibrium) which do not coincide. The problem is that the solution method, selfish routing, is incapable of sustaining the global minimum even if the flow distribution should occur. This is one of the mayor benefits of introducing road pricing ([Yang and Huang, 2004]), as the pricing might be calibrated to ensure that the social equilibrium is sustainable.

Returning to the models and the forecasts, today no country or major city can expect to see a decrease in the number of car-based commuters unless drastic countermeasures are applied. This means that the length and intensity of congestion will become increasingly troublesome.

Congestion in it self is self balancing as described above. The problem is that it only balances properly under normal or expected conditions. If the state and usability of the infrastructure diverges from general perception then the self balanced sifting can in worst case be replaced by a very severe jam or even complete traffic grid lock. At this point the driver becomes the most important part in the relative success in the progression of the traffic.

2.1 The Driver

As described earlier the mass of drivers tend to distribute themselves according to the Nash equilibrium. This happens primarily because each driver can be seen as an autonomous entity. At some point the driver will try another route and if perceived to be better then it will become the new preferred route. The term "preferred route" is used to reflect what is often encountered in traffic modeling: conservative drivers. Drivers stick to a specific route and if content with it they will seldom try other routes. This means that if the infrastructure changes then it will take some time before the equilibrium is reestablished. Trying a new route may be caused by several reasons, eg. curiosity, impatience, or advice. The driver may try something new for a change, become unsatisfied with the current route (to slow, long, boring, etc.), or the driver might have heard of a better route.

Above, this conservative attitude is presented almost as having a negative impact on the traffic, but this is not entirely so. If drivers are not conservative, the equilibrium would not become steady as too much of the flow would change path every day.

The behavior of drivers is important to mention. Although conservative attitude is good for the equilibrium, inconsiderate self righteousness is very bad for general flow. The steady state is still obtained by being conservative. The problem is that the often inconsiderate behavior might make the aggressor get a little bit (under congestion a very little bit) faster ahead, but at the expense of everybody else. The result is that the capacity of a given intersection is impeded by selfish or inconsiderate behavior.

The conservative attitude has besides the equilibrium conservation at least one other important impact. Recent research [Abdulhai and Look, 2003] shows that proposing new routes must be done with great care as it is shown to have impact on general safety. Traversing new routes mean that people do not know the local traffic conditions. Furthermore routes bypassing congestion are more complex[1].

2.2 The Communication

When driving to a predetermined destination we usually have a route or a very small subset of routes in mind; a preferred set of paths to the destination.

As mentioned above this subset of routes tends to be static. When altered, it is usually because we think or know that another route is better. The question is how can it be known if some route is better than another.

This can be done either by guessing, by becoming sufficiently unsatisfied with the current route or be told. Not so many years ago the latter was only performed primarily by the speaker on the traffic radio. This reaches many drivers, but it requires that the driver listen to the radio and it is the right station or the driver has a car radio that can switch to traffic announcements automatically.

Recent advancements in communication and surveillance have made it possible to add new and entirely different forms of communication to the "telling". Some of these are dynamic message signs (DMS)[2] and real time status messages available over fax, short message service (SMS) or World Wide Web. See [MTO, 1999] or [DRD, 2004] for examples of the latter.

All of this information has increased safety as well as the utilization of the infrastructure.

[1] In the article the authors explicitly point out that the number of turning movements in non-preferred intersections is essential to the number of accidents under high load.

[2] Dynamic message signs are also called variable or changeable messages signs.

3 The Future for Road Based Traffic

Over the recent years the amount of vehicles concurrently in transit has increased at an alarming rate. In Copenhagen, a capital with public transportation, a report [HUR, 2004] from The Greater Copenhagen Authority has shown that the average traveling speed on the highways during morning rush hour has dropped 15% to $37km/h$ in one year. As the critical mass of vehicles are approached on the highways so is the traffic in the center of the city. Traffic jams and grid locks are there to stay.

If we focus on the increasing vehicle traffic and leaving out alternatives two options are possible. Either increase the capacity of roads, which is immensely expensive, or change the usage of roads, which is equally complicated.

The latter is already attempted through the previously described communication media and through the use of dynamic intersectional control. The problem is that in most cases the individual driver has to decide solely by himself what to do in different traffic situations.

The idea of ABIT is to address this issue. Instead of forcing every driver to make his own choice unaided the system can propose a set of alternate routes. These propositions can be based on far more information than can be communicated to the driver and thus work as decision support for route choice.

I have previously described how equilibrium was established between possible routes under normal conditions. Intelligent vehicle-wide routing will decrease the time to reach the equilibrium, thus reducing the overall transport cost.

The problem addressed in my PhD study is *what if it is not under "normal conditions"*. In theoretical terms, this means the system is disrupted or suffering from a disruption.

The previous submission to Aalborg Trafikdage [Wanscher, 2004] contains a thorough description of disruptions and how ABIT is intended to function.

The remainder of this paper will concentrate on the requirements for ABIT:

- a theoretical base appropriate for understanding, solving and forecasting the mathematical representation of routing vehicles
- software and hardware to support the theoretical methodology
- In-vehicle information systems with communication and visualization capabilities
- Information gathering hardware and software for obtaining and processing real time information from the infrastructure

4 Theoretical Requirements

To address a real world problem scientifically usually requires a model. The model then requires a solution method which is equally important. Having a perfect model with absolutely no chance of solving it is just as bad as having a very poor model which is instantly solvable. The key issue is that the model is adequately aggregated to allow both proper representation of reality and efficient solution.

The most basic approach to a model for traffic networks was the Traffic Assignment Problem (TAP). The TAP is from a modeling perspective fairly simple. The crucial difficulty in solving an instance is the selection of a cost function.

A cost function is a function that yields the cost of traversing a link. The cost function can include both time and space to yield a very complicated, but hopefully more representative, function. It is important that we consider how representative a given cost function is and not how precise. If the function is representative of reality the resulting flows will also represent valid, feasible and optimal solutions dependent on the model. However the solution value will only be transferable if the precision is high. Evidently a more complicated cost function is more representative and precise. The difficulty however is that even rather simplistic cost functions require complicated solution methods. Examples of older cost functions can be found in [Ortúzar and Willumsen, 2001] and an example of a newer and significantly more complicated one can be found in [Meschini et al.,].

In the TAP the traditional cost function is both separable and time insensitive. The separability means that the cost of traversing any link is independent of the cost on any other link. The time insensitivity means that the cost of traversing a link is independent of at which point in the considered interval that the link is entered.

These two presumptions seems unrealistic given that rush hour is an excellent example of a situation where entering a link 5 minutes later may result in another 5 minutes of traveling time. The inseparability is easily argued as non representative. The first and most common example is the regular behavior when attempting a yielding turn. That is a turn where the driver has to yield for traffic on other sections. This indicates that the cost of traversing the link that the driver is turning from is dependent on the flow on all the right-of-way links in the given situation. Thus in reality the cost function appears inseparable.

However it still seems that these cost functions are widely used. The evolution from the 1950'ies is that with the increased gathered information from the infrastructure the statisticians are able to calibrate the functions to achieve high precision or representivity in specific cases.

The reason for still using this approach is that the computational requirements are insignificant compared to time sensitive cost functions.

Adding time sensitivity leads to the Dynamic Traffic Assignment (DTA). The DTA is actually still using the same cost function, but the surrounding model is expanded to include time as a constructing part of the model. However, the impact is devastating as increasing the time precision affects the number of variables exponentially and cumbersome algorithms must be used to yield usable results.

Dealing with the inseparability however has been a far greater challenge. Even though mathematicians proved the quasi newton search method many years ago only recent papers are applying it.

The delay from mathematical progress until its application in traffic science is up to 20 years. This is far too long to simply have been unnoticed. My assumption is that even though the theories were developed the actual hardware and software for realizing the theory on large and complicated networks was unavailable.

Through the later years computing power and communication possibilities have increased dramatically. This along with general increase in the implementation skills among researches has resulted in new and interesting approaches to precise and representative traffic modeling.

Examples of different models like Complementarity Problems found in [Isac, 1992], Variational Inequality Problems in [Friesz et al., 1989] or [Patriksson, 2004], hydrodynamic modelling in [Lighthill and Whitham, 1955] or Mathematical Programming in [Meschini et al.,], [Pang et al., 1999], [Ran and Boyce, 1996], [Ran et al., 2002b] and [Psaraftis, 1995] show that a wide variety of approaches are being used. [Peeta and Ziliaskopoulos, 2001] provide a more detailed overview of state of the art within DTA.

The most recent and promising research is [Bierlaire and Crittin, 2006], which applies efficient mathematics to get a solution to inseparable time sensitive traffic models. They also cover the newer variant within DTA, the Consistent Anticipatory Route Guidance.

Solving a single instance is however not sufficient to actually support ABIT. It will be sufficient for the immediate dispersion, which only concern a limited area for a short duration, but two questions remain.

Every model constructed considers a specific period of a daily or weekly cycle. As ABIT is pervasive and continuous a definition of the beginning and the end is not directly obtainable. This however is readily addressed by statisticians. Statistical modeling may be used to find critical periods within which a traffic model cannot "end". Extending the period considered beyond this interval will thus allow us to use the regular Traffic Assignment models at an increased time interval. As mentioned above time can have a devastating impact on the solution time. However for immediate dispersion the networks considered are small and the effect is limited.

The research in [Ran et al., 2002a] is also interesting as they consider the issue of non-completed trips.

On the other hand individual alleviation requires consideration of large networks and forecasting. Forecasting is complicated, but as the information is gathered intrinsically in ABIT model construction and calibration will be improved.

Another troublesome issue in individual alleviation is the size of the considered network. However as forecasting introduces some uncertainty actually knowing a section by section path far away is irrelevant. The key issue is an estimate on the time passing through different areas. An overall route is thus planned and as the driver travels along the path all the exact path is known for the local area. The rest of the network is reduced to a number of aggregated junctions that will reduce the number of links and consequently allow us again to use the presently developed models and solvers.

5 Computing Strength

The computing strength has greatly increased over the recent decades. Almost every resource available to the programmer has been increased. At present the computing power is sufficient for solving immediate dispersion and possibly coarse arealizations in individual alleviation. However as the computing power will continue to increase both the immediate dispersion and the individual alleviation will become more representative.

Considering grid computing is possible, but given the obviously very short response times it seems that dedicated computing is preferable. Grid computing may still be applied to precalculate the effect of the most likely disruptions and thus reduce the load on the dedicated servers in those cases.

The increase in both wire-based and wireless communication bandwidth will allow for both distributed and parallel approaches.

6 Vehicle Information Systems

The field of vehicle information systems has evolved significantly over the recent years. From the first high tech version simply telling where you are to the more sophisticated versions today that can propose alternate routes and also illustrate intersection layout.

Most of these information systems however are utilizing only static information of the network. This is as described above insufficient in most larger cities where disruptions occur on a daily basis. Whether the availability of car navigation results in greater frustration when it gives wrong advice is beyond this text. Lately Traffic Message Channel (TMC) as described in [Forum, 2004] is an attempt to alleviate exactly this by automating the distribution of information concerning disruptions.

The existence and increasing usage of TMC enabled devices shows that the technology to distribute information is already deployed and functional. However the delay from detection to broadcast in TMC is significant and coarse compared to the real time possibilities in ABIT.

The newer handheld navigation devices are also promising as they provide not only increased computing power, but also two way communication from the handheld to the Internet by either Global Packet Radio Service (GPRS) or Wireless Local Area Network (WLAN). These technologies however are either costly or not yet deployed sufficiently to actually support ABIT. With the programming tools today it will be possible to make a system that seamlessly can change between any available wireless communication.

Advanced compression is standard in almost any operating system and algorithms for minimizing the amount of transmitted information is available. Along with multicasting this may lead to both efficient and reliable communication.

Freescale's MobileGT Total5200 hardware unit [Freescale, 2004] for vehicles is an example of the level of possible integration.

7 Information gathering and processing

The information is one of the most crucial parts of ABIT. Poor information results in poor representation in the model and thus inadequate flow distributions. This in turn will result in distrust in ABIT. At present ABIT does not include any sanctioning possibilities and distrust will therefore result in ignorance, in which case the system is ineffective.

Gathering the information is readily done manually by video surveillance or semi automatically by sensors imbeded in the road surface. Advanced statistics are applied to this data to increase the usability of the obtained information.

Every single unit in ABIT is capable of obtaining and sending real time information. The coverage and detail of infrastructure status will greatly increase as the number of ABIT enabled vehicles increases. Gathering the informations is thus intrinsically solved by ABIT. The question here is how to handle the possibly devastating mass of information intelligently. However, this is already considered in the hierarchal construction of the solver. Only the local information is detailed. Information on more distant area is aggregated and the information handled at any single area is thus primarily the local information, which naturally is relatively limited. [Roughgarden and Tardos, 2002] calculates the impact of imprecise or out-of-date data in the decision process. The conclusion of their research in relation to ABIT is that slightly out-of-date information is sufficient. However great care must be taken as [Arnott et al., 1991] concludes faulty information leads to exacerbation of congestion in some areas.

8 Conclusion

Since the beginning of the ABIT project three years ago the number of relevant publications has increased dramatically. Movement in the industry as well as the increased rush hour impact for every mayor city indicates that ABIT-like systems are not far from here.

In practice the question of the necessary fraction of ABIT-enabled vehicles is crucial. Is it sufficient to have 10% of the vehicles ABIT-enabled to make a difference or is the critical fraction even higher?

This point is crucial in the future development of real PTI. Having 10 different systems run by different operators requires significantly more enabled vehicles. Hopefully governmental authorities will realize the necessity of highly advanced and cooperating PTI and enforce a common standard as inaugurated with TMC.

Given the lack of enforcible incentive (such as the London congestion charge) for the individual driver, I expect that ABIT or any PTI will only be capable of reestablishing the Nash equilibrium and not obtaining the social equilibrium. ABIT is inherently depending on the autonomous driver and can therefore only try to make a difference.

ABIT Agent Based Individual Traffic guidance

CARG Consistent Anticipatory Route Guidance

CP Complementarity Problems

DTA Dynamic Traffic Assignment

GPRS Global Packet Radio Service

MP Mathematical Programming

PTI Pervasive Traffic Intelligence

TAP Traffic Assignment Problem

TMC Traffic Message Channel

VIP Variational Inequality Problems

WLAN Wireless Local Area Network

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