A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGIES FOR NEW YORK METROPOLITAN AREA

Final Report

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16. Abstract

The increasing challenges in managing and operating transportation systems have behooved transportation agencies to consider innovative alternative technology solutions to improve transportation system performance. The goal of this project is to conduct a comprehensive survey and assessment of the emerging and promising technology that are likely to impact the transportation performance in the NYMTC region. A key purpose of this study is to develop a document which serves as a 'one-stop shop' for emerging technology that may be considered for implementation by the different transportation agencies in the NYMTC region.

The study was divided into the following 6 tasks:
Task 1: Comprehensive Literature Review
Task 2: Initial List of Emerging Technologies
Task 3: Screening of Emerging Technologies
Task 4: Shortlist of Emerging Technologies
Task 5: Assessment of Shortlisted Technologies
Task 6: Conference and Final Report

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Executive Summary

This study was commissioned as part of the update of NYMTC's Regional Transportation Plan and was conducted under the guidance of the Regional Transportation Plan Committee.

The increasing challenges in managing and operating transportation systems have behooved transportation agencies to consider innovative alternative technology solutions to improve transportation system performance. The goal of this project is to conduct a comprehensive survey and assessment of the emerging and promising technology that are likely to impact the transportation performance in the NYMTC region. A key purpose of this proposal is to develop a document which serves as a 'one-stop shop' for emerging technology that may be considered for implementation by the different transportation agencies in the NYMTC region. A key purpose of this study is to develop a document which serves as a 'one-stop shop' for emerging technology that may be considered for implementation by the different transportation agencies in the NYMTC region.

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Task 1: Comprehensive Literature Review

The review covered three broad NYMTC goals of (i) congestion reduction and management, (ii) safety and security systems, and (iii) air quality improvement and environmental impact mitigation. Both national as well as international studies have been included. The studies have been classified into sub-categories under each of the above broad categories. These classifications were based on transportation goals of NYMTC. Therefore they have been classified together as "Goal driven". On the other hand, several studies were focused on particular technologies instead of specific goals. These technologies have been classified as "Technology driven". Every "Goal driven" study is further classified into sub-categories under the three broad goals listed above. In addition few studies mainly focused on assessment/evaluation of a technology; these have been classified as "Assessment" studies.

The most important technologies from the literature review are summarized under each category below.
Congestion reduction and management:

1. Current major trends include congestion pricing and the use of ATIS.
2. However significant scope for improvement exists in these technologies including distance-based pricing and active travel guidance systems using vehicle-to-vehicle communication and VII systems.
3. Other congestion reduction and management strategies include telecommuting, ramp metering, and improved transit service (bus signal priority, information, etc.).

Safety and Security:

1. Among safety systems crash avoidance systems hold immense promise. These systems will utilize sensors to detect vehicle, environment, and driver characteristics and determine crash possibilities using intelligent algorithms.
2. Pedestrian safety systems that alert driver of presence of pedestrians in their path or pedestrian detection systems at pedestrian crossing.
3. Biometric identification

Air Quality Improvement:

1. Use of bio-fuels and hybrid vehicles are emerging in the short-term;
2. In the longer term hydrogen fuel vehicles may offer better benefits. However currently the operational costs and lack of institutional support hinder the use of hydrogen fuel on a large scale.

The above systems for achieving different goals are enabled because of developments in diverse technologies. These technologies include wireless communication systems, advanced sensors, electronic payment, and biometric identification among others.

Task 2: Initial List of Emerging Technologies

In this task, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared.

Emerging technologies were classified under the following categories based on the development stage of the technology:

1. Technology that is already developed and implemented elsewhere but has not yet been adopted in the NYC region.
2. Technology that has been prototyped but has seen limited to no real implementation.
3. Technology that is still at the conceptual stage.

Since 15 to 20 years is a long time in transportation technology cycle, the project team undertook a visioning process. The visioning process was done in two steps. First, it was recognized that technology advancements in several fields are likely to impact transportation and travel. Therefore in the first step, these broad technological domains and their general trends were identified. The broad technology domains studied include:

a) Nanotechnology
b) Energy and Fuel technology
c) Communication technology
d) Computing and Internet technology
e) Transportation, Vehicular and Automotive technology
f) Sensors
g) Freight technology

The second step of the visioning process involved identifying the potential impacts of the technological developments on transportation in general and transportation technology in particular. Further, fact-sheets of each technology were prepared which include details on features, timeline/costs, transportation applications, and challenges.

Task 3: Screening of Emerging Technologies

In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility.

A total of forty-six technologies were identified (see list below). In order to obtain a better understanding of the forty-six technologies listed above, a survey of existing studies was carried out. Information was gleaned from these existing studies and a database was constructed to store the information.

List of Technologies
Nanotechnology 1. Nano-sized batteries 2. Nano Fuelsaver 3. Fuel-cell Nano Catalyst 4. Nanosensors 5. Carbon-based nano-fibres 6. Nanocoating of metallic surfaces

7. Nanoparticle-reinforced materials
8. Nanomaterials in pavements
9. Automatic healing materials

Energy and Fuel technology

10. Hydrogen Fuel
11. Biodiesel Fuel
12. Ethanol Fuel
13. Methanol Fuel
14. Natural gas
15. Propane
16. Biogas Fuels
17. Biobutanol Fuels
18. Hydrogenation-Derived Renewable Diesel
19. P-Series
20. Ultra-low sulfur diesel
21. Electric-driven vehicle

Communication

22. Dedicated Short Range Communications (DSRC)
23. Wide area wireless communication *
24. Ultra high-speed Internet *
25. Vehicular Ad Hoc Networks (VANETs)

Computing and Internet Technology

26. Collaboration software *
27. Augmented Reality *
28. Personal travel assistant
29. HD video conferencing *
30. Advanced route guidance systems
31. Adaptive ramp metering

Transportation, Vehicular, and Automotive Technology

32. Small wheeled transport
33. Hybrid vehicles
34. Personalized rapid transit (PRT)
35. Automated vehicles
36. Flying cars
37. Waterbridge

Sensor Technologies

38. GPS
39. Radio Frequency Identification (RFID)
40. MEMS sensors
41. Smart Cards
42. Machine Vision
43. Biometric Identification

Freight Technology

44. Automated Guided Vehicles
45. Automated Container Transport system

46. Pick-up centers

***Note**: The technologies relevant to telecommuting have been marked with a **

The decision making process for screening the technologies was done in two stages. In the first stage the most appropriate goals or policies that are relevant to NYMTC was screened, and in the second stage the economic and technical feasibility of technologies useful for achieving the goals was assessed. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members.

There were 14 total responses. An important result from the survey is the ranking of the different policy sub-categories. Energy consumption is the highest ranked policy sub-category followed by transit-system improvements. Highway system improvements, transportation demand management strategies (including telecommuting), ITS, and highway safety are ranked next. These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist for task 4.

The feasibility assessment questionnaire was completed by 7 respondents including two outside experts. Feasibility assessment included both technical and economic feasibility. We present the average rating for the technical and economic feasibility and also provide a joint weighted measure. The technologies are ranked based on this weighted measure. The top 5 technologies in terms of the joint feasibility measure are GPS, HD video conferencing, machine vision, ultra-low sulfur diesel, and biodiesel fuel.

Task 4: Shortlist of Emerging Technologies

The methodology for shortlisting technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. A weighted sum method was used to obtain the rankings of the technologies. Since the focus on technologies have always been toward meeting the three broad goals of congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals were prepared.

Based on the ranking of the technologies and the project team's reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

The shortlisted technologies include:

Congestion Reduction and Management
Geographic Positioning Systems and Personal Travel Assistants
Adaptive Ramp Metering
Smart Cards and RFID
Personalized Rapid Transit
Collaborative Technologies

Safety and Security
Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication Machine Vision
MEMS and Nanosensors
Automated Vehicles
Biometric Identification

Energy and Environment
Natural Gas and Propane
Biogas
Bio-diesel and Ethanol

Electric-driven and Hybrid vehicles
Hydrogen Fuel

Task 5: Assessment of Shortlisted Technologies

In Task 5, technologies in each of the broad categories – congestion reduction and management (CRM), safety and security (S&S), energy and environment (E&E) – were ranked using the weights obtained from pair wise comparison process. Input is obtained from several experts to assist in the assessment process. Assessment is based on two criteria including the contribution of each technology towards the listed goals and the likely acceptance/growth of the technology in the NY metropolitan region.

In order to obtain pair wise comparison values a survey questionnaire was developed. The questionnaire was divided into five sections. Two sections each related to congestion reduction and management, and safety and security technologies, and one section dealing with energy and environment technologies. The first section in each of the technology categories included questions on pair wise comparison of the technologies with respect to the effectiveness of the technology towards meeting the broad category goal. The respondent chooses which of the two technologies compared are more effective towards meeting the broad category goal and then rates on a scale from 1 to 9 (9 being absolutely more effective) the relative importance or effectiveness. The remaining two sections obtained input on the degree of likely penetration of the technology or the future likelihood of implementation in the case of less developed technologies.

The criterion for comparison of the CRM technologies was "impact on congestion reduction". On the overall, GPS and Personal Travel Assistant was ranked the most effective (average weight of 0.27), followed by Smartcards and RFID (0.24), Collaborative technologies (0.22), adaptive ramp metering (0.21), and personal rapid transit (0.07). However, no single technology has emerged as a clear winner; this is according to the expectation that several varied technologies all have an interdependent role to play towards reducing congestion. In terms of the likelihood of implementation of the different technologies, personal rapid transit was widely perceived as an "unlikely" technology even in the next 20 years. On the other hand, the experts collectively regard webinars and video conferencing as the "likely to highly likely" method for business meeting in 20 years. In terms of the degree of penetration, GPS and personal travel assistants are likely to be used by 56.6% and 80.6% percent of individuals after 10 and 20 years respectively. Smartcards and RFID as well as Collaborative technologies are also likely to be widely used with over 70% estimated on average after 20 years. Given their potential to impact congestion, such high penetration could significantly help mitigate congestion over the next two decades. A related question on the percentage of work trips that are likely to be replaced by collaborative technologies, the average response was over 30% after 20 years.

The comparison in the S&S category was restricted to only the three technologies listed since automated vehicles were considered to be a superset of these three technologies. Also, biometric identification was treated as security technology and was not included in the comparison below. The overall response rating for the question "which technology is likely to improve safety to a greater extent?" yielded the greatest average weight for Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication technology, followed by MEMS and Nanosensors, followed by Machine Vision. In terms of the degree of penetration, MEMS devices had the greatest degree of penetration (34.3% after 10 years and 61.7% after 20 years). Over half-the-vehicles are likely to be equipped with V2V and V2I capabilities 20 years hence. Further, over a third of the vehicles 20 years hence are likely to be automated vehicles. Such high degree of penetration can have significant impacts towards improving road safety. In terms of the likelihood of implementing biometric identification for fare payment as a security measure, the overall average response remained neutral. However, 55% of respondents indicated a positive likelihood of such a technology being implemented.

The question posed to the experts evaluating the E&E category of technologies was:

"A key determinant of future energy sources is the set of policies adopted by governments and corporations involved in energy production. In terms of these policy decisions over the next 20 years which fuel types are more likely to be developed and promoted?"

As expected, electric and hybrid fuel vehicles were collectively ranked the highest (weight = 0.44). Unlike the previous two categories, electric and hybrid vehicles appear to be significantly more important than the next important fuel technology: Natural Gas and Propane (0.18). Surprisingly, Biodiesel and Ethanol has a lower weight than Natural Gas and Propane – perhaps indicative of growing concerns regarding food security. Hydrogen fuel is ranked 4th and had a high coefficient of variation – this is perhaps because of the limited success of the so far. At the same time, the immense promise of hydrogen as a transportation fuel must have triggered few of the respondents to rank it highly.

Task 6: Conference and Final Report

The final task of the project was the conference. Four experts in the areas of telecommuting, congestion reduction, safety, and fuel technologies made presentations and moderated break-out sessions. Over 60 participants representing the various stake-holders in the region attended the conference. The feedback from the participants and the results and insights obtained in the break-out sessions are summarized.

Contents

Chapter 1: Introduction

The increasing challenges in managing and operating transportation systems have behooved transportation agencies to consider innovative alternative solutions to improve transportation system performance. Recently, the International Technology Scanning Program at the Federal Highway Administration (FHWA) conducted an international technology scan to evaluate innovative technologies and practices in other countries that could significantly benefit U.S. highway transportation systems. This approach allowed for advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to re-create advances already developed by other countries. It was shown that there was large savings of research dollars and time, as well as significant improvements in the Nation's transportation system[1]. Similar technology solutions addressing the unique challenges in New York State (NYS) can have far-reaching impacts towards developing the state's transportation system.

In the context of NYS, New York Metropolitan Transportation Council (NYMTC) is at a crossroads in transforming the transportation system to address the new challenges and opportunities brought forth by increasing globalization and technology innovation. To capitalize on its past success, NYMTC and other transportation agencies have to synthesize the emerging technology innovations to address current and future transportation challenges. The need for performing this synthesis is further motivated by the following facts:

1. The NYMTC Congestion Management Process Status Report 2005 reports that the total daily cost of congestion is $26 million for the entire NYMTC region. This is expected to increase to $30.6 million by the year 2030.
2. The total number of fatalities in New York State in 2004 was 1493. Though the number of fatalities per 100,000 registered vehicles (13.25) was less than the national average of 17.92, the costs to the state are high. The 2000 estimated economic cost due to motor vehicle crashes to New York State was $19.49 billion. The corresponding per capita cost was $1,027 which was higher than the nationwide average per capita cost estimated at $819.
3. Finally, air quality is a primary concern for the region under NYMTC since it is a severe ozone non-attainment area.

Reducing congestion, increasing safety, and minimizing environmental impacts are three broad goals of metropolitan transportation organizations. Investment in road infrastructure while addressing the first two goals, adversely impacts the environment because of increased emissions. Further, providing additional road infrastructure leads to the problem of induced demand and within few years the new infrastructure is often rendered inadequate. The lack of land space for infrastructure expansion and the prohibitive cost of capital investment act as further deterrents to road expansion. An important alternative strategy is the *utilization of emerging new technologies* to meet the above three goals. In the context of this proposal, transportation technology is defined as 'a scientific/engineering method, device or material used to achieve transportation objectives'. This definition is broad and includes both hardware technology such as vehicular technology, vehicle detection systems as well as software technology such as automated vehicle

[1] See: http://international.fhwa.dot.gov/traveldemand/t1_p02.htm

navigation system, advanced traveler information systems. Software technology includes modeling and algorithmic advances for transportation. In practice, hardware and software technology may be utilized both independently as well as jointly to improve transportation system performance.

The goal of this project is to conduct a comprehensive survey and assessment of the emerging and promising technology that are likely to impact the transportation performance in the NYMTC region. A key purpose of this proposal is to develop a document which serves as a 'one-stop shop' for emerging technology that may be considered for implementation by the different transportation agencies in the NYMTC region.

Learning from the Past

The rapid advances in technology in diverse areas – including nuclear energy, computing, communication, medicine – over the last century shows the significant strides humans have made and yet we are faced with significant challenges and opportunities to push the technology frontier to newer heights. Predicting the path of future technology growth is a complex task. The variables are many; in addition, serendipitous discoveries could change the growth course in unexpected ways. Yet, forecasting the future of technologies is not merely guesswork nor do we have a crystal-ball to provide us a peek into the future. We need a systematic process to identify and track patterns. Through a combination of extrapolation of the past and a future visioning process we are able to make more scientific and educated predictions of the future. The systematic process could include literature review, market research, expert opinions, computer models, and interactive discussion sessions. However before starting the systematic process we need to learn the lessons from the past.

Over a 100 years back we saw the dawn of automobiles. Cars were considered the ideal solution to all the problems faced by New York city congested with slow-moving horse drawn carriages. A Scientific American Article in 1890's stated[2]: "If there are faults" with cars, the editors concluded, "only time is wanted to make them disappear…. There is no mechanism more inoffensive, no means of transport more sure and safe." New York City in 1900 was faced not only with congestion due to the horse carriages but also environmental problems: the horses dumped four million pounds of manure every day. The air which was infested with bacteria caused respiratory diseases. Tuberculosis rates plummeted in 1920s after the horses were replaced with cars. Horse carriages were also posing safety threats. In 1900, 200 people died from accidents involving horses in New York City – in contrast, in 2003, there were a total of 343 fatalities in New York City[3]. Often technology change is necessitated by current problems. At the turn of the last century, Automobile was widely favored to replace horse-carriages owing to its congestion, environmental, and safety problems. And yet, 100 years later, cars are the cause of congestion, safety, and environmental problems faced by New York City transportation planners. A simple extrapolation of the trends from horse-carriages to cars may be extended to forecast a shift from cars to flying vehicles where vehicles are now able to travel in space and therefore opening up the possibility for several orders of magnitude increase in throughput capacity – however, the degree of maturity of such technologies is still in primitive stages and we may not travel in flying cars to work within our lifetimes. Over the next 20 years, it is likely that less path-breaking changes would continue to provide the changes necessary to meet the problems of congestion reduction, safety improvement, and environmental impact mitigation.

The technology changes that could likely impact transportation in the future need not necessarily be restricted to transportation technologies. For example, advances in communication and computing technology could

[2] Transportation's perennial problems. Scientific American; Oct 97, Vol. 277 Issue 4, p54

[3] http://www.uctc.net/access/30/Access%2030%20-%2002%20-%20Horse%20Power.pdf (accessed 10/20/2008)

enable high-definition TV business meetings that could significantly reduce the number of work trips. Therefore, it is important to consider a broad range of technology domains when evaluating emerging technologies. Prediction of future technologies or emerging technology scan has been carried out in the past by several agencies in the recent past. Here we briefly review a few of these studies.

Past Technology Prediction Studies

A RAND monograph on global technology trends by the year 2015 released in 2001 provides broad trends in Bio / Nano / Materials technologies[4]. They postulate that by the year 2015 the growth in several diverse areas of technology resulting in information availability and its utility will impact social, economic, political and personal aspects of our lives. Effects could include improvements to human quality of life and life span, high rates of industrial turnover, continued globalization, redistribution of wealth, cultural amalgamation/invasion, shifts in power from nation states to NGOs and individuals, mixed environmental effects, and possible human eugenics and cloning. They also identify factors that could impact technology change: local acceptance, investments, market, and technology breakthroughs. Broadly, the identify the following areas of technology: bio-technology; materials and devices including smart materials, agile manufacturing, nanofabrication, and integrated Microsystems; and technology wild cards such as nanoscale computers, molecular manufacturing, and self-assembly. Midway from the prediction year of 2001 to the predicted year of 2015, it may be said that while few of the areas identified above have seen significant improvements several other areas have not achieved the expected level of improvement and may need a decade or more to realize the predicted potential.

Another report by Arnall[5] (2003) for Greenpeace Environmental Trust explored emerging technologies within the domains of nanotechnology, artificial intelligence (AI), and robotics. The focus of this emerging technology study was particularly geared towards potential environmental consequences of these technologies. A conclusion in this study is the difficulty to provide decisive conclusions due to the dynamism and uncertainty in these industries. They also draw an interesting comparison to prevailing mood with respect to these technologies. Nanotechnology being "new" was perceived as an exciting and new branch of science while AI was viewed as a highly specialized field with little proven results. The skepticism with AI may be because of the over-optimism surrounding the field in the 1960s to 1980s. It also alludes to the several barriers that exist for technological development – a promise of benefits, however significant it might be, alone does not ensure the success of an emerging technology. Sustained, significant proven results alone will ensure the acceptance of new technologies.

The magazine Popular Science also publishes articles on emerging technologies. While several such predictions have time and again proven to be overly optimistic, few studies surprise with their preciseness. An article in 1998[6], report Department of Energy's Pacific Northwest National Laboratory predictions that within a decade cars are likely to run 80 miles for a gallon of fuel, houses would be embedded with tiny heat pumps that could significantly reduce energy consumption, and advanced displays and wireless communications will lead to a paperless society. None of which have been completely realized. Similar optimism is observed when NASA along with Industry partners started in 1990 the High Speed Civil Transport (HSCT) project that envisioned speeds of Mach 2.4 (1600 mps) for

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[4] http://www.rand.org/pubs/monograph_reports/MR1307/index.html

[5] http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf

[6] Technologies for a cleaner world, Dawn Stover. Popular Science. New York: Aug 1998. Vol. 253, Iss. 2; pg. 28, 1 pgs

passenger aircrafts by 2010. Even till 1998, it was anticipated that the project is likely to succeed[7] however the project was stopped in 1999.

There are a few studies that evaluate its predictions and comment on what went wrong in retrospect. For example, an article titled Looking Back in Popular Science[8] lists the different predictions that went right and those that failed. An interesting example is the Personal Rapid Transit (PRT). In 1971, PRTs were viewed as “a radically different way of getting to work, across town, or to the airport-when you want to get there. Fast, comfortable Personal Rapid Transit promises to be an attractive substitute for the automobile in our traffic-choked cities.” However, by 1995 it was noted that “beyond some limited applications, this vision has yet to be efficiently exploited.”

An example of more accurate prediction is the “information superhighway”[9]. Below is an extract from the article and reflects remarkable accuracy of the present state of the art:

> “The vision is simple: an unprecedented nationwide--and, eventually, worldwide--electronic communications network that connects everyone to everyone else and provides just about any sort of electronic communication imaginable. You'd be able to hook up to the network through your computer, interactive TV, telephone, or some future device that somehow combines the attributes of all three. Even wireless gadgets such as pagers, future versions of cellular phones, and newfangled "personal digital assistants" would be able to tap into the highway.”

Other examples of technology scan studies include the series of international technology scan studies conducted by the Federal Highway Administration, US Department of Transportation[10]. Example of studies conducted include international scan of advance transportation technology (1995), scanning report on traffic management and traveler information systems (1998), innovative traffic controls technology and practice in Europe (1999), advanced traveler information systems in Europe (2003), and active traffic management: the next step in congestion management (2007).

Roadmap

The above studies provide a basis for the overall structure of our study. An emerging technology scan for New York Metropolitan region is broad by definition. To preserve the breadth of studies we carry out a literature search – including different goal categories, technology drivers, and assessment practices both nationally and internationally – and subsequently undertake a visioning process within an identified set of broad technology domains. This provides us an initial list of emerging technologies. In order to identify the likelihood of emergence of plausible technologies additional input was obtained from Regional Transportation Plan committee members, academicians, and industry experts. Technologies were shortlisted and assessed using group decision making theory. Finally, broad trends of shortlisted technologies were obtained. The overall study was divided into six tasks: The study was divided into the following 6 tasks:

Task 1: Comprehensive Literature Review
Task 2: Initial List of Emerging Technologies
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[7] 21st century SST, Bill Sweetman. Popular Science. New York: Apr 1998. Vol. 252, Iss. 4; pg. 56, 5 pgs

[8] Looking back, Sillery, Bob. Popular Science. New York: Nov 1996. Vol. 249, Iss. 5; pg. 112, 1 pgs

[9] The complete survival guide to the information superhighway, Popular Science. New York: May 1994. Vol. 244, Iss. 5; pg. 97

[10] http://international.fhwa.dot.gov/

Task 5: Assessment of Shortlisted Technologies
Task 6: Conference and Final Report

The rest of the report is divided into chapters – each devoted to the methodology and findings of each of the tasks listed above.

Chapter 2: Literature Review

Task 1 of the project is a comprehensive review of existing literature. Since the scope of the project is very broad, the literature review was carried out in several stages. The "Goal driven" studies were categorized broadly into three main goals of (i) congestion reduction and management, (ii) safety and security systems, and (iii) air quality improvement and environmental impact mitigation. Within each of the categories, sub-categories were identified. Table 1 below provides a complete list of the sub-categories investigated.

Table 1 List of Goal Categories and Sub-categories

Congestion Reduction and Management

1. Congestion pricing
2. Electronic freight management
3. Highway system improvements
4. Incident management
5. Intelligent Transportation Systems (ITS)
6. Inter-modal transfer technologies
7. Parking management
8. Pedestrian and bicycle systems
9. Transit system improvements
10. Travel Demand Management
11. Traveler Information Systems

Safety and Security Systems

1. Collision Avoidance
2. Crash Assessment
3. Driver Condition Warning
4. Emergency response
5. Freight security
6. Lane Change and Merge Collision Avoidance
7. Pedestrian safety
8. Road Departure Collision Avoidance
9. Vehicular safety technology
10. Weather and Safety
11. Work Zone Safety
12. Grade Crossing

Air Quality Improvement and Environmental Impact Mitigation

1. Fuel based
2. Hazardous materials safety
3. Infrastructure based
4. Vehicle based

The sub-categories in Table 1 were used as keywords to search in several transportation databases and search engines. Table 2 is a list of the databases and search engines used in the search.

Several studies were focused on specific technologies or the evaluation of technologies. These were grouped under separate perspectives – "Technology Driven" and "Assessment". However, these studies were categorized along the same lines as shown in Table 1.

Table 2 List of Databases and Search Engines

Link: Brief Description
http://ntlsearch.bts.gov/tris/index.do : National Transportation Library
http://database.path.berkeley.edu/reports/index.cgi : UC-Berkeley, PATH database
http://library.ctr.utexas.edu/index.html : Center for Transportation Research, U-Texas
http://www-mtl.mit.edu/researchgroups/itrc/itrc.html : ITRC, MIT
http://www.civitas-initiative.org/main.phtml?lan=en : European Commission
http://www.ertico.com/: Intelligent Transport Systems and Services in Europe
http://www.calccit.org/itsdecision/ : ITS Decision Web site
www.google.com : For general search such as news articles, company profiles

Comprehensive Literature Review: Brief Description of Studies

The studies were entered into Microsoft Access database program. The database generates a report of all the studies listed with brief descriptions of each study. Here we present a brief summary of the technologies. The references to particular studies are through the unique identification number of the study in the database.

The studies have been grouped based on three perspectives: Assessment, Goal-driven, and Technology-driven. Assessment perspective deals with evaluation of technologies (for example, cost-benefit analysis). Goal-driven perspective deals with a system of technologies that work together to achieve a policy goal (for example, congestion pricing). Technology-driven studies are those that describe a particular technology in detail which have potential applications in possibly several transportation objectives.

Goal-driven Perspective

The goal-driven perspective was further sub-divided into three main categories: Congestion Reduction and Management, Safety and Security systems, and Air Quality Improvement and Environmental Impact Mitigation.

Technology use for **Congestion Reduction and Management** (CRM) goals is more prevalent. Foremost of the strategies for CRM is **travel demand management (TDM)**. This will be elaborated in this section. Several different TDM strategies exist including congestion pricing, telecommuting, Carshare, and improved transit options (for a more detailed review of TDM strategies please refer to: http://www.vtpi.org/tdm/).

Congestion Pricing

Among the most successful demonstrations of *congestion pricing* is the London Congestion Charging scheme (G74). In order to support the existing congestion charging scheme Transport for London conducted a two stage evaluation of future technologies that could be implemented. They concluded that DSRC-based technologies are feasible to operate in an urban environment however distance-based charging may not be practical. The United Kingdom is also exploring the feasibility of a nation-wide road user charging scheme (G51). Several challenges are identified that include both political as well as technical challenges. Other countries where congestion pricing or some form of road pricing has been considered include Japan (G50), France (G45), Singapore (G39), and Norway (G40).

Several alternate technologies are available for enabling congestion pricing. These include dedicated short-range communication (DSRC), wide-area communication based systems, and video-based license plate recognition software (G80). The primary disadvantages of DSRC based systems are the speed restrictions on vehicles while passing the tag readers and the lack of direct enforcement on violating vehicles. Wide-area communication systems use a combination of GPS technology for tracking and GSM/DSRC technology for communication. The advantage of wide-area communication systems is the capability for distance-based and zone-based charging. However difficulties with determining exact location using GPS in densely-built urban areas have hindered its implementation (G75, G76).

Ukkusuri et al. (314) present a comprehensive synthesis and an evaluation framework for congestion pricing technologies. They compare different congestion pricing technologies: manual toll booths, automatic number plate recognition, DSRC, GPS, Infrared communications, and RFID. The technologies were compared along four main characteristic measures: economic, operational, impacts/integration/flexibility, and other measures such as credibility, availability of suppliers, and privacy. The technology evaluations were carried out using ELECTRE IV algorithm. The main insights from their study include:

(1) Given the performance measures, RFID is the best technology to implement, though this does depend on the desired pricing scheme.

(2) The subjective rankings of enforcement and privacy have significant impacts on the ultimate technology rankings. The implication from this insight is that technology that handles these issues better is more readily accepted and useful.

(3) GPS will become the preferred technology if its cost, reliability and privacy issues are adequately addressed.

Telecommuting

Telecommuting is yet another example of TDM strategy that is being successfully implemented. Though telecommuting was considered as early as 1980s and was considered a failure in the mid 90s (Technology Review, Vol 98, Iss 5), rapid advances in communication and computing technology in the last decade have made telecommuting an attractive TDM strategy. Choo, Mokhtarian, and Salomon (Transportation, Vol 32, 1) develop aggregate time-series models to examine the impact of telecommuting. Their models suggest that "telecommuting reduces VMT, with 94% confidence. Together with independent external evidence, the results suggest a reduction in annual VMT on the order of 0.8% or less. Even with impacts that small, when informally compared to similar reductions in VMT due to public transit ridership, telecommuting appears to be far more cost-effective in terms of public sector expenditures." Advances in video-conferencing and Internet and the growing transportation congestion problems have made telecommuting more attractive. Dedicated organizations (www.telcoa.org) and companies (www.telecommutect.com) have sprung up to support telecommuting initiatives. Other than driving alone, telecommuting is the only commute mode that has gained market share since 1980 (322). In 2005, 4.5 million Americans telecommute on most work days, roughly 20 million telecommute at least once per month, and 45 million once a year (322).

Electronic freight management powered by advances in freight identification and tracking technology can contribute towards CRM. Electronic freight management allows both shippers and transportation enforcers to better monitor the freight technology movement and thereby identify problem areas and identify solutions. In addition "intelligent freight technologies are used to improve freight system efficiency and productivity, increase global connectivity, and enhance freight system security against common threats and terrorism. These technologies are currently deployed in several areas: 1) asset tracking, 2) on-board status monitoring, 3) gateway facilitation, 4) freight status information, and 5) network status information" (L16).

Highway system improvements are a direct method towards congestion mitigation. Technologies that are used for highway system improvements include advanced signal management (G94, W2), freeway and arterial performance measurement (G7) and the use of the performance measurement in access management (G2). A traffic responsive signal control plan (G94) was successfully installed, verified, and demonstrated in three cities (Chania, Southampton, and Munich) in United Kingdom. The United Kingdom has also demonstrated the use of motorway access management strategies recently (G2).

Besides direct improvements to highway systems and auto-use disincentive measure of congestion pricing, CRM objectives may also be achieved through **improved transit service**. An important and tested strategy for transit service improvement is transit signal priority (TSP). The FTA has prepared a handbook about Transit Signal Priority implementation (G65). Another study has shown the need for a 'bundle' of technologies to encourage transit use. This study (G21) recommends the use of exclusive bus lanes and ITS technology in addition to signal priority to encourage transit-oriented development. A key issue with transit ridership is the ease of access to transit. Researchers at PATH, University of California, Berkeley (G34) demonstrate the use of "shared-use, low-speed mode vehicles, smart parking management systems, electronic lockers, and power supplied by hydrogen fuel cell" to address the issue of ease of access to transit.

Advanced Traveler Information Systems

The above studies focused on directly influencing the travel environment thereby inducing favorable travel choice shifts. Often, inefficient travel choices are a result of lack of adequate information. **Advance Traveler Information Systems** seek to ameliorate congestion by providing the road users with appropriate information. Several studies discuss the implementation of ATIS (L17, L36, L27) however the overall architecture and the true potential of TIS remains to be realized. Current implementations primarily focus on a centralized architecture and passive guidance where only information on network state is provided to individuals. A centralized architecture is both expensive and has scalability problems. An alternative emerging architecture involves decentralized vehicle-to-vehicle communication based architecture. Further, a decentralized architecture enables information to be delivered to each vehicle separately thereby allowing for active guidance where information on alternative routes, modes, and departure times can be delivered to each individual in real-time. The benefits from such architecture have not yet been fully understood though the opportunity remains promising. Recently the focus has been on Vehicle-Infrastructure Integratoin (VII). VII involves combining information from both vehicle and infrastructure sources and to use it to improve the operational capabilities of both vehicle and infrastructure systems (G29). A recent research effort involving Caltrans, California PATH and DaimlerChrysler RTNA demonstrated two VII services: one in traffic data probes and another with safety, using real cars and on Caltrans roadways (G24). Vehicle-Infrastructure integration and the use of decentralized vehicle-to-vehicle communication systems hold immense potential to operationalize truly real-time travel guidance systems. Besides the above applications, information systems also play a direct role in demand management (L23) and in improving toll charge information dissemination and collection process (L49).

Safety systems' is the third category under which goal-driven technologies were reviewed. Among safety systems the technologies reviewed were collision avoidance systems, driver condition warning systems, and pedestrian safety systems. All of these systems incorporate some sort of sensor technology, intelligent algorithms to compute likelihood of crash, and communication or automatic remedial action to ensure safety. Collision avoidance systems comprised vehicle-vehicle collision avoidance systems (W9), crash warning system interface (W20), lane change and merge collision avoidance (W11, W12), and road departure crash warning systems (W14, W19). The most advanced of these collision avoidance systems take into account: (i) the trajectory of the vehicle with respect to vehicles in the vicinity and the road environment, (ii) road conditions including pavement deterioration, curvatures, and presence of water/ice/foreign material on the surface, and (iii) the driver and passenger characteristics including details such as the eye gaze direction and alertness of the driver.

Driver condition warning systems seek to alert the driver in the case of lack of vigilance or in the event of impending accidents/emergency. The AWAKE project in Europe (W4) demonstrated a driver condition warning system based on diagnosis of driver's lack of vigilance in real-time. The diagnosis is based on both driving behavior (lane violation, speed) and physiological diagnosis (driver's eyelid activity, grip pressure etc.).

Pedestrian safety systems are either in-vehicle sensor and warning systems that alert driver of presence of pedestrians in their path or pedestrian detection systems at pedestrian crossing that switch pedestrian signal to walk mode in their presence. The former help avoid pedestrian-vehicle crashes by alerting the driver and pedestrians of a possible collision while the latter discourages pedestrians violations at signals.

Air quality improvement studies were classified into two different approaches: fuel-based technology and vehicle-based technology. Among fuel-based technology the most promising were the use of Hydrogen-fuel and bio-fuel. The European Commission conducted a comprehensive study (W26) on using Hydrogen as an alternative source of fuel. Besides outlining the expectations from using Hydrogen in transportation, the study also examined the feasibility of hydrogen supply infrastructure and demonstrated examples on buses (W27). The hydrogen bus trials were carried out for a two-year period and the total system availability was 80% which is lower than diesel or CNG bus fleet. However, the main emphasis of the demonstration project was to show the technology is workable.

The Alternative Fuels Study report (W69) tabled at the Congress by the US DOT presents a comprehensive picture of current practices and future trends of alternative fuels in the US. The study concluded that there are clear and immediate benefits from alternative fuels:

"In the longer term, depending on the source of the hydrogen, vehicles powered by hydrogen in fuel cells or internal combustion engines may ultimately be cleaner than other alternative fuel or diesel engines. Further, electric transit vehicles offer performance and noise reduction benefits and emit no exhaust gases, but their net environmental benefit depends on controlling emissions from the fuel used to generate electricity. Finally, hydroelectric, wind and solar generation of electricity produces no emissions, and so may become the optimal power source for hydrogen fuel cells or electric vehicles of all kinds."

However, they also report that "Every alternative fuel reviewed in this study imposes some combination of increased capital costs, operating costs, technical challenges, or institutional issues as compared to diesel fuel." The use of alternative fuels still requires considerable government backing in terms of favorable institutional changes and wide spread use to realize economies of scale. In the short-term substituting diesel with alternative bio-fuels and/or using hybrid mix of fuels appears to be the best strategy. However, in the longer term switching to hydrogen fuel may be more efficient and cleaner alternative.

Besides fuel-based technologies, air quality improvements can also be realized from vehicle-based changes. Both car manufacturers and the government have taken initiatives to ensure reduction in emission in vehicles. In the United Kingdom, a Clean Vehicles Task Force (W18) was established to encourage the manufacture and purchase of vehicles which are "cleaner, quieter, more fuel-efficient, and less resource intensive". Another vehicle-based initiative involves the use of electric vehicles and hybrid vehicles. The governmental agencies could play a lead role in encouraging their use. For example, in Italy, the Municipality of Reggio Emilia (W29) is currently using electric cars for municipal services and home assistance to elderly and disabled persons. In 1996, the technology review magazine (Technology Review, Vol 99, Issue 1, p30) examined the prospect of electric vehicle usage in the United States. The article identified several economic disadvantages of electric vehicles and emphasized the need to promote alternate technologies such as the Hybrid Vehicles. Hybrid vehicle sales have increased an average of 72 percent a year for the past five years and since 1999 the hybrid vehicles have saved close to 230 million gallons of fuel in the United States (source: The National Renewable Energy Labs).

Technology-driven perspective

Several diverse technologies were reviewed from this perspective. While most of the technologies had specific application or goal focus, few of them were more general and had a wide application potential. The technologies are presented sequentially here.

Adaptive ramp metering algorithms: advances in traffic sensors, communication, and control algorithms have enabled the implementation of adaptive ramp metering strategies. Researchers at PATH, University of California at Berkeley design and implement an adaptive ramp metering algorithm (G10). Evaluation of their algorithm on simulation platform yields 8.4% savings in total travel time on a 14.1 mile long freeway section.

Wireless communication systems: sensors with wireless communication capabilities have transformed traffic data collection methods. A guidebook (319) for selecting between alternative technologies for wireless communication is available. Newer architectures are also being developed with vehicles playing the part of communication transfer nodes also referred to Vehicular Ad-hoc Networks (VANET). L61 is an example of application of VANET for providing safety and commercial services. Rahman and Hengartner (322) report the use of VANETs for automatic vehicle crash event recording and communication to enable quick response and accurate data for investigators to reconstruct the events. Another VANETs project is the Cooperative Vehicle-Infrastructure Systems (CVIS, www.cvisproject.org). CVIS is a major new European research and development project aiming to "design, develop and test the technologies needed to allow cars to communicate with each other and with the nearby roadside infrastructure." Besides the technological advances, the CVIS project is also focusing on "key 'deployment enablers' such as user acceptance, data privacy and security, system openness and interoperability, risk and liability, public policy needs, cost/benefit and business models, and roll-out plans for implementation."

Electronic vehicle identification and toll collection technologies: Vehicle identification is an important component for automated toll collection. Several alternatives exist for electronic vehicle identification. Persad et al. (316, 317) reviews industry standards, performance, and costs of electronic vehicle identification technologies. Electronic vehicle identification also enables accurate determination of traffic and demand parameters when data is collected between successive identification stations.

Electronic payment technologies include the use of magnetic swipe cards and 'smart cards'. While magnetic swipe cards have been in use for over four decades, smart cards have gained acceptance only in the past 5 years. Smart cards are made of plastic, similar to a credit card, and contain microprocessors and memory chips with wireless communication capabilities (G66). Smart cards have been used in a range of applications including toll and parking payments, internet access, mobile commerce. Adoption of smart cards by transit agencies allow for partnerships with toll and parking systems, employers, universities, financial institutions, telecommunication companies (G66). However, transit system managers are often uncertain about the costs and, particularly, the benefits of moving to smart cards; this is especially the case for the often complex interoperable smart cards systems (G22). A recent successful implementation of smart cards is Transport for London's Oyster Card (G73). The smart card alliance (http://www.smartcardalliance.org/) provides updates on the advances in the state-of-the-art and state-of-practice in Smart Cards. The Alliance membership includes over 150 U.S.-based and international organizations.

The reduction in cost of sensor technologies coupled with advances in nanotech and wireless communication are enabling the widespread deployment of sensors in road networks. However the surfeit of information generated needs to be managed and knowledge extracted from the data. Battelle (G60) identifies innovative approaches including innovative contracting methods, standards, training for data collection, data sharing between agencies and states, and advanced traffic detection techniques. Malik and Russell (G4) discuss new traffic sensor technology for motion based grouping, vehicle classification, and tracking. Ritchie et al (G8) present field investigation of vehicle re-identification techniques and detector technologies. Cheung and Varaiya (G18) summarize a three-year research project in the prototype design, analysis and performance of wireless sensor networks for traffic surveillance, using both acoustic and magnetic sensors. They report that magnetic sensors are superior to the acoustic sensors.

Machine vision (W56, W54) provides intelligence to vehicles and is very useful in developing vehicle safety systems and automated vehicle systems. Automated vehicle systems are also being developed at PATH in University of California, Berkeley (G5).

Biometric identification technology is a promising technology with applications in enhancing security in transportation. The European Commission funded a study (G46) on assessing the impact of Biometrics on society: the study highlight a number of key issues to be taken into account when considering the large-scale implementation of Biometric technologies. The report also addresses the social, legal, economic and technological challenges of four biometric technologies - face, fingerprint, iris and DNA. The study also identifies the vulnerability of biometric technologies and points to the need to include biometric identification as only a part of an overall identification and authentication process. An important implementation issue raised in the report is the possible use of biometric identification to enhance privacy: biometric identification eliminates the need for individuals to reveal their identity at the point of screening. Among the different biometric technologies the major advantage and limitation are: face recognition – can be performed from a distance but identity may be stolen since faces are on public display; fingerprint – best known but an estimated 5% are not able to enroll satisfactorily; Iris – high level of accuracy however not everyone is comfortable with the technology and are unclear where to focus when providing a sample; DNA identification – highly accurate but expensive, time consuming and requires skilled human intervention (G46). Biometric (face) identification and contactless chip technology are also being used in the new Electronic Passport (e-passport) initiative of the United States Department of State. Similar technologies could be applied in driver's license and transit passes.

Bus rapid transit systems are emerging a cheaper mass transit alternative compared to light rail. SmartBRT (G6) is a tool for modeling and simulating hypothetical transit systems, especially Bus Rapid Transit technologies and policies. The tool has the capability to evaluate new technologies and policies that haven't been fully explored. Personal Rapid Transit (PRT) is emerging as a potential personal transit option in urban areas. However, the viability report (G1) of PRT in New Jersey concludes that PRT systems are "approaching but not yet ready for public deployment". Successful transit usage also requires the dissemination of real-time information. Countdown (G71) and London Underground Metro information system (G63) are example of transit information systems implemented in the United Kingdom. More recently in the US there has been an increased awareness on the use of tracking and communication technologies for Transit. Termed "Virtual Mass Transit" (http://www.state.sc.us/irc/minutes/080698.html), the system can "track all mass transit infrastructure, vehicles and routes across the state. Such a system could lower transportation costs by sharing resources between mass transit systems, such as using school buses during non-school times for city or county recreational use, and for collecting and dispatching vehicles in case of a natural disaster."

Assessment Perspective

Most studies on assessment focused on cost-benefit analysis. In particular, several studies (G48, G49, G47) examined the benefits of implementing ITS. These studies estimate returns of $6.30 to $12.20 for every dollar invested in ITS. Though the returns are high the results are only based on simulation studies and not on field-evaluation.

On the other hand, studies on safety (W65, W36) were more concerned with assessment based on objective evaluation of more direct consequences (crash reduction, success rate percent) instead of benefit-cost ratios. Often when dealing with safety and environmental issues, assessment based on direct objective measures could provide a better evaluation framework than dollar equivalent. Dealing with a direct objective measure also allows stakeholders to make subjective inferences on cost-benefit values. This eliminates bias that may be introduced due to imposed false values.

Another assessment method for technology involves the use of attitude and preference surveys (G22, G28). Often in computing cost-benefit values, an important component to the success of any technology – the end-user acceptance is ignored. Attitude and preference surveys provide a better understanding on the degree of acceptance of a technology. Besides providing a stand-alone assessment measure, these surveys can also better inform economic cost-benefit analysis.

The above assessment methods assume a reasonable level of maturity of the technology. In some cases, the technology may still be under development and only experts working on the technology and policy analysts who may implement the technology towards achieving the policy goals, may have sufficient knowledge to assess the technology. The best assessment technique in such cases involves group decision making or voting. Several techniques exist in the literature on group decision making: these include Delphi techniques, Analytic Hierarchy Process, ELECTRE IV, and prediction markets.

Telecommuting Technologies

Based on the input from Regional Transportation Plan committee members, a special review of studies and technologies on Telecommuting was conducted. Telecommuting, also referred to as e-commuting, e-work, telework, working at home (WAH), or working from home (WFH), refers to employees reporting to work remotely from their home or a local office. Since employees do not report to work at office a more general term – 'working away from office' (WAFO) is also used. Telecommuting is an example of Travel Demand Management strategy that is being successfully implemented[11]. Though telecommuting was considered as early as 1980s and was considered a failure in the mid 90s (Technology Review, Vol 98 (5)), rapid advances in communication and computing technology in the last decade have made telecommuting an attractive TDM strategy. However the true potential for telecommuting has not yet been achieved. According to the National Technology Readiness Survey (NTRS), sponsored by the Robert H. Smith School of Business' Center for Excellence in Service at the University of Maryland and technology research firm Rockbridge Associates Inc, only 11 percent of respondents telecommute despite over 25 percent respondents citing employer support for telecommuting. NTRS estimates that if everyone with the potential to telecommute did so for even 1.6 days per week, an estimated $3.9 billion could be saved every year assuming average distance of 20 miles per day and mileage of 21 mpg at gas rates if $2.89 per gallon.

> If everyone (in US) with the potential to telecommute did so for even 1.6 days per week, an estimated $3.9 billion could be saved every year.

Several factors impact telecommute choice. Walls, Safirova, and Jiang[12] in their paper report that telecommuting propensity increases with worker age and educational attainment. Telecommuting propensity also depends on worker's job characteristics such as industry and occupation category. Telecommuting also depends on the organizations management style. Telecommuting requires a shift in management style from management by observation to management by objectives. Equally important is the availability of right technologies could affect the propensity to telecommute. In this document, we review technologies that enable telecommuting.

Technology Enablers for Telecommuting

There are several technological enablers for telecommuting in the market. These include software for e-mail, instant messaging, fax, audio conference, video conference, data conference, collaborative management, real-time polls and surveys and desktop sharing. Besides the software technologies, Voice Over Internet Protocol (VoIP) has emerged as a preferred telecommunication method particularly for international calls.

> Technology enablers:
> - E-mail, IM and fax
> - Audio conference
> - Video conference
> - Data conference
> - Collaborative Management
> - Real-time polls & surveys
> - Desktop Sharing

While e-mail, instant messaging, fax, and audio conference have become commonly available and frequently used technologies in the work place, they act as principal enablers for telecommuting. However, they lack in visual communication, data sharing and presentations in real-time. Video conference is an effective method for visual communication. Most instant

> Collaborative Management software provides audio, video, data, and desktop sharing features in a single package.

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[11] See www.telework.gov for telework status report in the Federal Government and http://www.fhwa.dot.gov/environment/cmaqpgs/telework/ for examples of successful telework implementations.

[12] Walls, Margaret, Elena Safirova, and Yi Jiang, What Drives Telecommuting? Relative Impacts of Worker Demographics, Employer Characteristics, and Job Types, *TRB 86th Annual Meeting Proceedings in CD-ROM*, 2007.

messaging software provides basic video conferencing facilities. More advanced video conferencing tools are provided by Adobe, Cisco, and AT&T.

Often visual communication requires the sharing of data and presentations in real time. An alternative to video conference is a data conference where participants are allowed to write or load graphs and charts on electronic whiteboards to share with others. Several technologies provide the capabilities for seamless interaction known as Collaborative Management - their capabilities include audio, video, data, and desktop sharing features in a single package. Examples of collaboration software include *Microsoft Office Groove, Adobe Acrobat Connect, Webex,* and *OfficeScape* among others. More specialized offerings include special software to hold web seminar (webinars). This is efficiently provided by technologies such as *Infinite Conferencing* and *NCSA Habanero* - a collaborative framework to create Java applications.

VoIP has recently emerged as the preferred calling method particularly in small and medium-sized enterprises for international calls. Current VoIP providers include *Packet8, Vonage, Knightel, Vonics Digital,* and *BBTelsys LLC*. Another VoIP/instant messaging software that has become popular is *Skype*. *Skype* requires a computer to make telephone calls while the other providers can be used both through a computer and through traditional telephones connected to a phone adapter which is linked to the internet router.

The advances in virtualization software are likely to encourage telecommuting further and have led to the emergence of *Virtual Office*. While Virtual Office software is very similar to collaborative management software, they appear to be more general. Specific examples of Virtual Office software include *iareaOffice* and *Virtual Office*. Recent technologies in virtual office also allow the users to address security issues over the internet network thereby providing a secure exchange of information.

An important impediment to wide spread adoption of telecommuting among employers is the lack of direct auditing and overseeing capabilities. While most employers' measure performance based on final work output some management styles or job profiles require more constant monitoring. Project management software have been designed that can also account for employees working remotely. Examples include *@task* and *Ace Project*. A set of tools to accurately assess the economic feasibility and impact of telecommuting are TeleworkAudits and TeleworkAnalysys (www.teleworker.com/taudits.html).

Technology *Examples*:
- **Collaborative Management** - *Microsoft Office Groove, Adobe Acrobat Connect, Webex,* and *OfficeScape*
- **VoIP** – *Packet8, Vonage, Knightel, Vonics Digital*
- **Virtual Office** – *iareaOffice, Virtual Office*
- **Project management** - *@task, Ace Project*
- **Feasibility Assessment** - *TeleworkAudits.*

All the above technologies may be grouped as software technologies. The hardware technology includes communication infrastructure and computer and video hardware. Currently the hardware technology by itself may not be the barrier. The quality and the cost is an issue. Hi-definition video conferencing technologies are very expensive. For example, Cisco TelePresence costs between $80,000 to $299,000, Telanetix costs about $40,000 plus the monthly cost for T-1 internet lines (>$1000 per month), and at the lower end is Polycom's HDX-4000 at $8000[13].

Further advances in optical transmission technology can provide data transfers in the range of 10Gbps – 40 Gbps (or 20 to 80 times faster than current maximum speeds).

A key to deploying high-quality video conferencing and seamless communication of data/files is high-speed internet technology. Current broadband cable internet service speeds range from 2 Mbps (on average) to up to 50 Mbps (maximum) for downloads and 0.5 Mbps (average) to 20 Mbps (maximum) for uploads. Further advances in optical transmission technology such as Dense Wave Division Multiplexing (DWDM) can

[13] Source: http://www.networkworld.com/news/2007/082107-networker.html

provide data transfers in the range of 10Gbps – 40 Gbps (or 20 to 80 times faster than current maximum speeds). The next-generation of wireless technology such as ultra-mobile broadband is likely to provide speeds of 100Mbps to 1 Gbps with excellent quality of service and security.

Telecommuting Success Stories

Advances in video-conferencing and Internet and the growing transportation congestion problems have made telecommuting more attractive. Dedicated organizations (www.telcoa.org) and companies (www.telecommutect.com) have sprung up to support telecommuting initiatives. Other than driving alone, telecommuting is the only commute mode that has gained market share since 1980. In 2005, 4.5 million Americans telecommuted on most work days, roughly 20 million telecommute at least once per month, and 45 million once a year. However, the long-term success of telecommuting from the viewpoint of transportation planners will depend on how effective telecommuting is in substituting travel. Several issues remain with respect to the real impact of telecommuting on travel. Second-order effects such as increased non-work travel either by the telecommuter or other members of the household (since a vehicle becomes available) and choice of household location (stay farther away since commuting is not an everyday affair) may undermine any reduction in commute travel recognized through telecommuting. Choo, Mokhtarian, and Salomon[14] develop aggregate time-series models to examine the impact of telecommuting. Their models suggest that "telecommuting reduces vehicle miles traveled (VMT), with 94% confidence. Together with independent external evidence, the results suggest a reduction in annual VMT on the order of 0.8% or less. Even with impacts that small, when informally compared to similar reductions in VMT due to public transit ridership, telecommuting appears to be far more cost-effective in terms of public sector expenditures."

> In 2005, 4.5 million Americans telecommuted on most work days, roughly 20 million at least once per month, and 45 million once a year.

John Edwards, the former chairman of Telework Coalition, in an interview[15] claims increased productivity of 7% to 20%. Among the reasons for the increase in productivity he cites: no office politics, fewer interruptions, and fewer distractions, and could be available for duty outside traditional office hours. Further, he claims, telecommute program would allow employees to work from home when they, or their family members, get sick. Periodic transit strikes, bad weather, traffic incidents, and increased security due to terrorism threats at transportation hubs might also prompt employers to think about setting up a telecommute program.

Teleworkexchange (www.teleworkexchange.com) portal lists several successful telecommuting initiatives throughout the country in different employment sectors[16]. Several of these success stories were built on Virtual Office and Virtual Private Network technologies. For example, the Federal Aviation Administration "provides its workforce with access to a secure, shared virtual office suite that mimics a typical "real world" office setup. Think document management, meeting spaces, project teams, libraries, and tight security - all in cyberspace… called the Knowledge Services Network (KSN)"[7]. The core technology behind the KSN is Microsoft Windows SharePoint Services. The Internal Revenue Service on the other hand provided its remote workforce with SharePoint team rooms, secure messaging, Virtual Private Networks (VPN), multi-functional printing devices, and remote communications routing. Other organizations that have successfully implemented telecommuting programs include the Arizona Department of Administration, Defense Information Systems Agency (DISA) - Department of Defense, and the Washington Council of Governments (WASHCOG). In WASHCOG's an extra 18% of workers (in addition

[14] Sangho Choo, Patricia L. Mokhtarian, and Ilan Salomon, Does Telecommuting Reduce Vehicle-miles Traveled? An Aggregate Time Series Analysis for the U.S., *Transportation* 32(1), 2005, 37-64

[15] Interview with John Edwards, Chairman Telework Coalition, http://www.italladdsup.gov/newsletter/winter06/experts.html

[16] http://www.teleworkexchange.com/resource-center-case-studies.asp

to the 14.6% already telecommuting) have jobs that would allow them to telecommute and would be interested in telecommuting.

Telecommuting has also resulted in a new employment sector referred to as Microjobs. Microjobs refers to the method of working where individuals work as freelancers but use technology and the internet to do their work remotely. www.pajamanation.co.uk is a website that matches employers to potential microjob seekers.

Summary

To summarize the review, several different technologies have been applied to achieve different objectives. The most important technologies are summarized under each category below.

Congestion reduction and management:

1. Current major trends include congestion pricing and the use of ATIS.
2. However significant scope for improvement exists in these technologies including distance-based pricing and active travel guidance systems using vehicle-to-vehicle communication and VII systems.
3. Other congestion reduction and management strategies include telecommuting, ramp metering, and improved transit service (bus signal priority, information, etc.)

Safety and Security:

1. Among safety systems crash avoidance systems hold immense promise. These systems will utilize sensors to detect vehicle, environment, and driver characteristics and determine crash possibilities using intelligent algorithms.
2. Pedestrian safety systems that alert driver of presence of pedestrians in their path or pedestrian detection systems at pedestrian crossing.
3. Biometric identification

Air Quality Improvement:

1. Use of bio-fuels and hybrid vehicles are emerging in the short-term;
2. In the longer term hydrogen fuel vehicles may offer better benefits. However currently the operational costs and lack of institutional support hinder the use of hydrogen fuel on a large scale.

The above systems for achieving different goals are enabled because of developments in diverse technologies. These technologies include wireless communication systems, advanced sensors, electronic payment, and biometric identification among others. While the literature review has focused on technologies that have been developed and prototyped, it is reasonable to assume that several technologies currently under development may become available for the public to use within the next 10 years. The synthesis of emerging technologies including technologies that are currently under development was the focus of task 2.

Overview of Database

The database includes interactive forms and summary report templates to help the user navigate better. An interactive form (Fig 1) appears as soon as the database is opened.

The user can select one of three options available: View Entire Report, Enter New Studies, and Search Database. The view entire report option displays the report shown in Appendix 1. The report automatically updates any new studies that will be entered in the future. The report presents studies sorted based on the Perspective, Category and Sub-category. At present, the database has over 230 studies (18 under Assessment perspective, 116 under Goal Driven perspective, and 104 under Technology Driven perspective).

The second button, Enter New Studies, brings up another form (Fig 2) that allows the user to enter new studies to the database.

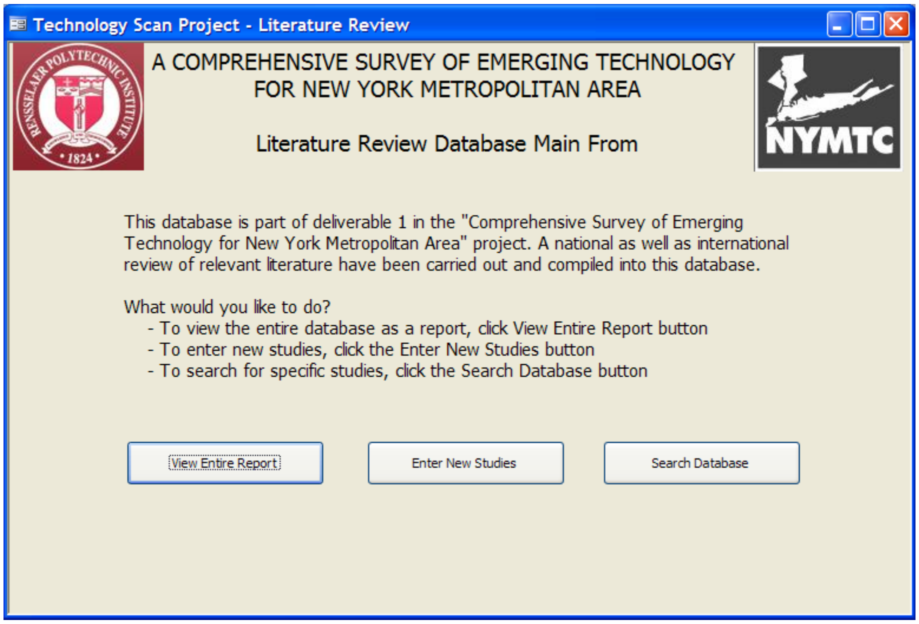


Figure 1 Main form in Database

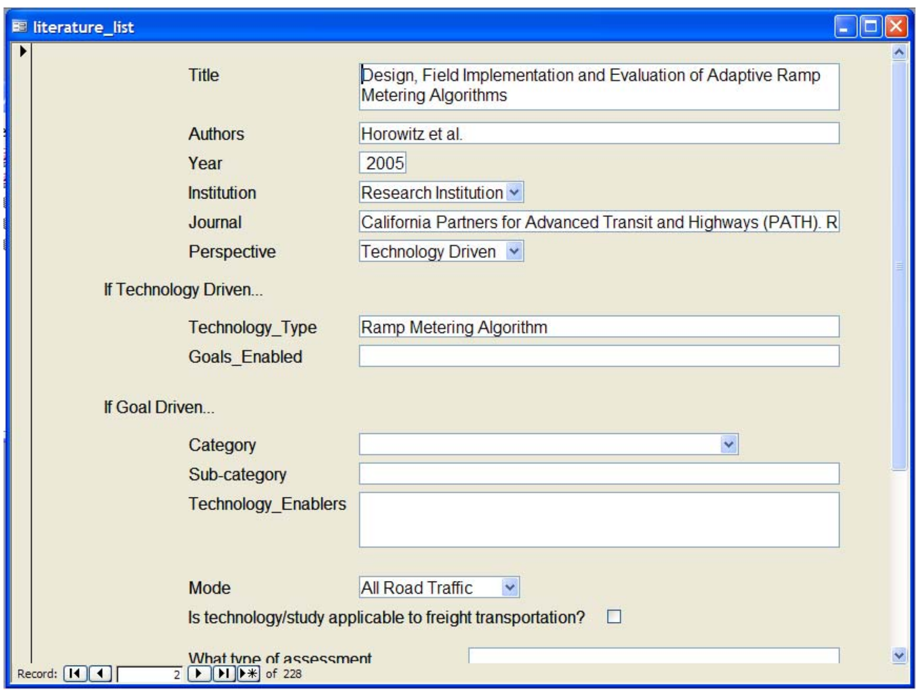


Figure 2 Enter New Studies form

The third button brings up a search form (Fig 3). The user can input the study reference ID to look-up a particular study or use specific keywords, author names and publication years to select a subset of relevant literature. The search results are displayed in the form of a report.

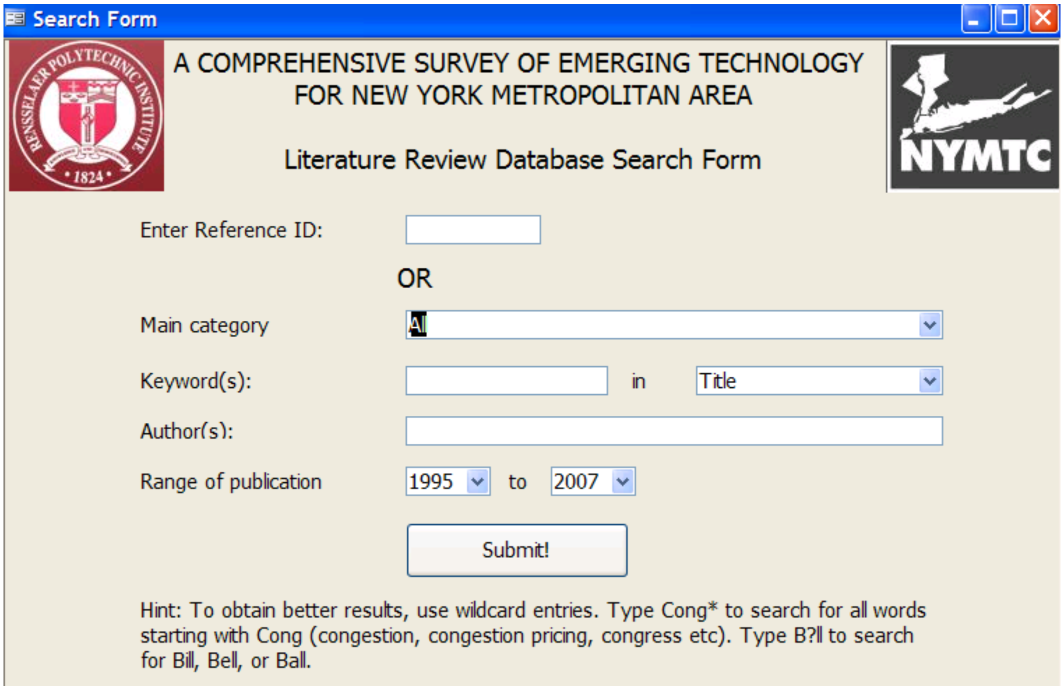


Figure 3 Search Form

Chapter 3: Emerging Technologies: Initial List

In this task, a comprehensive, initial list of emerging technologies to improve transportation systems will be prepared.

Emerging technology included in the present study can be classified under the following categories based on the development stage of the technology:

1. Technology that is already developed and implemented elsewhere but has not yet been adopted in the NYC region.
2. Technology that has been prototyped but has seen limited to no real implementation.
3. Technology that is still at the conceptual stage.

The methodology for choosing the different technologies is as follows: technologies in category 1 and some of the technologies in 2 were primarily identified based on the comprehensive literature review carried out as part of task 1. In task 1, a literature review of implemented as well as emerging transportation technology was carried out which included international studies. Several of these technologies have not yet been implemented in the NY metropolitan region but have immense potential.

The rest of the technologies in category 2 and the technologies in category 3 were identified based on a visioning process. Since 15 to 20 years is a long time in the transportation technology cycle, the project team undertook a visioning process that required intelligent, information supported extrapolations of possible future developments. The visioning process was done in two steps. First, it was recognized that technology advancements in several fields are likely to impact transportation and travel. Therefore in the first step, these broad technological domains and their general trends were identified. The broad technology domains explored include:

a) Nanotechnology
b) Energy and Fuel technology
c) Communication technology
d) Computing and Internet technology
e) Transportation, Vehicular and Automotive technology
f) Sensors
g) Freight technology

The second step of the visioning process involves identifying the potential impacts of the technological developments on transportation in general and transportation technology in particular. Further fact-sheets of each technology were prepared which include details on features, timeline/costs, transportation applications, and challenges.

We first present a brief summary on each technology domain and identify general trends. We then provide the fact-sheets for technologies identified under each of the domains.

Broad technology domains and trends

Nanotechnology

Nanotechnology is the study of matter whose dimensions are 1 to 100 nanometers (10^{-9}m). A nanometer is one-billionth of a meter; a sheet of paper is about 100,000 nanometers thick. At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental ways from the properties of individual atoms and molecules.

Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties (1). Nanotechnology has as yet only limited applications. Nano-materials have found applications in electronics, biomedical, pharmaceutical, energy, and materials applications. Current successful application of nanotechnology includes chemical polishing, magnetic recording tapes, sunscreens, automotive catalysts, electro-conductive coating, optical fibers, and disinfectants (see (2) for a detailed list of nanotechnology in consumer industry). Several examples of nanotechnology research in developing new technology abound. These include:

a. Molecular switches (3) that will eventually help make electronic devices even smaller and more powerful.
b. Nanowire LEDs (4) that could eventually be used for telecommunications and for faster communications between devices on microchips. The approach could also pave the way for a new type of bright, efficient display.
c. Denser data storage using nanorods and nanowires (5)
d. Nano weapon to fight cancer (6),
e. Flexible organic LED displays (7),
f. Fuel cell catalysts (8),
g. Self-cleaning, fog-free windshields (9),
h. Materials that reflect no light (10) which has applications in solar cells, camera lenses, and LEDs
i. Nanosensors (11) that could provide simple tests for cancer or bioterror agents,

The above list indicates the diverse applications of nanotechnology. In general, nanomaterials appear to enhance the strength, durability, and other physical attributes of materials allowing development of smaller and cheaper applications. These technologies can have myriad different impacts on transportation (12, 13):

- Carbon-based fibers which are 100x stronger than steel, at only one-sixth the weight provide light-weight yet stronger options for construction of bridges and vehicles.
- Nanocoating of metallic surfaces to achieve super-hardening, low friction, and enhanced corrosion protection
- "Smart" materials that monitor and assess their own status and repair any defects resulting from fatigue, fire, etc.
- New materials that will permit ultra-miniaturization of space systems and equipment, including the development of 'smart' sensors and probes.
- Nanosensors to monitor vehicle emissions and trigger traps for pollutants;
- Nanoparticle-reinforced materials that replace metallic components in cars;
- replacement of carbon black in tires with nanoparticles of inorganic clays and polymers, leading to tires that are environmentally friendly and wear-resistant;
- Carbon-based nanostructures that serve as 'hydrogen supersponges' in vehicle fuel cells.
- Nanofilms for water-repelling windshields
- High-brightness nano-enhanced polymer displays for in-vehicle displays
- Ceramics with improved catalysts for reduced emissions
- Air purification systems that can be fitted over air vents in cars.
- Hybrid Electric Cars Powered by Nano-Engineered Batteries
- Paint and Clothing that can generate electricity

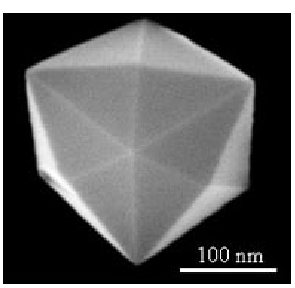
The University of Houston conducted a study (14) for the Texas Department of Transportation on the potential nanotechnology applications in highway pavements. Two different categories were investigated: smart materials for pavement construction and sensors for transportation and pavement infrastructure condition monitoring. In order to demonstrate the applications of nanotechnology in transportations systems, a fully functional smart stop sign was developed and tested. This smart stop sign is able to detect any malfunction including direction change, fall down, or tilt and report wirelessly to the TxDOT office using nanosensors and MEMS radio technology.

The Volpe Center's transportation strategic plans (15) vision document on future transportation lists the following impacts of nanotechnology in transportation:

- Nanotechnology will yield advanced materials that will allow for longer service life and lower failure rates. Among the key applications is nanocoating of metallic surfaces to achieve super-hardening, low friction, and enhanced corrosion protection; "tailored" materials for infrastructure and vehicles; and "smart" materials that monitor and assess their own status and repair any defects resulting from fatigue, fire, etc.
- Nanotechnology has great potential to support advanced communications that maximize the benefits of intelligent transportation systems and obviate the need for some travel altogether; sensors that continually monitor the condition and performance of roads, bridges, and other infrastructure; and "brilliant" vehicles that can avoid crashes and improve operator performance.
- New materials developed through nanotechnology will permit the ultra-miniaturization of space systems and equipment, including the development of "smart," compact sensors; minuscule probes; and microspacecraft. Applications include economical supersonic aircraft; low-power, radiation-hardened computing systems for autonomous space vehicles; and advanced aircraft avionics.
- Nanotechnology has the potential to reduce transportation energy use and its impacts on the environment. Applications include nanosensors to monitor vehicle emissions and trigger traps for any pollutants observed; nanoparticle-reinforced materials that replace metallic components in cars; replacement of carbon black in tires with nanoparticles of inorganic clays and polymers, leading to tires that are environmentally friendly and wear-resistant; and carbon-based nanostructures that serve as "hydrogen supersponges" in vehicle fuel cells.
- Breakthroughs in nanotechnology also should make possible quantum computers, which will exceed the limits on the speed and miniaturization of conventional computers by exploiting the quantum nature of reality.

The FHWA multiyear research program identifies Nanoscience research as one of the important research areas. Specific research areas include:

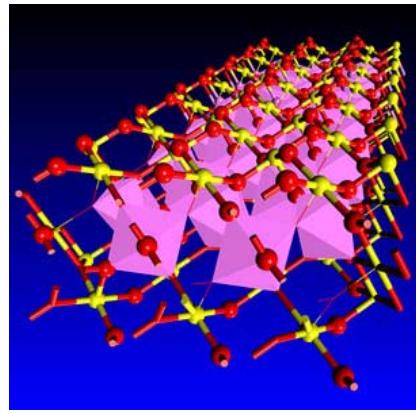
- Materials that perform well under extreme conditions of temperature and pressure. These can be strong, tough, ductile, lightweight, and low-failure materials.
- Smart materials such as paints that change color with temperature.
- Radiation-tolerant materials.
- Self-healing materials: Research is ongoing at the National Aeronautics and Space Administration's Langley Research Center on self-healing materials development to develop materials that will mend themselves if subjected to high-velocity projectile penetration. This technology has the potential for structural applications in bridges. Nanoscale self-healing materials can be developed to be embedded in structural materials that become activated at the site of a fracture, etc., and self-heal the material.



24-sided platinum nanoparticles – fuel catalyst

Source: http://www.technologyreview.com/Nanotech/18669/

The Nano-modification Workshop held at University of Florida and sponsored primarily by National Science Foundation explored the used of Nanotechnology applied to cementitious materials. Nanotechnology for safe and sustainable infrastructure is divided into two categories. Nanotechnology-based construction materials and intelligent materials based sensor system. Nano-modified Construction Materials include materials with high tensile strength and ductility, Super-high compressive strength, Low shrinkage, Engineered hydration processes, High durability, Low permeability, Fiber reinforcement instead of steel, Economical high reactivity additives, Green economical recycling.



SnO_2 nanoribbon
Used as ultra sensitive nanosensors for various gases, e.g., NO_2, O_2, and CO.

The technology fact-sheets in nanotechnology have been grouped under three broad categories: Nanofuels, Nanosensors, and Nanomaterials.

Nanofuels include nano-sized batteries, nano materials that serve as fuel savers, and nano materials for fuel-cell catalyst. Nano-sized battery fuel cell measuring just 200 nanometers across that potentially can be integrated on a chip to supply power from a hydrogen reservoir for decades. Nano Fuelsaver uses revolutionary nano-technology to treat petrol or diesel entering the engine in order to enhance the combustion process, saving 10-20% fuel/diesel in cars, trucks, boats, motorbikes. Nano fuel-cell catalyst could lead to cheaper catalysts for making and using alternative fuels.

Nanosensors have potential to track bio-terror agents, stress in materials, and detect polluting agents in the atmosphere and tailpipes. Nanosensors could be used in transportation to monitor pavement conditions, bridge conditions, pollution deduction, bio-terror agent detection, air quality monitor etc. The feasibility of "Cyberliths", or Smart Aggregates, as wireless sensors embedded in concrete or soil is being studied. Researchers at Johns Hopkins University's Applied Physics Laboratory have developed a robust wireless embedded sensor, suitable for long term field monitoring of corrosion in rebar, particularly in bridge decks.

The Golden Gate Bridge now has an experimental sensor network of approx. 200 small sensor 'motes', each with an accelerometer that measures movement such as traffic, wind, or seismic loads

Coatings which mimic the surface of the lotus leaf - to which nothing adheres - will lead to signage and work zone barricades which shed dirt and grime and never need to be washed

The Lotus Effect

Nanomaterials that are of interest in transportation include carbon-fibers that are 100x stronger than steel, nanocoating of metallic surfaces to prevent corrosion, nano-reinforcements in vehicle body, pavements, and other transportation infrastructure, and automatic healing materials that have potential to be used in guardrails that heal themselves, or concrete or asphalt that heal their own cracking.

Energy and Fuel technology

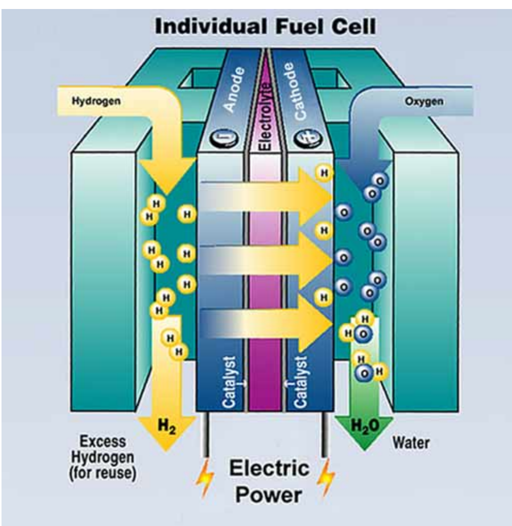
The Department of Energy forecasts that the global demand for energy in 2030 will increase by 70 percent compared to demand in 2005. Transportation energy use will grow by 1.4 percent per year from 2005 to 2030 (about the same as the growth rate from 1980 to 2005), despite relatively high fuel prices. Increases in travel by personal and commercial vehicles will only be partially offset by vehicle efficiency gains (18).

The primary technological developments in the field of energy/fuel technology in transportation are:

- **Hybrid Vehicles**: Present-day hybrids are equipped with ICEs and electric motors. However hybrid technology has been restricted to cars in the commercial market. The NREL Advanced Heavy Hybrid Propulsion Systems project focuses on improving hybrid fuel technology for heavy trucks and buses. Overall, the developed technologies are projected to save more than 20 million barrels of oil in 2010 and 250 million barrels of oil in 2020 (15).

> Transportation energy use grows by 1.4 percent per year from 2005 to 2030 (about the same as the growth rate from 1980 to 2005)

- A **fuel cell vehicle** (FCV) is an electric vehicle that uses a fuel cell rather than a battery to provide electricity that powers motors at the wheels. A fuel cell is an electrochemical device that produces electricity by separating the fuel (generally hydrogen gas) via a catalyst. Fuel cell vehicles are zero-emission vehicles. Appropriate tax incentives are likely to popularize the use of fuel cell vehicles. Most major car manufacturers have demonstrated prototype hydrogen fuel cell vehicles. Hydrogen fuel cells may also be fitted into motorcycles and bicycles (16). The website http://www.alternative-energy-news.info/headlines/transportation/ provides current developments in research and industry in alternative energy sources in transportation.
- **Aircar**: The Aircar (17) incorporates bi-energy (compressed air + fuel). The compressed air technology (CAT) Vehicles have increased their driving range to close to 2000 km with zero pollution in cities and considerably reduced pollution outside urban areas.



700 IEEE Fellows were surveyed in a joint study by the Institute for the Future (IFTF) and *IEEE Spectrum* on the future of different technologies. Among the energy experts (180 respondents) 55% said fuel cells will be widely used to power cars in the next 10 to 20 years.

Here we summarize current available alternative fuels, several emerging fuels and the corresponding alternative fuel vehicles. Specific information for each fuel can be obtained from the tables.

A hydrogen fuel cell

Source: http://p2library.nfesc.navy.mil/issues/emergeoc

Alternative Fuels: Currently, there are dozens of available alternatives and advanced fuels. Their common characteristics are

- Clean-burning
- Nontoxic
- High potential for domestic production

Use of these fuels can significantly increase fuel security and alleviate air pollution. Consumers, including government-regulated and voluntary private fleets, are now showing a growing interest in them. These fuels are defined as alternative

> A joint survey by Institute for the Future and IEEE *Spectrum* magazine among 180 energy experts indicated that 55% believe fuel cells will be widely used to power cars in the next 10 to 20 years.

fuels by the Energy Policy Act of 1992 and are currently, or have been, commercially available for vehicles:

- Biodiesel
- Electricity
- Ethanol
- Hydrogen
- Methanol
- Natural Gas
- Propane.

Emerging Fuels

In addition to the above alternative fuels, several emerging vehicle fuels are in early stages of development. Even though few of these fuels are applicable now, many of them are also considered alternative fuels and promise benefits such as increased energy security, reduced emissions, higher performance, or economic stimulation.

- Biobutanol
- Biogas
- Biomass to Liquids (BTL)
- Coal to Liquids (CTL)
- Fischer-Tropsch Diesel
- Gas to Liquids (GTL)
- Hydrogenation-Derived Renewable Diesel (HDRD)
- P-Series
- Ultra-Low Sulfur Diesel

Alternative Fuel Vehicles

Advanced technology vehicles using various light- and heavy-duty alternative fuels are currently on U.S. highways today. They are used by state and federal agencies, private companies, and consumers alike. Advanced vehicles run on a number of different alterative fuels which are summarized below.

1. Vehicles fueled with alternative fuels as defined by the Energy Policy Act of 1992:
   - ◊ Electric Vehicles (fueled with electricity)
   - ◊ Flexible Fuel Vehicles (can be fueled with ethanol)
   - ◊ Natural Gas Vehicles (fueled with natural gas)
   - ◊ Propane Vehicles (fueled with propane).
2. Alternative Fuel Blend-Capable Vehicles:
   - ◊ Diesel Vehicles (can be fueled with biodiesel)
3. Other Advanced Vehicles:
   - ◊ Hybrid Electric Vehicles
   - ◊ Plug-In Hybrid Electric Vehicles
   - ◊ Fuel Cell Vehicles (fueled with hydrogen).

Communication technology

It is envisioned that communication technology will be revolutionized in primarily two ways: growing speeds of data transfer and ubiquitous wireless broadband communication. These developments are likely to have impacts on several travel dimensions including: how individuals interact with one another, telepresence that includes telecommuting as a special case, the use of anytime-anywhere networks to stay online always, and vehicle-vehicle communication that enable safety and automated vehicle applications.

Terabit optical networks will be common. Next generation optical networks will transfer data at the rate of 10 gigabits per second (gbps) to 100 gbps. Such **ultra-high-speed networks** will enable immersive collaboration environments, resource-sharing, real-time computation-intensive simulations, HDTV-quality video on demand. These developments will also provide advanced telecommuting options, advanced traveler information systems and traffic management capabilities, and result in possible drastic changes in life-style that could significantly affect demand for travel.

Next generation optical networks will transfer data at the rate of 10 gigabits per second (gbps) to 100 gbps.

The other significant advance in communication is wide area wireless communication including WiMax, Mobile WiMax, Ultra Mobile Broadband (UMB) and UMTS.

WiMAX provides large coverage distances of up to 50 kilometers under line of sight (LOS) conditions and typical cell radii of up to 5 miles/8 km under Non-LOS conditions. Mobile WiMAX can provide tens of megabits per second of capacity. The high data throughput enables efficient data multiplexing and low data latency. Attributes essential to enable broadband data services including data, streaming video and VoIP with high quality of service (QoS). Universal Mobile Telecommunications System (UMTS) is the European standard for 3G mobile communication systems which provide an enhanced range of multimedia services. UMTS supports up to 1920 kbit/s data transfer rates.

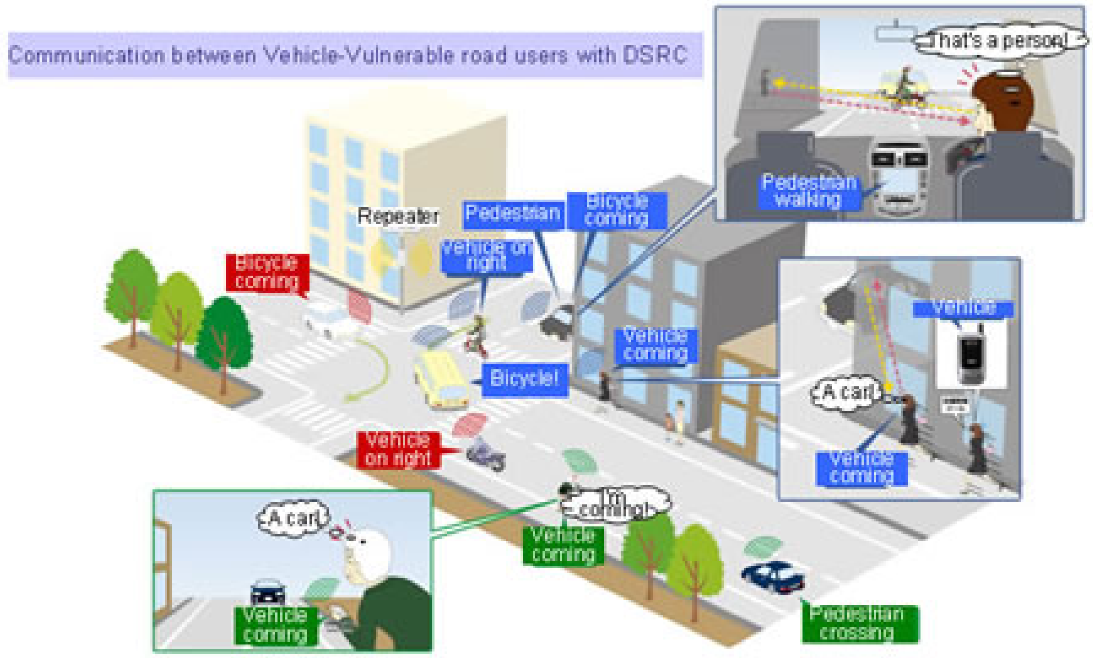
The advances in wide area wireless communication will enable several transportation applications including: in-vehicle communication, inter-vehicle communication, anytime-anywhere connectivity that allows for personalized real-time information dissemination, encourages telecommuting and provides greater work flexibility.

The advances in communication technology are also enabling vehicles to talk to each other (19). Vehicle-to-vehicle communication holds immense promise for safety applications and for improving network throughput by providing online traveler information and/or enabling automated vehicle navigation.

Foremost of the vehicle-to-vehicle communication technology is Dedicated Short Range Communications (DSRC). It is a block of spectrum in the 5.850 to 5.925 GHz band allocated by US Federal Communication Commission to enhance the safety and the productivity of the transportation system. DSRC technology will provide secure, reliable communication links between vehicles and infrastructure safety subsystems that can increase highway safety. The promise of DRSC is to deliver a far greater data rate and range to wireless highway applications. "Compared with existing RFID toll applications, DRSC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters," says Richard Schnacke, vice president of industry relations for TransCore.

"Compared with existing RFID toll applications, DRSC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters"

The DSRC system supports communication links up to the following parameter limits:
Vehicle speed (up to 120 mph), Communication range (up to 1000 meters for special vehicles; nominal is 300 meters), System Latency (< 50 ms), Data rate (default is 6 Mbps; up to 27 Mbps), Single transaction size (up to 20K bytes).



Source: http://www.fareastgizmos.com/2007/05/

DSRC should enable several transportation applications including Active safety systems communication on-board the vehicle, vehicle-vehicle and roadside-vehicle communications, roadside-vehicle wireless communications for Intersection Decision Support, cooperative Adaptive Cruise Control (CACC) system with potentially significant impact at highway merge junctions, Traffic Flow (Speed & Volume), Lane Occupancy, Priority Signal Preemption, Toll Collection, Freight Tracking, Roadway Conditions, Intersection collision avoidance, Approaching emergency vehicle warning, Vehicle safety inspection, Transit or emergency vehicle signal priority, Electronic parking payments, Commercial vehicle clearance and safety inspections, In-vehicle signing, Rollover warning, Probe data collection, Highway-rail intersection warning.

An emerging area of research that studies the science of vehicle-to-vehicle communication networks is **Vehicular Ad-Hoc Network**, or **VANET**. It is a form of Mobile ad-hoc network, to provide communications among nearby vehicles and between vehicles and nearby fixed equipment, usually described as roadside equipment. VANET is a technology that could significantly increase traffic productivity in the future. For safety purposes, police and fire vehicles are estimated to be instrumented first so that vehicles can communicate with each other. VANET related application can be categorized into safety and non-safety groups. Prototype system in research includes StreetSmart and TrafficView.

Computing and Internet technology

Computing and the Internet have revolutionized the global economy in the past decade. Advances continue to push the frontiers of their applications. In the *Extreme Futures* book, James Canton predicts five future trends of the Internet. These are *Smart, Media Rich, Always On, Wireless, Pervasive networks*. Every manufactured product will be online. E-mails are likely to be multimedia. "Telepresence" will become common. The Internet will be the medium through which more than 50% of the world population will be trading.

The Internet will be the medium through which more than 50% of the world population will be trading.

To exploit the advances in communication and internet technologies, Computers will become ubiquitous and/or wearable devices; ultra-compact and ultra-powerful. Nano-storage devices will enable limitless data storage capabilities even on devices the size of a mobile phone.

These technologies could revolutionize people's travel. Activities that do not require physical presence will all be substituted by "telepresence". Further, the possibility of high-speed networks allows the use of 'idle' computers to come together and become a networked super computer. "There are roughly a billion PCs on the Internet, and they're 98 percent available for computing," says Larry Smarr, professor of computer science and engineering at the University of California, San Diego, and director of the California Institute for Telecommunications and Information Technology. "That's like having a billion-processor computer just sitting there, with nobody using it." The advances in computing will also enable highly sophisticated data mining and combinatorics allowing the use of advanced algorithms to improve the efficiency of complex transportation systems. Interactive computer graphics will be so lifelike that it will be hard to distinguish on screen between what is real and what is "virtual." Simulations will be accurate and cheap to reproduce thousands of scenarios allowing for improved decision making.

Collaboration software will allow individuals located remotely to interact seamlessly and *produce* jointly. *Augmented reality* which deals with the combination of real world and computer generated data will enhance our perception of the world around us and open new paradigms of social interactions. This is primarily achieved by augmenting human perception by adding to it information not normally detectable by the human senses. Already demonstrated simple examples include cell-phone alarms to indicate the presence of a friend who is passing near-by. Augmented Reality technology can provide for driving enhancement as well as driving performance testing under different scenarios, enable traffic tracking by combining data from a plurality of sensors.

Personal Awareness Assistant (Augmented Reality)
Source: http://www.learningcircuits.org/2004/dec2004/0412_trends.htm

Wearable computing will also act as a personal travel assistant which provides individuals, in vehicle and on foot, with location based information services. An example of this technology in application now is Verizon Wireless (>50 million users), Sprint-Nextel (>50 million users), and Alltel (>10 million users) that use GPS technology to provide E-911 services. Additional transportation applications include real-time information on traffic delays, personalized public transit information systems, advanced route guidance capabilities, and multi-modal information applications such as personalized multimodal trip planning, continuous on-trip information to multimodal travelers, information on transfers, tools to assist travelers in finding their way to the destination address once they get off at the last stop provided by public transport.

Transportation, Vehicular and Automotive technology

Advances in transportation, vehicular, and automotive technology are likely to have the most direct impact on future transportation. The technologies surveyed here include small wheeled transport including segways and electric scooters/skates, hybrid vehicles, personalized rapid transit, automated vehicles, and flying cars.

Small-wheeled transport is a category of Nonmotorized Transportation. Future implementations are likely to be electric with a range of options. Segway is a two-wheeled, self-balancing, electric transportation device. It is a versatile, agile, short-range device that utilizes the patented dynamic stabilization technology and advanced alternative-power systems. Small-wheeled transport impacts include modal shifts from automobile travel to alternative modes, improved access to public transit, faster and efficient movement of pedestrians, and easier mobility for people who are physically and economically disadvantaged.

Personalized rapid transit (PRT) system includes fully automated vehicles capable of operation without human drivers over a reserved guideway. The vehicles are available on-demand, providing direct origin to destination service for an individual or a small group - typically 1 to 6 passengers. PRTs are a hybrid of personal vehicles and mass transit and therefore provide the advantages of both. However, PRT systems are capital intensive and are feasible in city centers only. Capital costs per mile are estimated at $5,458,013 while annual operating costs are $8,927,723. However, with increased need to move towards more sustainable transport, PRT may emerge as a major player in future.

A Segway

Despite the improvements to mass transit and alternatives such as PRT, personal autos continue to be the most preferred transport mode in the US. Significant network throughput improvements may still be realized by improving the operations of road networks and personal vehicles. The intelligent vehicle-highway system (IVHS) initiative in the 1990s was a step in this regards. But IVHS required significant public investment on upgrading the infrastructure. The initiative lost steam in the late 90s. However, the private auto-makers have continued to develop technologies that automate vehicle navigation. Examples include adaptive cruise control, lane departure warning, and collision avoidance. The transportation implications include significant throughput improvement (reduced congestion) and safety improvements (no accidents). Adaptive cruise control would help prevent backward shockwave propagation. At an average speed of 67 miles per hour, if only one in five vehicles used adaptive cruise control, no traffic jams would form and traffic would generally flow freely.

Flying cars have been tested since the 1950s but their widespread use is still not a reality. However advances in vehicle location and navigation technologies and suitable legislations could pave the way for flying cars over the next 25 years. Currently several companies are developing prototypes. Examples include Moller's Skycar (3) and Terrafugia's transition (4). NASA has been actively supporting the development of Personal Air Vehicles (PAVs). Flying cars could significantly reduce congestion; vehicles can travel through the three dimensional space and fly straight to destinations instead of having to follow flat guided pathways.

Terragfugia's Transition – Flying Car

Sensors

As sensor technology advances towards miniaturization with communication capabilities, tiny smart sensors will increasingly be embedded in everyday objects and places, forming the basis for a ubiquitous sensory infrastructure. "Smart dust" sensors will perform complex tasks such as monitoring of health conditions to air quality. These sensors will also be linked together to form a massive, nano-scale sensor network. The sensors range from micro-scale (referred to as Micro-electrical mechanical systems, MEMS) to nano-scale (discussed earlier). Already several applications of sensors in transportation infrastructure have been explored.

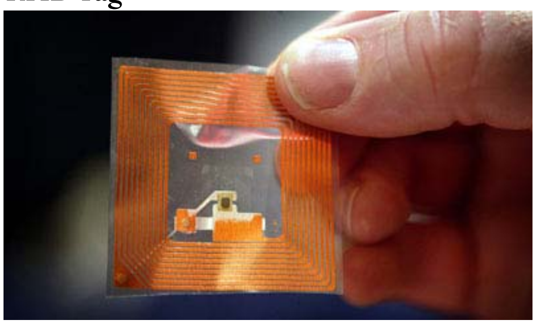
MEMS can be used in Advanced Driver Assistance Systems, Crash Detection, Electronic Stability Control, LED Taillight Driver, both monitoring and testing of transportation infrastructure, and in transportation air-quality studies where MEMS "smart dust" has the potential to collect data for both analysis and forecasting the air-quality. The

majority of the potential MEMS applications in transportation infrastructure will act as sensors. These include sensors used in monitoring temperature, crack measurements and monitoring, corrosion testing and monitoring, alkali-silica reaction (ASR) and other related reactions in concrete, and reliability of welding units in structural steel. MEMS thermal accelerometers in navigation systems with maps and global positioning satellite capabilities, MEMS-based display can overlay automobile diagnostics and repair instructions directly to the technician, and seat-based MEMS for passenger deduction.

Hewlett-Packard's Memory Spot wireless chip

More traditional sensors including GPS, RFID, smart cards, and biometric identification will be available with enhanced capabilities.

RFID Tag



Accuracy of GPS has been improving with enhancements (2). Targets include 5 -10 m resolution by 2009 and 1- 5 m resolution by 2013. Further the enhancements will improve reception near tall buildings, canyons, etc. It also will allow devices to reduce the amount of power they need to expend to receive a GPS signal. This will make putting accurate GPS receivers into mobile phones, watches, etc easier. Similarly, future RFID tags will shrink in size (example HP's memory spot 6, 7) to few millimeters, have greater storage capacity, faster transfer rates, and longer transfer range. Smart cards are likely to become common in wide range of transportation applications including secure identification (e-passport and e-license), security personnel identification at ports, and in transit and parking systems for fare payment. Yet another form of secure identification that will witness widespread use and acceptance is biometric identification.

Freight technology

The NYMTC Region is expected to have a 47% increase in volume (tonnage) through 2025. A majority of the region's freight is exchanged with the rest of the East Coast, and from manufacturing centers in the Midwest. The developments mentioned in the above technological domains are likely to impact freight transportation in addition to their impact on passenger transportation.

The focus of the technologies reviewed so far was on their impact on surface transportation. The freight mode split in NYMTC region indicates over 18% share for water based transportation. The ports and waterways in NYMTC region therefore handle a significant amount of freight transportation. Several technologies specific to water-based transportation exist.

The Waterbridge in Germany (21) connects two important German shipping canals by a giant kilometer-long concrete bathtub. The waterbridge will connect Berlin's inland harbor with the ports along the Rhine river. The project took six years to build and cost about half a billion Euros.

A technology that can improve material handling capabilities in ports is Automated Guided Vehicles (22). A more advanced concept is Automated Container Transport system between Inland POrt and Terminal (ACTIPOT) (23). ACTIPOT involves dedicated lanes between an Inland Port and terminals where trucks would go back and forth under full automatic control.

An equally important focus area is city logistics. With the growth of e-business and increasing material transactions, city logistics plays an important part in urban planning. The importance is furthered by the impacts on congestion and air quality of city logistics.

The Waterbridge in Germany

An emerging technological initiative for more efficient distribution of goods to the customers is pick-up centers. "Pick up points are local collection and distribution depots, or boxes, from which consumers can pick up goods they have ordered via home retail services" (20). The best known examples of pick up points in Europe today are the Kiala network in France and Benelux, and the Packstation network in Germany (20). Adopting similar freight technology should work well for densely populated regions such as New York City.

Chapter 4: Screening of Emerging Technologies

In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. The screening process will be a two-stage process where in the first stage the most appropriate goals of NYMTC will be screened, and in the second stage the technologies useful for achieving the goals will be screened.

List of Technologies

The list of technologies identified in task 2 is presented in List 1 below. Broadly, the technologies were divided into the following seven technology domains:

a) Nanotechnolog
b) Energy and Fuel technology
c) Communication technology
d) Computing and Internet technology
e) Transportation, Vehicular and Automotive technology
f) Sensors
g) Freight technology

List 1 List of Technologies

Nanotechnology

1. Nano-sized batteries
2. Nano Fuelsaver
3. Fuel-cell Nano Catalyst
4. Nanosensors
5. Carbon-based nano-fibres
6. Nanocoating of metallic surfaces
7. Nanoparticle-reinforced materials
8. Nanomaterials in pavements
9. Automatic healing materials

Energy and Fuel technology

10. Hydrogen Fuel
11. Biodiesel Fuel
12. Ethanol Fuel
13. Methanol Fuel
14. Natural gas
15. Propane
16. Biogas Fuels
17. Biobutanol Fuels
18. Hydrogenation-Derived Renewable Diesel
19. P-Series
20. Ultra-low sulfur diesel
21. Electric-driven vehicle

Communication

22. Dedicated Short Range Communications (DSRC)
23. Wide area wireless communication *
24. Ultra high-speed Internet *
25. Vehicular Ad Hoc Networks (VANETs)

Computing and Internet Technology

26. Collaboration software *
27. Augmented Reality *
28. Personal travel assistant
29. HD video conferencing *
30. Advanced route guidance systems
31. Adaptive ramp metering

Transportation, Vehicular, and Automotive Technology

32. Small wheeled transport
33. Hybrid vehicles
34. Personalized rapid transit (PRT)
35. Automated vehicles
36. Flying cars
37. Waterbridge

Sensor Technologies

38. GPS
39. Radio Frequency Identification (RFID)
40. MEMS sensors
41. Smart Cards
42. Machine Vision
43. Biometric Identification

Freight Technology

44. Automated Guided Vehicles
45. Automated Container Transport system
46. Pick-up centers

***Note**: The technologies relevant to telecommuting have been marked with a **

A total of forty-six technologies were identified. Several of these technologies (automatic healing materials, nano catalysts, augmented reality, flying cars etc.) have only been demonstrated in small-scale laboratory experiments while a few of the technologies (for example: VANETs, PRT, guided vehicles) have been prototyped or tested in limited field experiments. Few other technologies (GPS, RFID, Hybrid vehicles etc.) have been in use for several years now but newer advances will enable wide-spread adaptation. Figure 1 below presents the approximate timeline and cost/benefit category for each of the technologies. Each cell in the figure represents a particular timeline-cost/benefit category. For example, the technologies in the top-right cell are those that are still in the conceptual stages and have excellent cost/benefit estimates.

Database with Details on Technology

In order to obtain a better understanding of the forty-six technologies listed above, a survey of existing studies was carried out. Information was gleaned from these existing studies and a database was constructed to store the information. The database allows easy access to the information and allows the user to organize the information in convenient formats.

Timeline	Poor	Promising	Excellent
Conceptualized	Automatic healing materials Ultra high-speed net Augmented Reality Flying cars	Nano-size battery VANETs	Automated container transport system
Demonstrated	Fuel-cell nano-catalyst DSRC Carbon nano-fibers Personal rapid transit Automated vehicles	Nano Fuel Saver Wide area wireless Personal travel asstt. Adaptive ramp meter Biometric identification	Collaboration software Pick-up centers
Developed	Machine Vision Hydrogen fuel HD Video conferencing	Nanosensors Electric-driven vehicle Advanced route guidance systems	Biodiesel / Ethanol Propane / Natural gas Hybrid vehicles GPS, RFID Smart Cards

Cost/Benefit

Figure 1 Timeline – Cost/Benefit Categorization of Technologies

The details for each technology include: features, timeline, costs, applications to transportation, and challenges. The features field describes the technology in detail including the components and capabilities of the technology. The timeline provides a subjective estimate of the level of maturity of the technology and the time to implementation. Costs provide estimates of the implementation and operational cost and economic benefits from the technology. Given the uncertainty involved and the fact that these technologies are still under development, in most cases the costs are rough estimates. The next field identifies the potential application of the technology to transportation domain. What are the different benefits arising from the technology in terms of congestion reduction and management, air quality improvement, safety and security etc. is also discussed in the database. Finally, the field corresponding to 'challenges' lists the main hurdles to the development of the technology. In addition to these details the database has provision for additional information with regard to how effective the technology is towards meeting specific policies or goals. This is a rating and will be carried out as part of task 4 in order to short-list the technologies.

Decision Making Process

The decision making process for screening the technologies was done in two stages. In the first stage the most appropriate goals or policies that are relevant to NYMTC were screened, and in the second stage the economic and technical feasibility of technologies useful for achieving the goals were assessed. Two online surveys were conducted for the purpose of obtaining input from the Regional Transportation Plan (RTP) committee members. The details of the survey and the results are presented in the following sections.

Scope Assessment Survey

The scope assessment survey was divided into two sections. In the first section five broad transportation goals were presented and the respondents were asked to rate the importance of each transportation goal on a scale of 1 to 5 (5 being very important and 1 representing not important). Figure 2 below presents a screenshot of the first section of the survey.

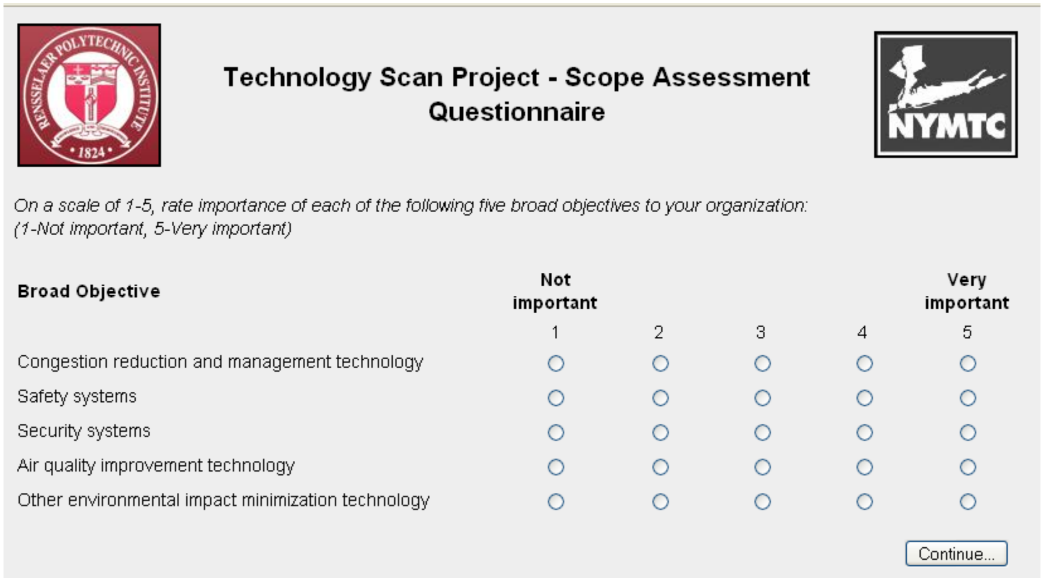
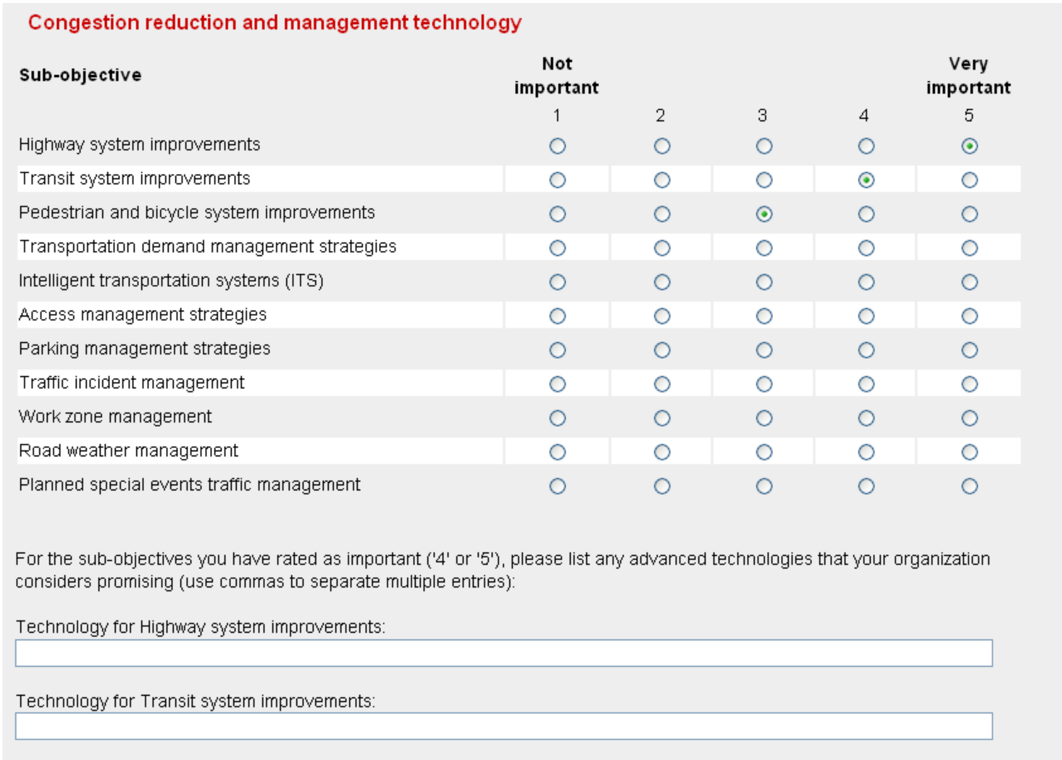


Figure 2 First Section of Scope Assessment Survey

The primary purpose of the above questions was to gauge the importance of each of the broad objectives to the different participating agencies across different counties in the NYMTC region. A secondary purpose was to reduce the burden of response by reducing the number of questions in the section 2 based on the response in section 1. For example if a respondent indicated that Security is not an important goal (rating ≤ 2) for their organization, section 2 did not have any questions pertaining security.

Having obtained input on broad transportation goals, the second part of the scope assessment survey divided each of the broad goals into several sub-categories. List 2 below presents all the sub-categories that were included. The respondent was asked to rate the importance of each sub-category in a scale of 1 (Not important) to 5 (Very important). Figure 3 below presents a screenshot of the survey 2.



Congestion reduction and management technology

Sub-objective	Not important 1	2	3	4	Very important 5
Highway system improvements					
Transit system improvements					
Pedestrian and bicycle system improvements					
Transportation demand management strategies					
Intelligent transportation systems (ITS)					
Access management strategies					
Parking management strategies					
Traffic incident management					
Work zone management					
Road weather management					
Planned special events traffic management					

For the sub-objectives you have rated as important ('4' or '5'), please list any advanced technologies that your organization considers promising (use commas to separate multiple entries):

Technology for Highway system improvements:

Technology for Transit system improvements:

Figure 3 Second Section of Scope Assessment Survey

In addition to the rating of the sub-categories, the section also collected information on promising (from the organization's perspective) future technologies to meet each of these sub-categories. This additional information was sought only from those respondents who rated a sub-category as very important (≥ 4). These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist for task 4. The results from this survey are summarized in Section 4.

Feasibility Assessment Survey

The feasibility assessment survey was the second internet survey administered to obtain input from RTP committee members. The purpose of this survey was to obtain subjective inputs on the technical and economic feasibility of each of the forty-six technologies in List 1. For each technology and for each of the two categories of feasibility (technical and economic), the respondent was requested rate on a scale from -4 (Highly infeasible) to 4 (Highly feasible). A snapshot of the questionnaire is shown in figure 4.

The feasibility assessment questionnaire was completed by 7 respondents including two outside experts. Feasibility assessment included both technical and economic feasibility. We present the average rating for the technical and economic feasibility and also provide a joint weighted measure. The technologies are ranked based on this weighted measure. The results of this survey are presented in figure 5.

List 2 List of Sub-categories
Congestion Reduction and Management 1. Highway system improvements 2. Transit system improvements 3. Pedestrian and bicycle system improvements 4. Transportation demand management strategies 5. Intelligent Transportation Systems (ITS)

6. Access management strategies
7. Parking management strategies
8. Traffic incident management
9. Work zone management
10. Road weather management
11. Planned special events traffic management

Traffic Safety Technology

13. Auto passenger safety
14. Pedestrian and biker safety
15. Vehicle safety
16. Highway safety
17. Emergency medical services
18. Traffic management

Security Technology

1. Transit security
2. Highway security
3. Freight security

Air Quality Improvement

1. Vehicle based technology
2. Fuel technology
3. Transportation infrastructure technology

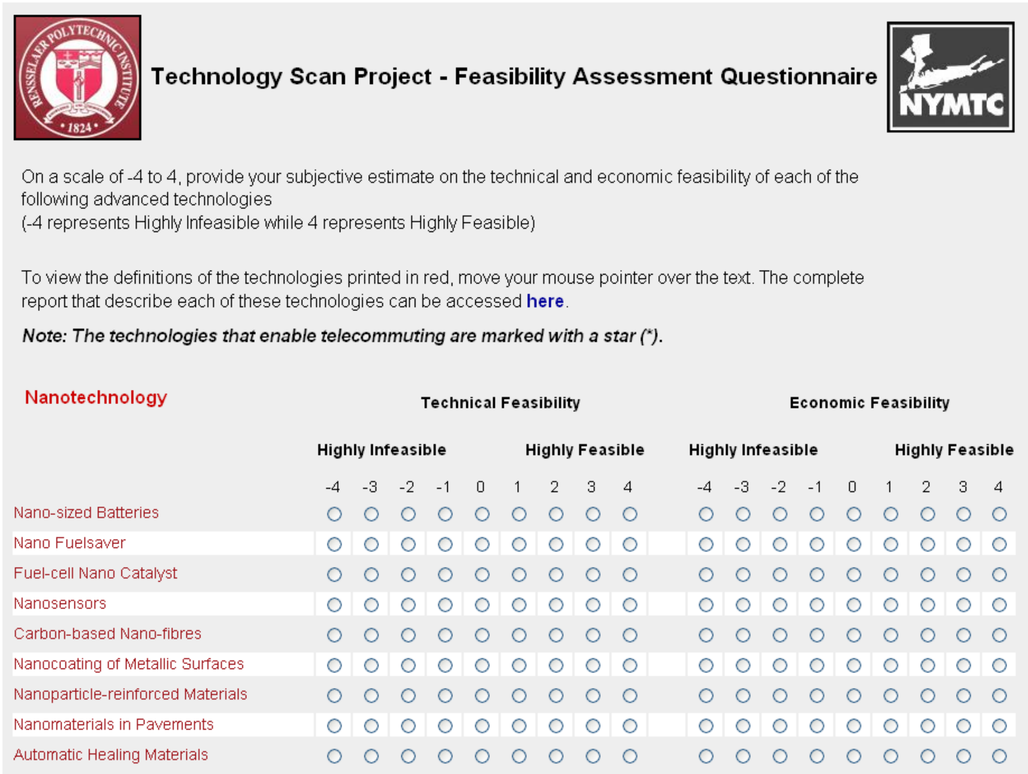
Environmental Impact Mitigation

5. Noise pollution
6. Energy consumption
7. Wildlife habitat loss
8. Water and land pollution

Results from Survey Response

In this section, we present the results of the scope assessment survey. There were 14 total responses. These responses were from the following organizations: Westchester County, Rockland County, NYC Dept. of City Planning, MTA, Nassau County Planning Commission, Suffolk County DPW-Transportation Division, New York City DoT (4 responses), New York State DoT (4). However, only nine of the respondents completed all sections of the survey.

An important result from the survey is the ranking of the different sub-categories. The table below presents the rankings of the sub-categories based on all the responses.



Technology Scan Project - Feasibility Assessment Questionnaire

NYMTC

On a scale of -4 to 4, provide your subjective estimate on the technical and economic feasibility of each of the following advanced technologies
(-4 represents Highly Infeasible while 4 represents Highly Feasible)

To view the definitions of the technologies printed in red, move your mouse pointer over the text. The complete report that describe each of these technologies can be accessed **here**.

Note: The technologies that enable telecommuting are marked with a star (*).

Nanotechnology	Technical Feasibility									Economic Feasibility								
	Highly Infeasible							Highly Feasible		Highly Infeasible							Highly Feasible	
	-4	-3	-2	-1	0	1	2	3	4	-4	-3	-2	-1	0	1	2	3	4
Nano-sized Batteries																		
Nano Fuelsaver																		
Fuel-cell Nano Catalyst																		
Nanosensors																		
Carbon-based Nano-fibres																		
Nanocoating of Metallic Surfaces																		
Nanoparticle-reinforced Materials																		
Nanomaterials in Pavements																		
Automatic Healing Materials																		

Figure 4 Feasibility Assessment Survey

As expected energy consumption is the highest rated policy sub-category followed by transit-system improvements. Energy is an important policy category particularly because of rising gas prices in the country. In addition, transit related technology is important since NY metropolitan region has one the highest ridership in the country. Highway system improvements, transportation demand management strategies (including telecommuting), ITS, and highway safety were ranked next. These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist in task 4.

Table 1 Rankings of Sub-categories

Rank	Goal/Policy Sub-Category	Total Points
1	Energy consumption	43
2	Transit system improvements	42
3	Highway system improvements	41
3	Transportation demand management strategies	41
3	Intelligent transportation systems	41
3	Highway safety	41
7	Pedestrian and bicycle system improvements	40
7	Pedestrian and biker safety	40
7	Traffic management	40
7	Transit security	40
7	Air Quality Improvement: Vehicle based technology	40
7	Air Quality Improvement: Fuel technology	40
7	Air Quality Improvement: Transportation infrastructure technology	40
14	Road weather management	39

14	Water and land pollution	39
16	Access management strategies	38
16	Traffic incident management	38
16	Emergency medical services	38
16	Highways security (including bridges and tunnels)	38
16	Noise pollution	38
21	Auto passenger safety	37
22	Vehicle safety	36
23	Work zone management	35
23	Freight security	35
25	Parking management strategies	34
26	Planned special events traffic management	33

Note: 9 total responses.

The feasibility assessment survey results are presented in figure 5. A total of 7 respondents completed the technical feasibility component of the survey while the economic feasibility component was completed by 6 respondents. Figure 5 presents three measures of feasibility: economic, technical, and weighted joint measure. The technologies are ranked based on the weighted measure. The top 5 technologies in terms of the joint feasibility measure are GPS, HD video conferencing, machine vision, ultra-low sulfur diesel, and biodiesel fuel.

In terms of the broad categories, three technologies (biodiesel, biogas, and ultra-low sulfur diesel) from energy and fuel technology category are ranked in the top ten, three (GPS, RFID, machine vision) from sensor technologies, two (HD video conferencing, personal travel assistant) from computing and internet technology, wide-area wireless communication from communication technologies, and hybrid vehicles from transportation technologies. None of the freight technology and only one nanotechnology are present in the top twenty. The rankings are along expected lines. Alternative energy sources are important both from economic and environmental perspective. The sensor technologies have a wide range of application including in pricing, route guidance, and safety. These technologies have also reached considerably levels of maturity and its wide-spread adoption is very likely over the next ten years. On the other hand, technologies that are still under development such as nano-materials and flying cars have been ranked low in terms of feasibility.

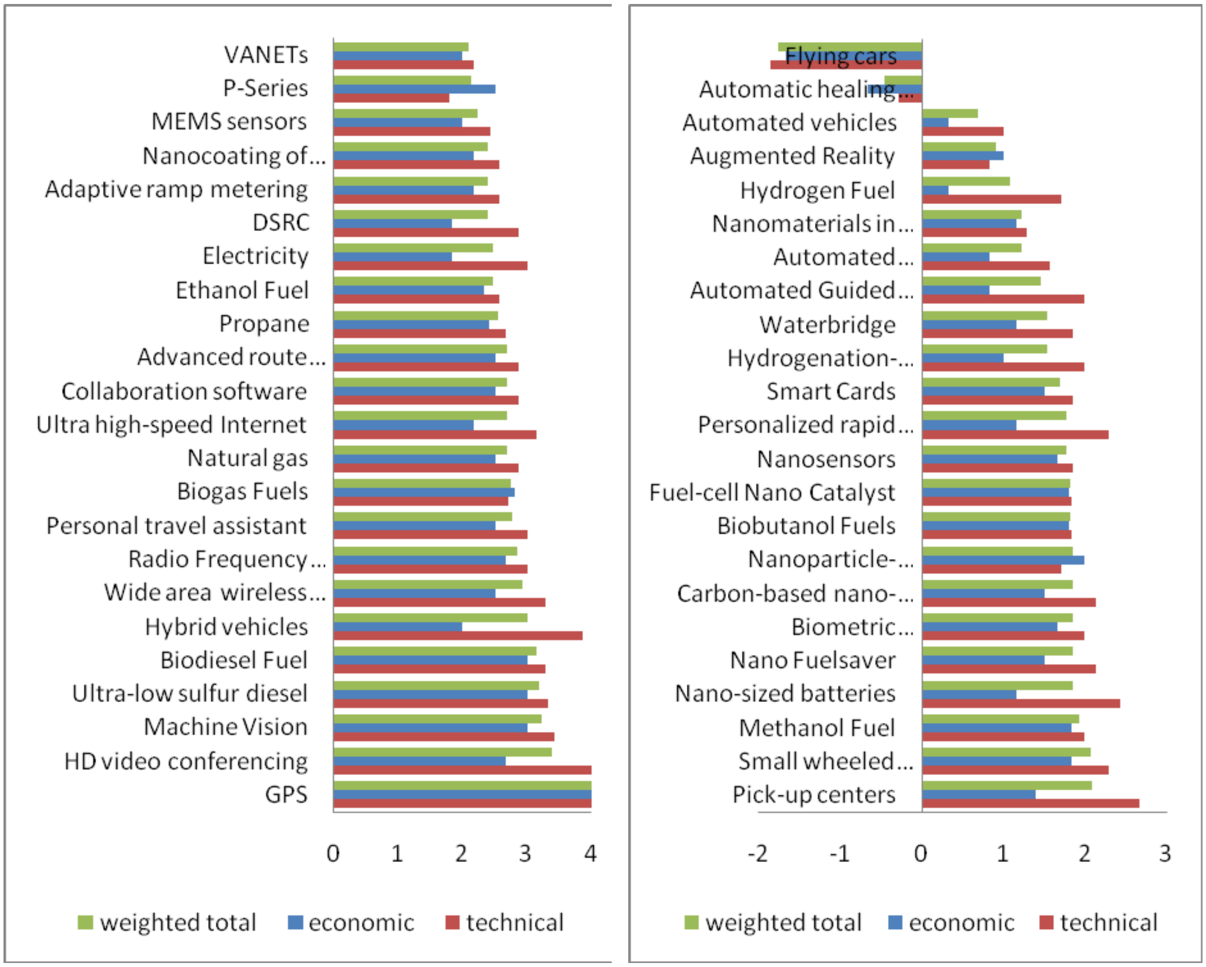


Figure 5. Feasibility Assessment Survey Results (7 respondents)

HD video conferencing (ranked 2), wide area wireless communication (7), ultra-high speed internet (12), and collaboration software (13) are four telecommuting technologies in the top twenty. Telecommuting will play an important role in substituting work-related trips in the future. The above technologies will enable a rapid acceptance of telecommuting by both employers and employees.

In summary, the rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input to determine the shortlist of most relevant and likely technologies in Task 4.

Chapter 5: Shortlist of Likely Technologies

In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. The screening process was a two-stage process where in the first stage the most appropriate goals of NYMTC was screened, and in the second stage the technologies useful for achieving the goals was screened.

Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members. An important result from the first survey is the ranking of the different policy sub-categories. Energy consumption is the highest ranked policy sub-category followed by transit-system improvements. Highway system improvements, transportation demand management strategies (including telecommuting), ITS, and highway safety are ranked next. These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist for task 4.

The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The top 5 technologies in terms of the joint technical and economic feasibility measure are GPS, HD video conferencing, machine vision, ultra-low sulfur diesel, and bio-diesel fuel.

The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be used in the New York Metro region. Below, we describe the methodology for determining the shortlist and subsequently provide details of each shortlisted technology.

Methodology for Short-listing Technologies

The methodology for shortlisting technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. Task 3 report outlined the exhaustive list of technologies, the survey questionnaires, and their results. Two questionnaires were used to get importance ratings for the NYMTC goals and policies and technical and economic feasibility of the different technology. Table 1 in Task 3 report (shown below) lists the ranking of the NYMTC goals and policies.

Table 1 Rankings of Sub-categories

Rank	Goal/Policy Sub-Category	Total Points
1	Energy consumption	43
2	Transit system improvements	42
3	Highway system improvements	41
3	Transportation demand management strategies	41
3	Intelligent transportation systems	41
3	Highway safety	41
7	Pedestrian and bicycle system improvements	40
7	Pedestrian and biker safety	40
7	Traffic management	40
7	Transit security	40
7	Air Quality Improvement: Vehicle based technology	40
7	Air Quality Improvement: Fuel technology	40
7	Air Quality Improvement: Transportation infrastructure technology	40

14	Road weather management	39
14	Water and land pollution	39
16	Access management strategies	38
16	Traffic incident management	38
16	Emergency medical services	38
16	Highways security (including bridges and tunnels)	38
16	Noise pollution	38
21	Auto passenger safety	37
22	Vehicle safety	36
23	Work zone management	35
23	Freight security	35
25	Parking management strategies	34
26	Planned special events traffic management	33

Note: 9 total responses.

The second questionnaire obtained input on the technical and economic feasibility of each of the 46 technologies. The table below presents the re-scaled (-4 to +4 => 1 to 5) economic and technical feasibility ratings.

Table 2 Economic and Technical Feasibility Ratings

Technology	Economic Feasibility	Technical Feasibility
Adaptive ramp metering	3.78	4.05
Advanced route guidance systems	4.00	4.24
Augmented Reality	3.00	2.89
Automated Container Transport system	2.89	3.38
Automated Guided Vehicles	2.89	3.67
Automated vehicles	2.56	3.00
Biobutanol Fuels	3.53	3.56
Biodiesel Fuel	4.33	4.52
Biogas Fuels	4.20	4.14
Biometric Identification	3.44	3.67
Carbon-based nano-fibres	3.33	3.76
Collaboration software	4.00	4.24
DSRC	3.56	4.24
Electric driven vehicles	3.56	4.33
Ethanol Fuel	3.89	4.05
Flying cars	1.22	1.10
Fuel-cell Nano Catalyst	3.53	3.56
GPS	5.00	5.00
HD video conferencing	4.11	5.00
Hybrid vehicles	3.67	4.90
Hydrogen Fuel	2.56	3.48
Hydrogenation-Derived Renewable Diesel	3.00	3.67
Machine Vision	4.33	4.62
MEMS sensors	3.67	3.95
Methanol Fuel	3.56	3.67
Nano Fuelsaver	3.33	3.76
Nanocoating of metallic surfaces	3.78	4.05
Nanomaterials in pavements	3.11	3.19
Nanoparticle-reinforced materials	3.67	3.48

Nanosensors	3.44	3.57
Nano-sized batteries	3.11	3.95
Natural gas	4.00	4.24
Personal travel assistant	4.00	4.33
Personalized rapid transit	3.11	3.86
Pick-up centers	3.27	4.11
Propane	3.93	4.11
P-Series	4.00	3.53
Radio Frequency Identification (RFID)	4.11	4.33
Small wheeled transport	3.56	3.86
Smart Cards	3.33	3.57
Ultra high-speed Internet	3.78	4.43
Ultra-low sulfur diesel	4.33	4.56
VANETs	3.67	3.78
Waterbridge	3.11	3.57
Wide area wireless communication	4.00	4.52

The project consultant team rated on 1-5 scale (5 being very important) each of the above technologies with respect to their importance under each of the NYMTC policy objectives listed in Table 1. These ratings together with the two ratings in Table 1 provided the importance rating matrix. The complete rating matrix is provided in Appendix 1.

A weighted sum method was used to obtain the rankings of the technologies. A weighted sum method is a simple multi-criteria decision making tool. Given *n* alternatives and *m* criteria, each alternative is provided a rating value for each criterion. This generates an n x m data matrix. If the m criteria are assigned weights given by w, then the weighted sum for each technology can be obtained using the following formula:

$$r_i = \sum_{j=1}^{m} a_{ij} w_j$$

The overall ranking of the technologies can be obtained by sorting with respect to the r_i values.

Since the focus on technologies have always been toward meeting the three broad goals of congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals were prepared. The ratings for policies in Table 1 were converted to an exponential scale (exp(rating – minimum rating) = exp(rating – 33)) to reflect the inherent bias that was observed in the survey responses; almost all respondents rated all the policies as important. The weights were subsequently obtained by taking a sum-average. The policies were further divided based on the above broad goals. Economic and technical feasibility were given individual weights of 20% each and the remaining 60% were distributed to the policy objectives in each broad goal category. The rankings of the technologies and the weighted sum rating values for each of the broad categories are presented in Table 3.

Table 3 Ranking of Technologies

Congestion Reduction and Management	
GPS	4.74
Personal travel assistant	4.00
Radio Frequency Identification (RFID)	3.89
Adaptive ramp metering	3.46
Smart Cards	3.43
Personalized rapid transit	3.25
DSRC	3.16
MEMS sensors	3.13

Wide area wireless communication	3.09
Machine Vision	2.98
Advanced route guidance systems	2.96
Small wheeled transport	2.84
Biometric Identification	2.77
HD video conferencing *	2.68
VANETs	2.67
Automated vehicles	2.66
Ultra high-speed Internet *	2.56
Hybrid vehicles	2.49
Collaboration software *	2.41
Electricity	2.35
Hydrogen Fuel	1.98
Nanosensors	1.85
Nano-sized batteries	1.70
Nanoparticle-reinforced materials	1.54
Augmented Reality	1.38
Automatic healing materials	0.94
Flying cars	0.94
Safety and Security	
Machine Vision	3.75
Nanosensors	3.66
DSRC	3.53
MEMS sensors	3.48
VANETs	3.46
Radio Frequency Identification (RFID)	3.11
GPS	2.89
Automated vehicles	2.66
Adaptive ramp metering	2.60
Nanoparticle-reinforced materials	2.55
Wide area wireless communication	2.35
Advanced route guidance systems	2.20
Personal travel assistant	2.03
Biometric Identification	1.96
Automatic healing materials	1.88
Nano-sized batteries	1.86
Smart Cards	1.78
Carbon-based nano-fibres	1.74
Augmented Reality	1.20
Energy and Environment	
Ultra-low sulfur diesel	4.46
Natural gas	4.33
Biogas Fuels	4.32
Propane	4.29
Electricity	4.26
P-Series	4.19
Nano Fuelsaver	4.10
Biobutanol Fuels	4.07

Hydrogenation-Derived Renewable Diesel	4.01
Nano-sized batteries	3.97
Hydrogen Fuel	3.89
Hybrid vehicles	3.88
Ethanol Fuel	3.73
Advanced route guidance systems	3.69
Methanol Fuel	3.62
Small wheeled transport	3.53
Biodiesel Fuel	3.41
HD video conferencing	3.35
Wide area wireless communication	3.24
Automated vehicles	3.23
Personal travel assistant	3.20
Adaptive ramp metering	3.17
Ultra high-speed Internet	3.17
Fuel-cell Nano Catalyst	3.05
DSRC	1.64
VANETs	1.57

Telecommuting technologies marked with a *

Short-listed Technologies

Based on the ranking of the technologies in Table 3 the top 5 technologies in each category were selected. Few of the technologies that overlapped or jointly formed a technology "system" were grouped; for example, smart cards use RFID chips and therefore they were combined. Additional technologies were added to the list based on the project team's reality-checks. We discuss this process of selection and the rationale for choosing some technologies which were not necessarily in the top five.

In Congestion Reduction and Management the top five technologies were Geographic Positioning Systems (GPS), Personal Travel Assistants, RFID, Adaptive Ramp Metering, and Smart Cards. Since GPS were an integral part of personal travel assistants the two technologies were combined to form a single technology system. Similarly, RFID and Smart Cards were combined since RFID is the primary mode of recognition in smart card systems. Two additional technologies Personal Rapid Transit and Collaborative technologies were added to the list to bring the total list of technologies to five. Personal Rapid Transit was chosen since it was ranked sixth in the list. Three technologies listed HD Video Conferencing, Ultra high speed internet, and collaborative software together comprises collaborative technologies. These technologies together act as telecommuting enablers. Since the RTP committee members expressed that telecommuting is an important policy focus, these technologies were grouped together and included in the shortlist as collaboration technologies. The technologies are identified based on their likelihood of being implemented in the NY metropolitan area.

The top five Safety and Security technologies were: Machine Vision, Nanosensors, Dedicated Short-Range Communication, Micro-Electronic Mechanical Systems Sensors (MEMS), and Vehicular Ad-hoc NETworks (VANET). Nanosensors and MEMS represented sensor technologies though at different size scales. Since the overall objective of these technologies was sensing they were grouped together into a single category. Similarly DSRC and RFID are likely to be an important component in VANET. Further, vehicle to infrastructure communication is developing alongside vehicle to vehicle communication. These technologies were grouped together into vehicle to vehicle and vehicle to infrastructure communication technologies. The technologies that were added to the list subsequently were automated vehicles and biometric identification. GPS technologies was not included since the project team believe even with improvements to GPS technologies, the accuracy (and more importantly relative positions between objects and vehicles) may not be sufficient for safety applications. Further, automated vehicles are likely to incorporate GPS and all of the other technologies ranked above. Preliminary models of automated vehicles that incorporate adaptive cruise control and lane departure warning are already available in the market and are likely to grow steadily in the future. Therefore, automated vehicles technology was included in the shortlist ahead of GPS. Finally, with increasing emphasis on security, biometric identification – a promising security technology – was also added to the shortlist.

The top technologies in Energy and Environment policy category were primarily fuel technologies. Ultra-low sulfur diesel, natural gas, biogas, propane, and electricity were the top five technologies in this category. Ultra-low sulfur diesel (ULSD) which was the top-most technology in the Energy and Environment category has already become a widely established fuel alternative. Therefore it has not been included in the list of "emerging" technologies. ULSD is diesel fuel with 15 parts per million (ppm) sulfur content. Ultra-low sulfur diesel enables use of advanced emission control technologies on light-duty and heavy-duty diesel vehicles. Effective June 1, 2006, 80 percent of the highway diesel fuel produced or imported is required to be ULSD fuel replacing most Low Sulfur Diesel (LSD) fuel, which contains a maximum of 500 ppm sulfur. Used in combination with cleaner-burning diesel engines and vehicles, ULSD fuel helps to improve air quality by significantly reducing emissions. By December 1, 2010, all highway diesel fuel offered for sale must be ULSD fuel (23). Natural gas and propane which had several similarities were grouped together. Hybrid vehicles (ranked 12) was included along with electric vehicles since they share several common technology components and hybrid development is likely to help advanced electric vehicle development. Finally, two other technologies – Hydrogen fuel (ranked 11) and Ethanol/Bio-diesel (ranked 13 and 17) were included to the list because of their predicted market potential in the long-term and near-term respectively. Hydrogen fuel received a lower ranking primarily because of the low score it received based on the technical and economic feasibility. The cost of fuel cell stacks has decreased tenfold in just three years (121). Improvements in technology are likely to bring the cost down further. In the longer term – 20 to 30 years – with rising cost of traditional fuel sources hydrogen fuel holds greater promise. Ethanol and Bio-diesel received lower rankings primarily because of the threat to food-security they pose. Nevertheless, in the next 10 years, they are likely to play the role of dominant alternative fuel source (105) since they are easily compatible with existing vehicle engines and have therefore been included in the shortlist.

Table 4 Shortlisted Technologies
Congestion Reduction and Management
Geographic Positioning Systems and Personal Travel Assistants
Adaptive Ramp Metering
Smart Cards and RFID
Personalized Rapid Transit
Collaborative Technologies
Safety and Security
Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication (DSRC, RFID, VANETs)
Machine Vision
MEMS and Nanosensors
Automated Vehicles
Biometric Identification
Energy and Environment
Natural Gas and Propane
Biogas
Bio-diesel and Ethanol
Electric-driven and Hybrid vehicles
Hydrogen Fuel

Detailed Description of Short-listed Technologies

Congestion Reduction and Management

Geographic Positioning Systems and Personal Travel Assistants

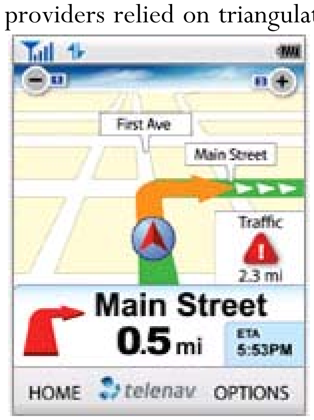
<u>Description and Features:</u> Geographic positioning systems (GPS) provide accurate location coordinates. While GPS devices have become common use, the next generation of such devices will have the following characteristics:

- Miniaturization
- Increased accuracy
- Supplementary location technologies to cover GPS-denied areas (inside buildings, or downtown streets)

A Personal Navigation Device

Early GPS technology was bulky and cumbersome and was suitable only for use by skilled personal for survey techniques. However over the last decade GPS technologies have become portable and have enabled advanced navigation capabilities for the everyday traveler. Initially, GPS were equipped in vehicles and personal navigation devices that provided in-vehicle route guidance for users. More recently GPS has become available on cellular phones. In fact it is anticipated that every cellular phone to be produced from the later part of 2008 will be equipped with integrated GPS. This miniaturization of GPS has allowed for anywhere anytime location-awareness for users. Among other benefits, these devices serve as personal travel assistants that can guide users to make optimal travel decisions.

Personal travel assistants provide individuals, in vehicles and on foot, with location based information services. It brings together several features including navigation, traffic information, as well as utility and entertainment through stand-alone GPS or mobile phones. Initially, network-based location technologies from cellular service providers relied on triangulation using cell-tower signals to determine individual location; This method is increasingly giving way to leveraging built-in GPS chips in each handset, mostly because these chips have become dramatically more cost-effective and less power consumptive while improving location availability over the last several years (1). For example, Texas Instruments has recently integrated GPS with Bluetooth and FM transmission capabilities in a single-chip. Intelligent power consumption technology will enable cell-phones provide all of the capabilities simultaneously for extended periods of time.



Handheld Navigation

Another important development is the possibility of greater accuracy. The GPS modernization project as well as the European Union's plan to implement an alternative complementary satellite navigation system will increase the accuracy and reliability of GPS tracking. Galileo will provide greater accuracy than GPS (±[illegible]0 meters for commercial applications) because of the greater number of signals available.

<u>Timeline</u>: Both the GPS modernization project and the Galileo satellite system is expected to be operational by 2013.

ABI Research said personal navigation devices (PNDs) will grow to a global sales volume of more than 100 million units by 2011. ABI Research expects the market for GPS-enabled handsets to grow strongly in the next five years, from around 140 million handsets in 2007 to more than 600 million handset shipments in 2012.

In-Stat predicts that "Sales of mobile devices with integrated GPS [will] grow from 180 million units in 2007 to 720 million units in 2011."

Costs: The cost of PNDs and GPS equipped Handsets is comparatively high. However, these prices are expected to reduce in the future.

The cost of PNDs ranges from $200 to $1200. The cost of GPS enabled handsets ranges from $400 to $800. Handsets without in-built GPS have the option to add Bluetooth GPS receivers for $50 - $150. Further, subscription services to obtain real-time traffic updates are available from $5 per month to $10 per month.

Transportation Applications: More accurate GPS enables better navigation systems. Mobile and wearable GPS allow for better personal navigation and quicker emergency response. GPS may also aid in collecting travel behavior data (2) that could be used in building models for planning and operations.

Dash's 2-way internet-connected Navigator

Real-time information on traffic delays enables personalized public transit information system, advanced route guidance capabilities. Multi-modal information applications: Personalized multimodal trip planning, continuous on-trip information to multimodal travelers, information on transfers, assist travelers in finding their way to the destination address once they get off at the last stop provided by public transport. (3)

Real-time information can also be utilized to update travelers about dynamic toll prices. The availability of accurate up-to-date information will enable travelers make more optimal decisions and seek alternate plans thereby increasing the efficiency of congestion pricing schemes. Most PNDs and Handheld navigation devices feature some form of subscription service to real-time information services.

Adaptive Ramp Metering

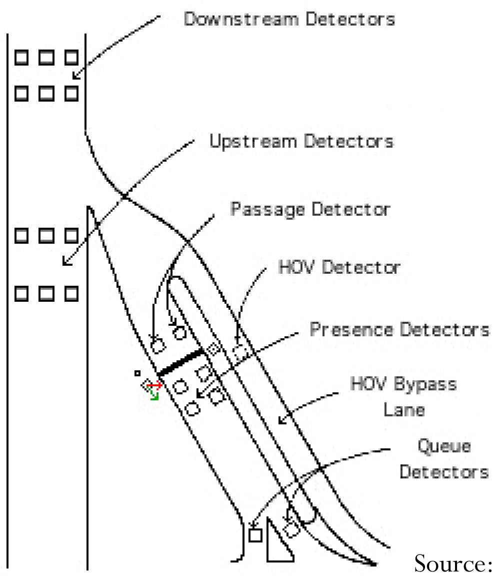
Description and Features: Adaptive ramp metering includes algorithms that ensure efficient traffic flow by controlling number and frequency of vehicles entering the freeway system through on-ramp signals. Broadly, these algorithms can be divided into three categories: local ramp metering algorithms, system-wide coordinated ramp metering algorithms, and a combination of the two. The following material is borrowed mostly from the paper by Rafferty and Treasize (4).

Local Ramp Meter Algorithms

Local control is a process of selecting ramp meter rates based solely on conditions present at an individual ramp. In some cases, congestion problems at the ramp may appear to be fixed, when in reality problems are transferred to or uncovered at upstream or downstream locations.

- **ALINEA.** The control input is based on the system output. The goal of ALINEA is to sustain near maximum flow downstream of the on-ramp by regulating the downstream occupancy to a target value, which is set a little below the critical occupancy at which congestion first appears.
- **ALINEA/Q**. This algorithm extends ALINEA by calculating a second rate: the minimum rate needed to keep the ramp queue at or below the maximum allowable queue length.
- **FL-ALINEA**. FL-ALINEA uses flow measurements from downstream detectors instead of occupancy measurements.
- **MALINEA**. MALINEA addresses a shortcoming of ALINEA by also measuring the upstream occupancy.
- **UF-ALINEA**. It uses the sum of the upstream flow and the ramp flow to estimate the downstream flow.

- **UP-ALINEA**. Uses occupancy measurements, but from upstream detectors, and estimates the downstream occupancy.
- **X-ALINEA/Q.** This is where any of the modified ALINEA algorithms are used with queue control. All of these algorithms, except for X-ALINEA/Q are less efficient than the traditional ALINEA algorithm but are useful when various occupancy measurements are not available.
- **Demand-Capacity**. This traffic responsive algorithm measures the downstream occupancy. If it is above the critical occupancy, congestion is assumed to exist. The metering rate is then set to the min rate. Otherwise, the volume is measured upstream of the merge, and the metering rate is set to the difference between the downstream capacity and the upstream volume.
- **Fixed-Rate or Time-of-Day**. Ramp meter timings are adjusted automatically by specified time-of-day parameters. This algorithm does not afford flexibility for changing traffic conditions.
- **Percent-Occupancy.** This strategy uses only upstream sensor occupancy measurements to identify and measure congestion. The critical occupancy is measured using historical data.



Metered Freeway Ramp

Source: (5)

System Coordinated Ramp Meter Algorithms

This is a process of selecting metering rates based on conditions throughout the entire length of the metered corridor. This makes system wide control more flexible in handling reductions in capacity that occur as a result of congestion or non-recurring incidents.

- **ARMS (Advanced Real-time Metering System)**. ARMS works on two levels. In the first level, a system wide control policy is to maintain free flow conditions. A prediction and pattern recognition algorithm is also developed to predict in real-time the potential occurrence of recurrent congestion. In the second level, the algorithm works to resolve congestion once it develops. It does this by minimizing the congestion clearance time and queues on the controlled ramps.
- **BEEX (Balanced Efficiency and Equity).** BEEX seeks to minimize the total weighted travel time, which involves weighting both the freeway mainline travel time and the ramp delays.
- **Fuzzy Logic.** It can balance several performance objectives simultaneously, such as occupancy, flow rate, speed, and ramp queue. The performance objectives are divided into finite categories and then rules are developed with different weighting factors to relate traffic conditions with metering levels. Fuzzy logic can anticipate a problem and take temperate, corrective action before congestion occurs. With congestion indicators as inputs, the Fuzzy Logic can handle poor data, incidents, special events, and adverse weather without modifying the control parameters.
- **Linear.** The linear algorithm maximizes the weighted sum of ramp flows. It also computes a real-time capacity for each road segment. The drawbacks of this algorithm are (a) its performance is heavily dependent on accurate origin-destination data, and (b) it is static, i.e., it neglects the variation of travel time in its computation of ramp metering rates.

- **METALINE**. The metering rate of each ramp is computed based on the change in measured occupancy of each freeway segment under METALINE control and the deviation of occupancy from critical occupancy for each segment that has a controlled on-ramp.
- **Metering model for non-recurrent congestion**. It has a dynamic traffic flow model to describe the traffic flow process, explicitly links control with a clear set of objectives, takes into account system wide physical and environmental constraints and projected traffic conditions, and uses a rigorous yet straightforward solution procedure to obtain real-time metering rates.
- **MILOS (Multi-Objective, Integrated, Large-Scale, & Optimized System)**. The area wide coordinator assigns target ramp metering rates to maximize freeway throughput, balance ramp queue growth rates, and minimize queue spill-back into the adjacent surface street interchanges.
- **SZM (Stratified Zone Metering)**. Effective in reducing ramp delays and queues, reducing freeway travel time and delay, increasing freeway speed, smoothing freeway flow, as well as reducing the number of stops.

Local and System wide Coordinated Ramp Meter Algorithms

The following algorithms have both local and coordinated capabilities.

- **Bottleneck.** For each ramp, the more restrictive of the two rates is chosen. Local: A control strategy compares the upstream demand with the downstream supply; then takes the difference of them as the locally determined metering rate. System wide: A coordinated control strategy first identifies bottlenecks, decides the volume reduction for the bottleneck based on flow conservation, and then distributes the volume reduction to upstream ramps according to predetermined weights.
- **Compass**. The more restrictive of the following two rates is selected. Local: Determines the metering rates from an ad-hoc lookup table, which has multiple levels for each ramp, determined by the local mainline occupancy, the downstream mainline occupancy, and the upstream mainline volume. System wide: Coordinated control use of off-line optimization to generate metering rates based on system wide information. Compass addresses spillback through overriding restrictive rates. If the occupancy at a ramp queue detector exceeds its threshold value, the metering rate is increased by one rate level until the detected occupancy is back below the threshold level.
- **Dynamic metering control**. Local control attempts to maintain traffic conditions close to the target traffic conditions that are provided by area-wide control. It obtains metering rates through minimizing the total system travel time that includes travel time on freeway and delay on ramps, subject to demand and queue capacity constraints.
- **FLOW**. FLOW tries to keep traffic at a predefined bottleneck below capacity and works best at very high traffic volumes. The more restrictive of the following two rates is chosen. Local: The metering rates associated with each upstream occupancy are the difference between the capacity and volume associated with the occupancy on the fundamental diagram. System wide: For the bottleneck metering rate, bottleneck locations on the freeway must be determined. The bottleneck metering rate for each ramp is then calculated by subtracting the bottleneck metering rate reduction from the measured on-ramp flow during the previous interval.
- **Helper (or incremental)**. A freeway corridor is divided into six groups consisting of one to seven ramps per group. Local: In the local traffic responsive metering component, each meter selects one of six available metering rates based on localized upstream mainline occupancy. System wide: If a ramp grows a long queue and is classified as critical, its metering burden will be sequentially distributed to its upstream ramps.
- **Linked**. Local: It is separated into a number of local traffic responsive controllers. This algorithm is based on the demand-capacity concept, and the local metering rate is determined based on upstream flow measurement at each location where the metering rate is equal to the target flow rate minus the upstream flow rate. System wide: Whenever a ramp’s metering rate is in one of its lowest three metering rates, then

the upstream ramp is required to meter in the same rate or less, and, if necessary, the further upstream ramps are also required to do so.

- **Neural Control**. Local: This algorithm uses feedback regulation to maintain a desired level of occupancy, or the target occupancy, which is usually chosen to be the critical occupancy. Moreover, the neural control algorithm is limited in adaptive control if on-line tuning is not implemented. System wide: This uses artificial neural networks to learn and memorize the metering plans generated by a traffic simulation model and a ramp control expert system.
- **RAMBO (Ramp Adaptive Metering Bottleneck Optimization)**. Local: RAMBO I evaluates plans generated based on ramp metering specifications. System wide: RAMBO II evaluates ramp metering rates based on forecasted traffic conditions along an extended section of freeway containing up to 12 metered on-ramps and 12 exit ramps. RAMBO II develops ramp metering rates using capacity and merge constraints for the entire freeway segment specified by the user.
- **SWARM (System Wide Adaptive Ramp Metering)**. SWARM has to stay within a TOD max and min range. The most restrictive rate is selected for each ramp. Local: The local control decides ramp metering rates based on local density. System wide: When a bottleneck is detected, a new set of ramp metering rates are determined. Downstream ramp meters will be shut off and upstream ramp meters will have a more restrictive timing. SWARM has the potential to be proactive, rather than reactive. It has a built-in failure management module to clean faulty input data from detectors. It also allows further adjustment to accommodate queue spill-back handling. It automatically adjusts timing for incidents and holidays.
- **ZONE**. Local: Zone provides for local control by using the occupancy control philosophy. System wide: ZONE divides a freeway into several zones of three to six miles in length. The upstream end of a zone is a free-flow area, whereas downstream end of a zone is a critical bottleneck. ZONE calculates metering rates based on volume control in each zone. To accomplish this, ZONE relies on proper division of zones, accurate estimates of bottleneck capacity, and accurate measurements of all in- and out-flows from a zone. (4)

According to the Federal Highway Administration, evaluations from across the country show that ramp metering reduces collisions on freeways and ramps from 15 to 50%. Ramp management strategies often increase travel speeds while reducing travel time and delay. Freeways that have metered entrance ramps usually carry more traffic than they did before metering began while attaining the improvements mentioned previously. The table below provides a brief summary of common measures of effectiveness for ramp metering (4).

<u>**Timeline**</u>: Ramp metering is currently implemented across the United States and Europe. (5) Also, new algorithms are being developed which will be more efficient than the current algorithms.

Table 1. National ramp meter benefits (WisDOT 2006)

City	Study road	Speed increase	Travel time reduction	Crash reduction	Flow increase	Program initiation
Minneapolis	I-35	26%	-	- 27%	25%	1970
Portland	I-5	61%	12 min	- 43%	-	1981
Seattle	I-5		11.5 min	- 39%	62%-86%	1981
Long Island	Multiple	9%	-	- 15%	2%	1989
Detroit	I-94	8%	-	-50%	14%	1982
Austin	I-35	60%	-	-	7.9%	Late 1970s
San Francisco	I-80	-	- 1 min	-	14%	1974
Denver	I-25	57%	37%	-5%	-	1981
Milwaukee	US-45	6%–13%	5%	-16%	-	1969

Source: Rafferty and Treasize (4)

<u>**Costs**</u>: Costs to the implementing agency include the development and calibration of metering system algorithms as well as infrastructure and maintenance expenses. In addition, a control center may be desired to monitor the system

as a whole. The cost of a particular ramp metering system varies widely according to the sophistication of the algorithm used to set the metering rate and the number of ramps included in the system. Potential costs to the public are: (5)

- Undesirable levels of traffic diversion to surface streets
- Increased emissions and/or fuel consumption at ramps
- Ramp delay and spillback onto surface streets
- Promotion of longer trips
- Transfer of land values

Transportation Applications: Benefits include the following:

- Travel time savings
- Improved safety
- Effective use of capacity
- Reduced travel time variability (5)
- Air quality improvements owing to smoother traffic flow.

As long as the target level of service (LOS) could be maintained through the regulation of ramp meters, the more congested the traffic condition is, the more effective the adaptive ramp metering control can be. (6)

Challenges/Drawbacks:

If the congestion becomes severe and the target LOS could not be maintained by using ramp metering, the effectiveness of adaptive ramp control is marginal. (6)

ZONE can work with fixed bottlenecks only, which need to be identified during the pre-implementation phase based on historical traffic conditions. (6)

Implementation of ramp metering is almost always initially opposed by the public because of increased queues at on-ramps. The most successful programs have instituted large campaigns to educate the public on the benefits of ramp metering. In addition to this initial opposition, equity issues may arise due to the fact that ramp metering often promotes longer trips over shorter ones. This problem may be addressed by adjusting metering rates. Finally, existing ramps must have enough capacity to accommodate increased ramp queues without causing excessive spillover onto the surface street network. If ramps do not already have this capacity, construction costs can be formidable. (5)

Smart Cards and RFID

Description and Features: A Radio-Frequency Identification tag (RFID tag) is an electronic chip that can be applied to any object for the purpose of identification using radio waves. RFID tags can be classified as passive (only read data) or active (read and write data). Passive tags have practical read distances ranging from about 10 cm (4 in.) up to a few meters. Active tags typically have much longer range (approximately 500 m/1500 feet) and larger memories than passive tags. EZ Pass - a type of RFID tag - has been extensively used in the Northeastern US for the past 15 years.

Smart cards are pocket sized cards with RFID tags and embedded integrated circuits which can process information. Examples in transportation include: Oyster card in London and Octopus card in Hong Kong. Advantages of using smart cards in public transit ticketing include: reduced passenger/staff fraud levels, reduced delays at entry gates, improved cash handling procedures, reduce staff handling costs, improved staff utilization, and flexibility in fare policies (7). These advantages primarily accrue from the contact-less nature of the technology. The RFID transponders in the cards enable users to simply tap their card close to the readers and walk through the gates without having to stop.

In the future, it is anticipated that RFID transponders as well as Smartcards will become increasingly common methods of toll and fare payments. Improvements in efficiency will enable use of RFID transponders in open road tolling where vehicles are not required to slow down to record toll transactions.

Smartcards will become the preferred method for transit fare payments. The Smart Card Alliance (8) lists five potential contactless transit fare payment methods:

- Traditional fare payment systems that incorporate a stored value model. These systems use contactless smart cards to carry a data file that is read and updated by readers. The data file includes all of the information about the electronic token or pass purchased by the customer that is required for the reader to calculate transaction-specific charges. To date, implementations throughout the world have used this model, including U.S. transit systems in Washington, D.C.; Baltimore; San Francisco; Oakland; Los Angeles; Chicago; San Diego; Seattle; Minneapolis; Houston; Boston; Philadelphia; Atlanta; and the New York–New Jersey area.
- Traditional payment card industry systems that use existing financial networks to process transactions and load value onto traditional fare payment cards. Transit agency devices such as ticket vending machines and point-of-sale (POS) systems are simply merchant terminals that process fare payment transactions just as they would any other retail transaction. It is common for most medium and large transit agencies in the United States to accept credit and debit card payment for some or all fare products sold.
- Enhanced payment card industry systems that incorporate an intermediate back office step. This step calculates the correct fare before the transaction is processed through traditional financial networks. These systems sometimes aggregate transactions to reduce transaction fees. An example of this model is the New York City Transit pilot program (9), which accepts contactless credit and debit transactions for paying subway fares. The Utah Transit Authority has conducted a pilot program, which accepted contactless credit and debit transactions for paying bus fares, and is now launching a full system bus/rail deployment using this approach.

A pay-pass based key fob used by NYC MTA

- Basic combined systems that use contactless media. With this system, the contactless payment media carry two types of data files. One is the transit application data file used in traditional fare payment systems. The other is the credit/debit cardholder information needed to process transactions using traditional financial payment card industry systems. The two payment systems are not integrated in any way at the card level. The transit application is used to pay for transit fares; the credit/debit card application is used for other retail purchases. Examples of this model are the London Oyster/Barclaycard and the Taipei EASYCARD.
- Enhanced combined systems that give customers a choice of fare payment methods. Methods include the contactless fare card used in traditional fare payment systems, the multi-application card used in basic combined systems, and the standard credit or debit card used in traditional financial payment card industry systems.

London Oyster/Barclay Card

The Smart Card Alliance has two white papers on two of the methods of payments: the first (10) discusses the direct acceptance of American Express, Discover, MasterCard, and Visa contactless payment products. The second (11) discusses the *basic combined system* described above.

Costs: The price of RFID tags has fallen, from around $2 each in 1999 to around $0.10-0.15 today [2007] (12). Typical costs of Smartcards range from $2.00 to $10.00.

Transportation Applications: In addition to the above applications Smartcards can be used for secure identification (e-passport) (13), security personnel identification at ports (14), parking systems (15), and other financial transactions (16).

The major benefits to customers of smart cards have included (17): 1) the availability of features such as registration/balance protection, employer autoload, and negative balance; 2) the ability to use the same card on multiple operators; and 3) the improved convenience of the contactless interface, i.e., the card does not have to be removed from a wallet or purse. Potential benefits of smart cards for customers include multi-application capabilities (e.g., use of the card for non-transit purposes) and innovative fare options (e.g., WMATA's planned Fair Fares strategy, which would guarantee that the customer is paying the "lowest possible fare" for each ride). Users of smart cards have expressed generally high levels of satisfaction with the cards and programs. For instance, in Chicago, 93% of survey respondents were satisfied or very satisfied with the cards, and 86% expressed willingness to continue using the card after the conclusion of the pilot period and to recommend the card to others. In the TransLink program, both survey respondents and focus group participants expressed a high level of satisfaction with the program. Moreover, two-thirds of noncard users surveyed said that they are "very likely" to try the card. Sales of the SmarTrip card in Washington have grown steadily since its introduction, despite the fact that WMATA has done very little marketing of the program.

Personalized Rapid Transit

Description and Features: PRT system includes fully automated vehicles capable of operation without human drivers over a reserved guideway. The vehicles are available on-demand, direct origin to destination service for an individual or a small group - typically 1 to 6 passengers. (18)

The key characteristics of PRT include (19):

- On-demand, origin-to-destination service
- Small, fully-automated vehicles
- Exclusive-use guideways
- Off-line stations
- A network or system of fully-connected guideways

In terms of the carrying capacity, the following chart prepared by one of the companies developing PRT systems (Taxi 2000) provides an estimate.

A report by the Advanced Transit Association (20) is the best on the state-of-the-art of PRT systems. Another report (19) on viability of PRT for New Jersey provides an excellent evaluation of implementing PRT in a state neighboring New York State. The conclusions from this study are:

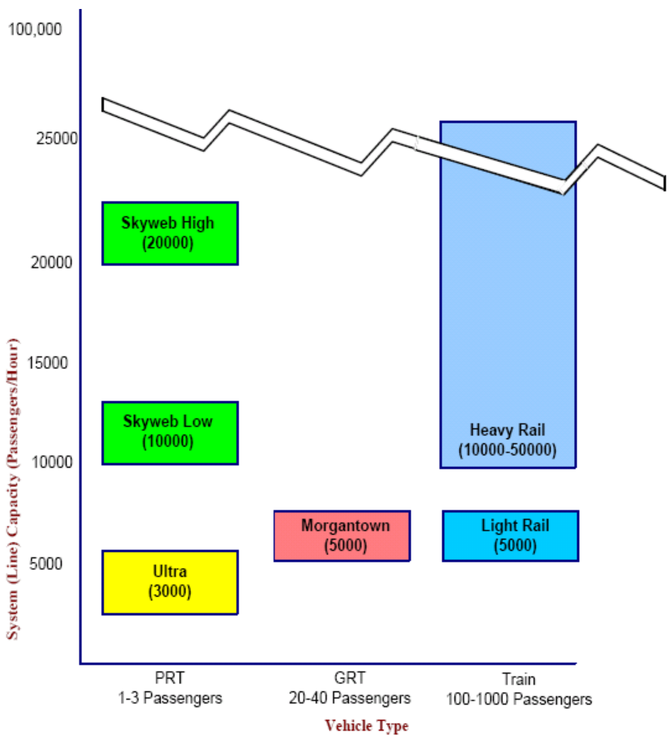
- PRT systems are approaching but not yet ready for public deployment.
- Many of the technical components needed to support PRT systems are commercially available and are used in other industries
- Global PRT interest and development programs are expanding
  - An active test track in Cardiff Wales and a joint development program between ULTra and the British Airport Authority for an installation at Heathrow Airport;
  - A comprehensive development program including test tracks in Sweden and Korea for the Vectus system;

- A prototype vehicle and section of guideway in Minnesota as well as a small-scale network model for the SkyWeb Express system in the United States; and
- An extensive test track (not currently operating) that verified system technology and operation of the Cabintaxi system.

- A fully operational PRT system is needed to demonstrate the theoretical benefits of PRT and establish commercial readiness.
- A comprehensive technology research and demonstration program is needed to develop a PRT system.

ULTra

Timeline: The first completely operational PRT system (ULTra) will debut at the Heathrow Airport London in Spring 2009 (21). Several other PRT variants are at different stages of development. The Morgantown transit system which has been in successful operation for over 30 years is an example of a variant of PRTs referred to as Group Rapid Transit. A completely deployed PRT system will successfully allay the fears and doubts that are currently withholding planners from implementing them. Almost all studies indicate PRTs are highly beneficial particularly in densely developed urban centers such as Manhattan and other counties that are a part of NYMTC.



Source: http://www.taxi2000.com/images/Generic1.pdf

Responses from vendors were as follows:

System	Guideway (M$/km)	Vehicle (k$)	Notes, Justification
Austrans			not supplied
Autran	1.3 (e)	20	costed by principal in company
Cybertran	3.1 (bep)	100	costed by four separate large firms and based on prototypes
Frog (CyberCab)	unknown	63	based on pilot project
Higherway	2.0	unknown	preliminary estimate
MegaRail	1.3 (ep)	18	preliminary estimate
MicroRail	0.8 (ep)	15	preliminary estimate
Mitchell (ADA)	1.5 (ep)		cost based on bids by manufacturers of the prototypes
Pathfinder	12-15		includes stations; estimated by principals in company
Ruf	2.2	20	estimated by principal in company
SwedeTrack			unknown
Taxi 2000	1.6 (ep)	26	costed by a university and three other large firms
ULTra	1.5	50	actual cost of prototype
Urbanaut	4.5 (ep)		

Notes on table – what costs are included in estimates

(b) bi-directional

(e) electronic guideway based control system

(p) power substations, transformers

Source: Advanced Transit Association (20)

Costs: The total cost of an ULTra system - vehicle, infrastructure and control system - works out between £3million and £5million per km of track.

Of the 14 systems reporting cost estimates, four have actually built a prototype: Cybertran, Frog (CyberCab), Taxi 2000, and ULTra.

- For those four, guideway costs range from $2.6M/mile for Taxi 2000 to $5.0M/mile for Cybertran.
- Assuming a saturation level of one vehicle every 100 feet (or 50 per mile of guideway), vehicle costs range from $2.1M/mile for Taxi 2000 to $8.0M for Cybertran. [Note that Cybertran vehicles carry 6-20 passengers while Taxi 2000 and ULTra vehicles hold a maximum of 4 passengers. The smaller vehicles and superstructure likely account for the lower costs of both Taxi 2000 and ULTra.]
- As indicated in the "Additional component costs" on page 90, station costs can range from $100K to $500K per station. Stations would be ADA compliant and usually include elevators. Planning for two stations per mile would add, at most, $1M/mile to guideway costs.
- Costs for land acquisition are excluded because public right-of-way (primarily roadways) will be used. Due to the small footprint of each supporting post (approximately 4 square feet every 60-90 feet) and the flexibility of routing, utility relocations will be minimal and relatively insignificant. Other costs might include modifying buildings, providing parking at stations, and enhancing aesthetic features. Adding an extra 10% for planning, environmental studies, and management seems reasonable.

In summary, full costing for these four systems can be expected to range from $6.27M/mile to $15.4M/mile. Bi-directional costs, which are useful for comparison to corridor-type transit systems, would be $12.5M to $31M/mile.

Implementation or Commercial Examples: Several models of PRT have been developed. Most of the companies that develop PRT systems are listed below (20):

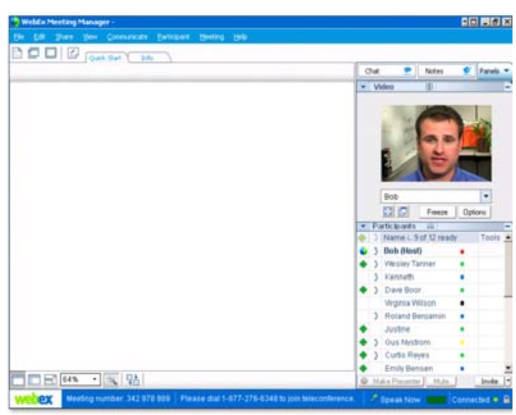
Supported, simple PRT:

Austrans: http://www.aebishop.com
Autran: http://www.autrancorp.com
Cybertran: http://www.cybertran.com/
Megarail/Microrail: http://www.megarail.com
Mitchell
Taxi 2000: http://www.taxi2000.com/
ULTra: http://www.atsltd.co.uk/
Urbanaut
Suspended, simple PRT:
Higherway: http://www.artwerkz.com/h/
Pathfinder
SwedeTrack: http://www.swedetrack.com/
Other:
Frog / 2getthere – http://www.frog.nl
MAIT: http://www.maitint.org
Ruf: http://www.ruf.dk/

Collaborative Technologies

<u>Description and Features:</u> Broadly collaborative technologies can be divided into three categories: communication, conferencing, and collaborative management tools. Communication technologies include e-mail, instant messaging, and VoIP. Conferencing technologies include webinars, web conferencing, and HD video conferencing. Collaborative management tools include shared electronic calendars, project management, knowledge management systems, prediction markets, and desktop sharing services such as concurrent versions system (CVS).

Different types of collaborative technologies have different features. While few of the technologies such as e-mail and instant messaging are commonly used, others are still emerging. We discuss each of these emerging technologies below.



VoIP: VoIP has recently emerged as the preferred calling method particularly in small and medium-sized enterprises for international calls. Current VoIP providers include Packet8, Vonage, Knightel, Vonics Digital, and BBTelsys LLC. Another VoIP/instant messaging software that has become popular is Skype. Skype requires a computer to make telephone calls while the other providers can be used both through a computer and through traditional telephones connected to a phone adapter which is linked to the internet router. Recently Skype has introduced mobile phone-like devices that enable users to tap into wireless internet sources to place and receive Skype calls.

Webinars: Webinar is short for Web-based seminar that is broadcast over the Internet. A webinar allows participants to be active members contributing to the seminar. Several alternative formats are available including video/presentation and audio broadcast over the internet or audio access provided separately by telephone conference. A significant advantage of webinar software is its relative ease of use and accessibility: any user with broadband internet connectivity can participate in a webinar. Adobe Acrobat Connect, Lotus Sametime Connect, Microsoft LiveMeeting, WebEx, GoToMeeting are few examples of webinar software. Few of these software require every participant to install in his/her machine while others such as WebEx and GoToMeeting allow any individual with an internet connection and browser to participate.

HD Video Conferencing: The technology has created a new term to describe video conferencing: telepresence. As the term telepresence suggests, HD video conferencing provides crystal clear video images at larger-than-life-size. Currently, the technology is primarily used by high-level executives and medical professionals. However, in the future the technology could be accessible to even small and mid-level companies. HD video conferencing requires a dedicated ultra high-speed internet line, HD video cameras, and screens/monitors for display. Presently the cost of such systems is high. Companies that produce HD video conferencing systems include: Lifesize, Polycom, Cisco, Sony, Tandberg, HP, Teliris.

Timeline: Most of the above technologies have already been developed and tested. However, they are still not used widely. Adoption of new technologies takes between 5 to 10 years and it is anticipated over the next decade these technologies will become commonly used.

Costs: Hi-definition video conferencing technologies are very expensive. For example, Cisco TelePresence costs between $80,000 to $299,000, Telanetix costs about $40,000 plus the monthly cost for T-1 internet lines (>$1000 per month), and at the lower end is Polycom's HDX-4000 at $8000 (source: http://www.networkworld.com/news/2007/082107-networker.html)

Adobe Acrobat Connect: $40/month or $395/year
GoToMeeting: $49/month or $468/month
VoIP: $10 - $50/month

Transportation Applications: All the above collaborative technologies encourage telecommuting. Further, the collaborative technologies provide novel methods for social interaction and entertainment opportunities that can significantly alter activity-travel behaviors.

Challenges/Drawbacks: Costs of few of these advanced technologies are high. However, over the next 10 years these costs could significantly scale down.
A more important challenge is the need for adaptability of organizations. Telecommuting requires an entirely different management paradigm and there could be significant inertia to implement these technologies.

HD video conferencing requires very large bandwidths and cannot be supported by current broadband network infrastructure. In the future, emergence of ultra-high speed internet will enable HD video conferencing.

Implementation or Commercial Examples: Several companies currently produce the above collaborative technologies.

VoIP: Packet8, Vonage, Knightel, Vonics Digital, and BBTelsys LLC, Skype.

Webinars: Adobe Acrobat Connect, Lotus Sametime Connect, Microsoft LiveMeeting, WebEx, GoToMeeting

HD Video Conferencing: Lifesize, Polycom, Cisco, Sony, Tandberg, HP, Teliris

Safety and Security Technologies

Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication

Description and Features: Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication opens up several new safety applications. The Vehicle Safety Communications (VSC) project (22) was established to evaluate vehicle safety applications enabled or enhanced by communications. In 2002, seven automotive manufacturers—BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and VW—formed the VSC Consortium (VSCC) to participate in this project with the U.S. Department of Transportation (USDOT). 34 vehicle safety application scenarios enabled or enhanced by wireless communications were identified. From the 34 application scenarios, the VSCC identified 8 scenarios as high-priority and selected for further research based on the estimated potential safety benefits. Of these 8 application scenarios, 4 involve vehicle-to-vehicle communications and 4 involve communications between vehicles and the infrastructure. Three of the vehicle infrastructure communication applications involve intersections. The 34 applications include:

Collision Avoidance
- Traffic Signal Violation Warning
- Stop Sign Violation Warning
- Left Turn Assistant
- Stop Sign Movement Assistant
- Intersection Collision Warning
- Blind Merge Warning
- Pedestrian Crossing Information Warning

Public Safety
- Approaching Emergency Vehicle Warning
- Emergency Vehicle Signal Preemption
- SOS Services
- Post-Crash Warning

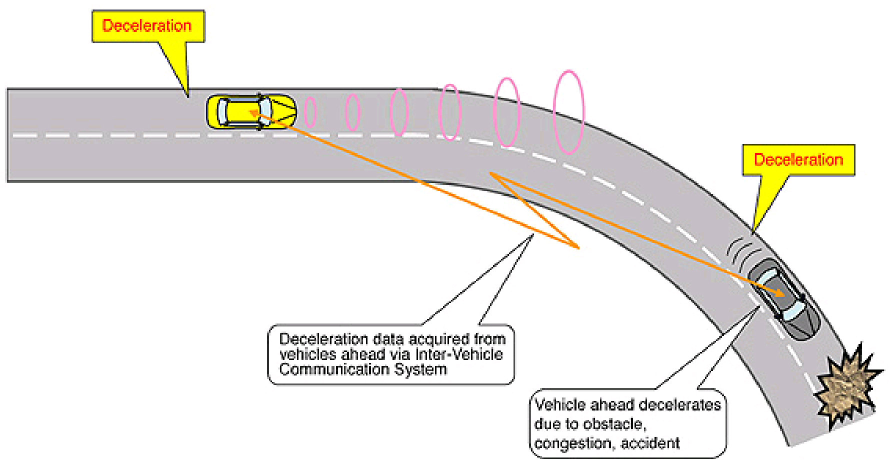
Sign Extension
- In-Vehicle Signage Warning
- Curve Speed Warning
- Low Parking Structure Warning
- Wrong Way Driver Warning
- Low Bridge Warning
- Work Zone Warning
- In-Vehicle Amber Alert Warning

Vehicle Diagnostics and Maintenance
- Safety Recall Notice
- Just-in-Time Repair Notification

Information from Other Vehicles
- Cooperative Forward Collision Warning
- Road Condition Warning
- Emergency Electronic Brake Lights
- Lane Change Warning
- Blind Spot Warning
- Highway Merge Assistant
- Visibility Enhancer
- Cooperative Collision Warning
- Cooperative Vehicle-Highway Automation System (Platoon)
- Cooperative Adaptive Cruise Control
- Road Condition Warning

• Pre-Crash Sensing
• Highway/Railroad Collision Warning
• Vehicle-to-Vehicle Road Feature Notification
• Cooperative Glare Reduction
• Adaptive Headlamp Aiming

The primary mode of communication identified for V2V and V2I communication is Dedicated Short Range Communications (DSRC) 5.9-Ghz. DSRC applications now in use include electronic toll collection, and electronic credentialing and monitoring of commercial vehicle operations (CVO) (24).



Unlike other sensor technologies, DSRC does not require line of sight
Source: http://world.honda.com/news/2005/c050902.html

The promise of DRSC is to deliver a far greater data rate and range to wireless highway applications. "Compared with existing RFID toll applications, DRSC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters," says Richard Schnacke, vice president of industry relations for TransCore (25).

The DSRC system supports communication links in the following parameters (26):
Vehicle speed (up to 120 mph), Communication range (up to 1000 meters for special vehicles; nominal is 300 meters), System Latency (< 50 ms), Data rate (default is 6 Mbps; up to 27 Mbps), Single transaction size (up to 20K bytes).

Timeline: Government and vehicle manufacturers plan to make a collaborative decision on deployment of DSRC in the year 2008 that could signal the beginning of the deployment process in the auto industry and public agencies (27). DSRC is the technology for the 2010 decade and beyond (26).
Costs: No cost estimates are available, but they will clearly be a lot more expensive than today's standard toll tags (9). However, it is anticipated that the costs will be absorbed by car manufacturers and the additional cost compared to cost of the automobile is likely to be low.

Transportation Applications: In addition to the safety applications listed earlier, V2V and V2I will enable the following non-safety related applications (22):

Traffic Management
• Intelligent On-Ramp Metering
• Intelligent Traffic Flow Control
Tolling
• Free-Flow (or Open Road) Tolling
Information from Other Vehicles
• Instant Messaging (Probe data)
• Adaptive Drive-Train Management
• Enhanced Route Guidance and Navigation

• Point-of-Interest Notification
• Map Downloads and Updates
• GPS Correction
• Real-time scheduling of transit and fleet vehicles

Challenges/Drawbacks: There are several challenges associated with widespread implementation of V2V and V2I technologies including:

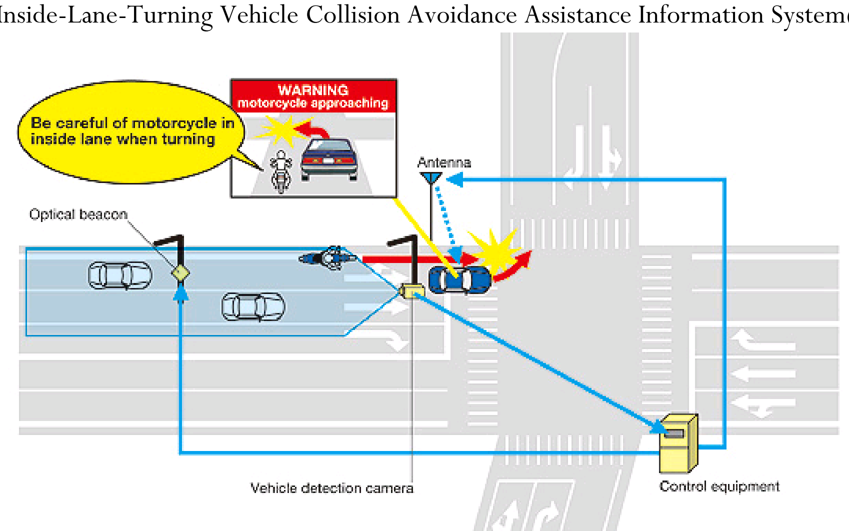
- Privacy concerns (28)
- Sabotage
- Benefits will depend on penetration

Zimmer (28) observes that "…VSC applications is a potential rise in the ability to surveil a driver engaging in her everyday activities on the public roads… [could lead from] V2V safety technology to V2V traffic enforcement and insurance information gathering." Privacy concerns will have to be addressed before the public is comfortable with using the technology. However, if the potential benefits are significant privacy concerns are likely to be definitely addressed amicably to ensure the benefits are realized.

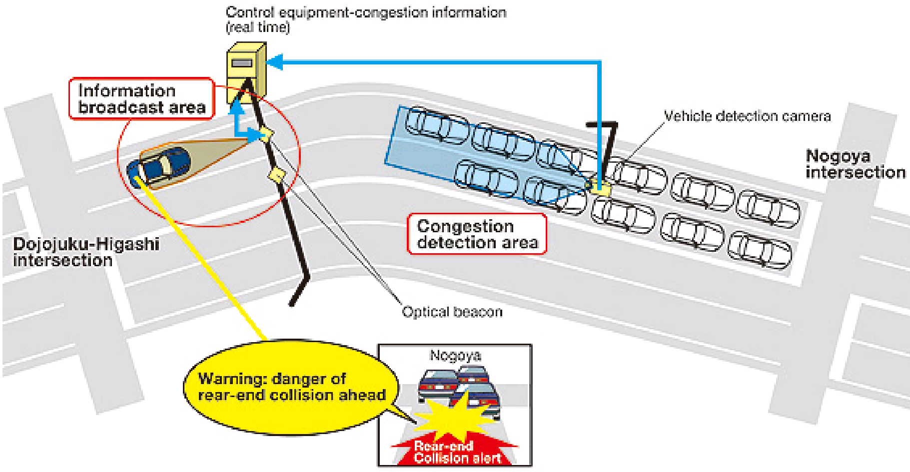
The VSCC (22) identified four types of threats of increasing empowerment related to vehicle safety communication systems' endangerment:
• Type 1: Attackers with a programmable radio transmitter/receiver
• Type 2: Attackers with access to an un-modified VSC unit
• Type 3: Attackers with access to a modified VSC unit who have obtained the keying material
• Type 4: Attackers inside manufacturing or security programming with full access

The threat model and constraints led to the core of the task—an architecture design that the VSCC believes may adequately address the identified threats while meeting the estimated constraints within this task.
• All on-board units and roadside units (RSUs) are issued certificates (OBUs are issued multiple certificates) in a special, compact format.
• The certificates for RSUs contain authorization information such as the area in which the unit is permitted to operate and the type of information it is allowed to broadcast.
• OBU certificates do not contain the permanent vehicle-identity information.
• All messages are digitally signed. Any units suspected of being compromised are put on a revocation list that is flooded to all other units.

Inside-Lane-Turning Vehicle Collision Avoidance Assistance Information System(ASV/DSSS)



Rear-end Collision Avoidance Assistance Information System (DSSS)



Source: http://world.honda.com/news/2008/4080324Advanced-Safety-Vehicles/

Implementation or Commercial Examples: GM, Honda, and Mazda among other automobile manufacturers have been testing V2V and V2I applications for several years.

Machine Vision

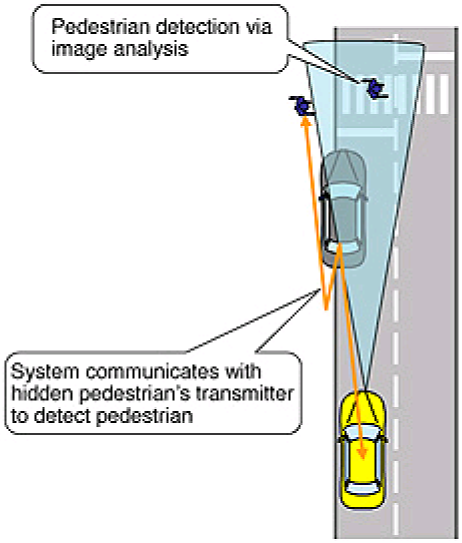
Description and Features: Machine vision involves the digitization, manipulation, and analysis of images, usually within a computer (29). Machine vision has been applied in industrial image processing for quality control, to identify swimmers who are drowning (30), fire alert system (31), and many more (32. However it has been applied in only limited context in transportation. For example, Saab's Driver Attention Warning System (33) utilizes two miniature infra-red cameras, one installed at the base of the driver's A-pillar and the other in the center of the main fascia, which are focused on the driver's eyes. The image from the cameras is analyzed by software that deploys a series of alerts when the pattern of eye-lid movement indicates the onset of drowsiness, or when the driver is not looking at the road ahead. Infra-red imaging is used to ensure good performance in all day and night light conditions, and even if the driver is wearing dark glasses.

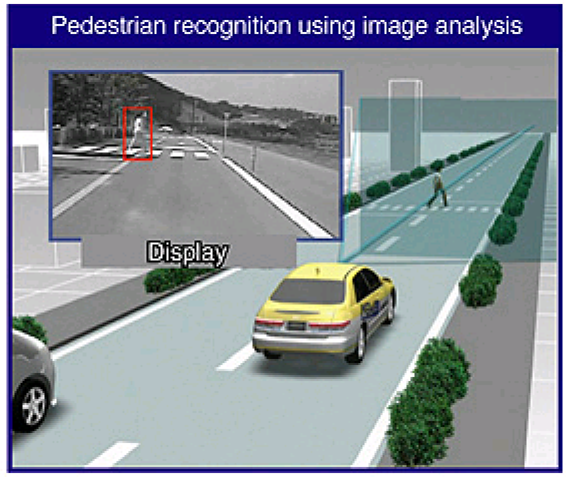
Timeline: Most machine vision systems have already been tested and implemented. However, in transportation these systems are available only in high-end cars because of their cost.

Transportation Applications: Machine vision has applications in traffic monitoring, navigation, and transport safety (34). Using machine vision we can deduct lane markings, vehicles, pedestrians, road signs, traffic conditions, traffic incidents, and even driver drowsiness (35), Road/Railroad Structure Analysis, Seaport Monitoring, vehicle License/Number Plate Analysis (32). Machine vision provides more accurate classification capabilities (36) compared to other sensor types.

Challenges/Drawbacks: Challenges include making machine-vision systems less expensive, more compact, and more robust in various weather and traffic conditions. (5)

Implementation or Commercial Examples:





Source: http://world.honda.com/news/2005/c050902.html

Omnivision develops lane-departure detection and warning systems, blind spot displays, night vision, intelligent airbag deployment, panoramic rear view cameras, adaptive cruise control, rain detection systems and car security, which are being touted as major selling points for security and driver assistance. Improvements in component quality and reliability, and lower production costs mean that the use of cameras in automotive applications is no longer limited to high-end luxury cars and SUVs.

SafeTRAC Lane Tracker is an in-vehicle safety system that uses a forward-looking video camera to monitor the road ahead. It tracks road features to determine a vehicle's position and trajectory and generates a warning if a vehicle begins to drift out of its lane. SafeTRAC also detects drowsy or distracted driving by sensing weaving or erratic lane keeping.

Mobileye has developed core technologies in the areas of algorithms and ASIC architecture design for monocular video processing supporting driver assistance and for safety related applications such as Lane Departure Warning, Pedestrian Protection, Adaptive Headlight Control, Traffic Sign Recognition, and additional applications. Mobileye provides its technology in six production platforms to BMW, GM and Volvo including:

- Lane Departure Warning
- LDW + Vehicle Detection + Fusion
- Driver Impairment Monitoring
- Advance Warning System
- LDW + Adaptive Headlight Control + Traffic Sign Recognition
- Collision Mitigation by braking with Pedestrian Recognition

Other commercial players include:
Iteris (Santa Ana, California): Lane departure warning systems for trucks and cars that monitor position on the road. Used in over 35,000 trucks (2007). Also creates traffic monitoring systems.
Smart Eye (Göteborg, Sweden): Systems to track eye and gaze position of a driver to detect drowsiness or inattention.
Appian Technology (Bourne End, Buckinghamshire, UK): Systems for reading automobile license plates.

AutoVu (Montreal, Canada): Systems for reading automobile license plates.
Image Sensing Systems (St. Paul, Minnesota): Created the Autoscope system that uses roadside video cameras for real-time traffic management. Over 40,000 cameras are in use (37).

MEMS and Nanosensors

Description and Features: Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology (38). MEMS technology have been applied to motion-based approach to navigation within and between pages in PDAs or MP3 players, in game controllers, MEMS sensors allow the player to play just moving the controller/pad (39). Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose (38).

Nanosensors on the other hand are much smaller compared to MEMS. They have potential to track bio-terror agents, stress in materials, and detect polluting agents in the atmosphere and tailpipes. Nanosensors could be used in transportation to monitor pavement conditions, bridge conditions, pollution deduction, bio-terror agent detection, air quality monitor etc. The feasibility of "Cyberliths", or Smart Aggregates, as wireless sensors embedded in concrete or soil is being studied. Researchers at Johns Hopkins University's Applied Physics Laboratory have developed a robust wireless embedded sensor, suitable for long term field monitoring of corrosion in rebar, particularly in bridge decks. An advantage of nanosensors over MEMS could be the significantly reduced power consumption. This allows nanosensors to be implemented in a wide scale (as "smartdust") without having to worry about battery outage or battery maintenance.

Apple iPhone and Wii Power Glove use MEMS sensors to determine orientation and hand movements.

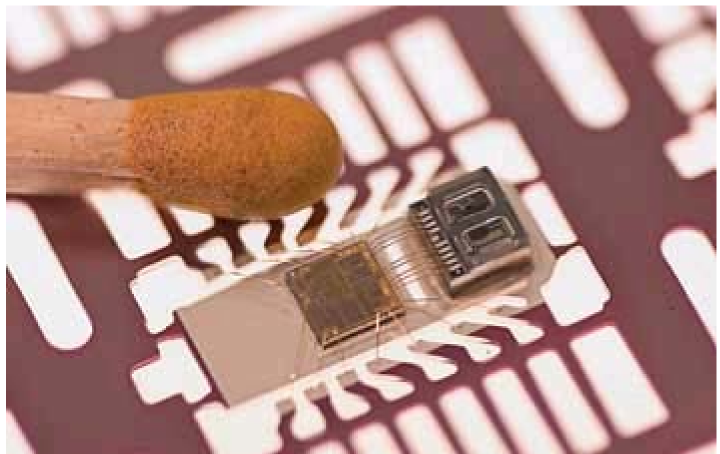
Timeline: Air bag accelerometers that detects the beginning of the car's sudden impact by measuring the movement of an impossibly small (.10 microgram) "mass," which then causes the air bag to fire have been in use for about 10 years (40). However future applications will have to be identified and MEMS developed for the particular applications. The technology for development is already available; what is requires is identification of specific applications that will benefit from these sensors.

Costs: Because of their size and low cost, MEMS could make measurement and control strategies that were not possible with macro or discrete devices now feasible. MEMS have the problem of a high initial development cost. But once developed, MEMS can be mass-produced for a relatively low per-unit cost: $5 to $50 each. (41)

Transportation Applications: MEMS can be used in Advanced Driver Assistance Systems, Crash Detection, Electronic Stability Control, LED Taillight Driver, Navigation (42), monitoring and testing of transportation infrastructure (43. In transportation air-quality studies, MEMS "smart dust" has the potential to collect data for both analysis and forecasting the air-quality (41).

The majority of the potential MEMS applications in transportation infrastructure will act as sensors. These include sensors used in monitoring temperature, crack measurements and monitoring, corrosion testing and monitoring, alkali-silica reaction (ASR) and other related reactions in concrete, and reliability of welding units in structural steel (41).

MEMS thermal accelerometers could be used in navigation systems with maps and global positioning satellite capabilities, MEMS-based display can overlay automobile diagnostics and repair instructions directly to the technician, and seat-based MEMS for occupant deduction (42).



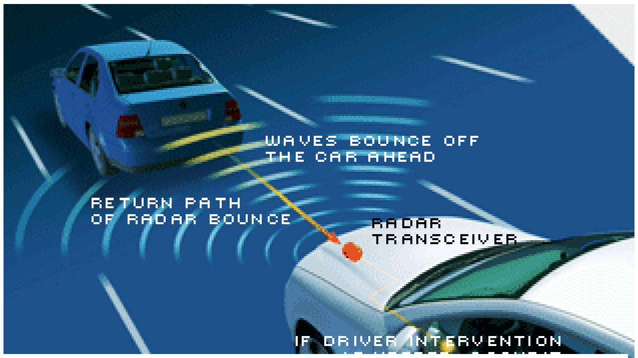
A tire pressure MEMS sensor

Crash sensing for air bag control represents the largest automotive use of inertial MEMS sensors. In this application, an accelerometer continuously measures the acceleration of the car. Vehicle dynamic control (VDC) systems help the driver regain control of the automobile when it starts to skid. If the VDC works properly, the driver may not even be aware that the system intervened. A VDC system consists of a gyroscope, a low-g accelerometer, and wheel-speed sensors at each wheel (the wheel-speed sensors may also be used by the ABS). Navigation systems rely on compass and GPS information when the system is first started. The direction of travel is matched up with map data to give the system more certainty regarding direction. Once initial direction is established, gyroscope information is used to determine when and how much the car has turned, until directional data can be verified by map matching. In urban settings, it's not unusual for the GPS signal to be obscured by tall buildings or tunnels for short periods. At these times, the navigation system relies on the gyroscope for heading information and a low-g accelerometer for position information (43).

Challenges/Drawbacks: One drawback to extensive MEMS application is that MEMS products are application specific rather than generic. The vast majority of applications require solutions that necessitate the funding and completion of an evaluation or development program. In addition, the environment in which the MEMS devices has to operate and the possible effect of the environment on the performance of the MEMS device has to be assessed. Protection of the MEMS device against damage from installation or construction procedures as well as from contact with materials is paramount (41). Nanosensors are still under research; there are no commercial examples of the use of nanosensors.

Automated Vehicles

Description and Features: Adaptive cruise control (44), lane departure warning, collision avoidance (45, 46) are all part of intelligent or automated vehicles (47, 48). Automated vehicles include sensors to detect vehicles and obstacles, and intelligent algorithms (49) to enable these technologies. Vehicle based technology includes adaptive cruise control, lane departure warning, and collision warning devices. These have already been successfully demonstrated.



Radar-based Adaptive Cruise Control System (50)

Adaptive cruise control maintains a desired speed taking into account the vehicles in the front and back. Lane departure warning control vehicle's linear orientation and collision warning identifies and warns drivers of impending collision. These technologies together with advanced navigation systems will enable completely automated vehicle in the future.

Adaptive Cruise Control: Vehicles using adaptive cruise control are able to slow down from speeds over 70 mph to a speed of 45 mph without requiring driver assistance, allowing the vehicle to automatically avoid a rear end collision with the slower vehicle ahead of it. Also, if a car or even a motorcycle enters the lane in front of the vehicle with adaptive cruise control at a speed of 45 mph, the equipped vehicle will detect this and immediately decelerate. (50)

Lane Departure Warning System: The Lane Departure Warning System detects unintentional lane departures on motorways at speeds exceeding 80 kilometers per hour. It uses the existing road markings as well as six infrared sensors under the vehicle. Lane departures are detected by variations in the reflections of the infrared beams emitted. (51)

Collision Avoidance Technologies: These technologies use sensors on-board vehicles or embedded in the infrastructure to monitor vehicle movements and, in some instances, the driver's behavior and process that information and either directly modify vehicle operation, warn the driver, or make adjustments to safety devices to mitigate an impending collision.

Certain types of collisions, however, are more amenable to being prevented or minimized by technologies that involve more public investment, or contribute such a significant burden to the accident rate as to justify additional research involving systems with larger public investments. For example, lane departures (resulting in lateral collisions) and intersection crashes are major components of a National Highway Traffic Safety Administration research program for collision avoidance. (46)

Automated Highway Systems: An automated highway system uses magnetized stainless-steel spikes embedded in the roadway. A car is equipped with sensors and controlled by a computer in platoons to lessen congestion. The PATH project tested this technology in San Diego, California. However, the National Automated Highway System Research Program concluded that the program should not be continued, focusing on technologies that require less infrastructure (52).

Timeline: Many features of the technology have been demonstrated; May require more time before it becomes accepted and widely used.

Adaptive cruise control has been included with luxury cars since the end of the 20th century. (53)

Japan is farthest along in deploying autonomous, vehicle-only systems, with Europe not far behind. In the U.S., certain elements of collision avoidance and warning systems are starting to be available, but mainly on higher-priced car models. (46)

Costs: Adaptive cruise control is currently fairly expensive, costing $600 per vehicle for a cheaper version and over $2000 for systems that are more precise. (53)

Costs of these new technologies are generally passed on to the consumers, which can cause problems for implementation. (46)

Lane departure warning systems currently cost only a few hundred dollars. (54)

Transportation Applications: Automated vehicles can have significant impact on throughput (reduced congestion) and safety (no accidents).

Adaptive cruise control breaks backward shockwave propagation. At an average speed of 67 miles per hour, if only one in five vehicles used adaptive cruise control, no traffic jams would form and traffic would generally flow freely. However, at speeds lower than 50 miles per hour, adaptive cruise control would have no positive impact on congestion. (55)

Longitudinal collision avoidance is being studied for use in automated precision docking for buses, freight handling at ports, and semi-automated systems to guide parallel parking maneuvers. (46)

Challenges/Drawbacks: Application of technology in mixed traffic where only a fraction of the vehicles have the technology will be a challenge (56); lacks wide spread tests in real situations.

Systems that use alarms to warn the driver need to be accurate enough to avoid having too many false alarms that annoy the driver. In addition, drivers may over-rely on collision avoidance, causing accidents unless the system is flawless (46).

BMW Lane Departure Warning

Understand human-factors in using the technology (57). When real-world factors such as inclement weather, difficult terrain, or limited visibility due to dust or nightfall are introduced, the problem of vehicle control can quickly become intractable. (58)

Commercial Examples: The Lexus LS includes an advance parking guidance system, which can help the driver parallel park. All that is required of the driver is selecting a parking space as well as applying the brakes. It also includes a pre-collision system with sensors that can determine if a frontal collision is imminent and helps the driver stop the vehicle). The Ford Mondeo comes equipped with Adaptive Cruise Control technology, using radar to maintain a pre-set distance from the car in front of the vehicle. Volvo has developed a system where a car will brake by itself if it realizes that the driver will not stop in time to avoid hitting a car in front of it. The Buick Lucerne includes a Lane Departure Warning that provides an audio and visual warning when the vehicle drifts into another lane. BMW also provides lane departure warning with a vibrating steering wheel.

Biometric Identification

Description and Features: Biometrics is the science of identifying people using physiological features. Biometric identification includes finger-print, face, DNA, hand geometry, voice, retina and Iris identification. Important characteristics of a biometric identification technology are accuracy, ease of use, user acceptance, ease of implementation, and cost (59).

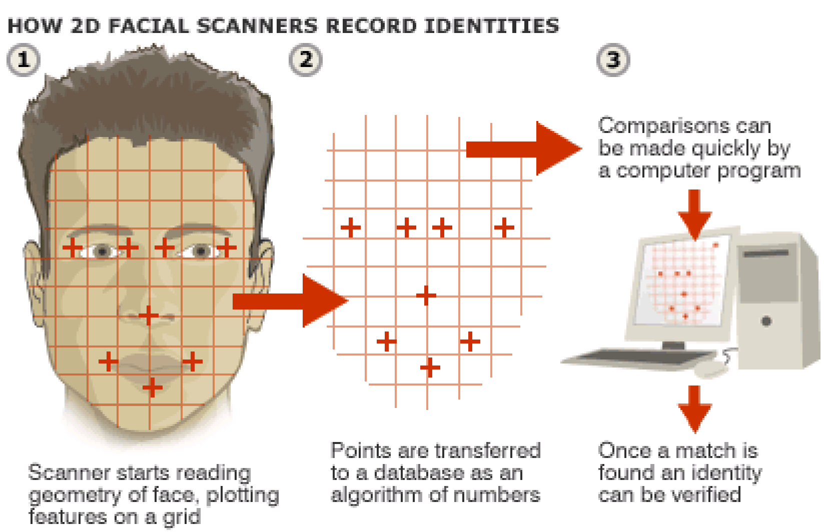
Iris Identification: Iris recognition is a biometric identification technology that uses high-resolution images of the irises of the eye. The iris of the eye is well suited for authentication purposes. It is an internal organ protected from most damage and wear, it is practically flat and uniform under most conditions and it has a texture that is unique even to genetically identical twins. Iris recognition algorithms produce remarkable results. IrisCode, a commercial system derived from Daugman's work, has been used in the United Arab Emirates as a part of their immigration process. After more than 200 billion comparisons, there has *never been a false match*.

Iris scans are extremely accurate and can be done regardless of whether the subject is wearing contact lenses or glasses. However, it is necessary for the system to take eye lids and eye lashes into account; both can obscure the necessary parts of the eye and cause false information to be added into automated systems. (60)

Features of iris recognition include accuracy, with an unmatched equal error rate performance of 1 in 1.2 million. The iris is also stable, with patterns remaining constant from age 1 until death. It can find nearly 20 times more matches per minute than it's closest competitor, can manage very large databases due to a small storage size required, and is non-invasive, using no bright lights or lasers and no tie-in to law enforcement fingerprint databases. (61)

Fingerprints: Finger printing takes an image (either using ink or a digital scan) of a person's fingertips and records its characteristics. Whorls, arches, and loops are recorded along with the patterns of ridges, furrows, and minutiae. This information may then be processed or stored as an image or as an encoded computer algorithm to be compared with other fingerprint records. To prevent fake fingers from being used, many systems also measure blood flow, or check for correctly arrayed ridges at the edges of the fingers. Finger printing has been in use in criminal investigations for over 100 years and continues to expand every day. Fingerprint scanning secure entry devices for building door locks and computer network access are becoming more common. Recently a small number of banks have begun using fingerprint readers for authorization at ATMs and grocery stores are experimenting with a fingerprint scan checkout that automatically recognizes and bills a registered user's credit card or debit account. The potential uses for this biometric appear to be limited only by the willingness of people to use it (62).

Face Recognition: Like fingerprint biometrics, facial recognition technology is widely used various systems, including physical access control and computer user accounts security. Usually these systems extract certain features from face images and then perform face matching using these features. A face does not have as many uniquely measurable features as fingerprints and eye irises, so facial recognition reliability is slightly lower than these other biometrical recognition methods. However, it is still suitable for many applications, especially when taking into account its convenience for user. Facial recognition can also be used together with fingerprint recognition or another biometrical method for developing more security-critical applications (63).



Source: http://news.bbc.co.uk

Retinal Scanning: Retinal scanning analyses the layer of blood vessels at the back of the eye. Scanning involves using a low-intensity light source and an optical coupler and can read the patterns at a great level of accuracy. It does require the user to remove glasses, place their eye close to the device, and focus on a certain point. Whether the accuracy can outweigh the public discomfort is yet to be seen.

The user looks through a small opening in the device at a small green light. The user must keep their head still and eye focused on the light for several seconds during which time the device will verify his identity. This process takes about 10 to 15 seconds total. There is no known way to replicate a retina, and a retina from a dead person would deteriorate too fast to be useful, so no extra precautions have been taken with retinal scans to be sure the user is a living human being (64).

Timeline: The first year for the first known systematic use of fingerprint identification began in the United States is 1902. The New York Civil Service Commission established the practice of fingerprinting applicants to pre-vent them from having better qualified persons take their tests for them. The New York state prison system began to use fingerprints for the identification of criminals in 1903. In 1904 the fingerprint system accelerated when the United States Penitentiary at Leavenworth, Kansas, and the St. Louis, Missouri, Police Department both established fingerprint bureaus. During the first quarter of the 20th century, more and more local police identification bureaus established fingerprint systems. The growing need and demand by police officials for a national repository and clearinghouse for fingerprint records led to an Act of Congress on July 1, 1921, establishing the Identification Division of the FBI. (10) The first major vendor for the research/development and production of retinal scanning devices was a company called EyeDentify, Inc., created in 1976 (65).

Costs: According to many security experts, iris recognition is likely the most fail-proof and high-tech security tool out there, which is why companies like Panasonic are jumping into the cargo of this possibly profitable ride. Panasonic's BM-ET200 scanner is voice activated and identifies a user within 0.3 seconds. It can hold over 10,000 user records and is priced at about $2,500 (66). The cost of fingerprint imaging systems continues to decline. Where fingerprint imaging systems cost over $1000 several years ago, consumers can now buy a system for under $100 per seat (67).

Transportation Applications: Primary applications in transportation include for security, fare-payment, and access restriction.

A new security fast lane at Albany International Airport has lured more than 200 subscribers to the $99.95 service. The new iris and fingerprint scan system and service was introduced at the Albany airport this week, but frequent fliers have been signing up since mid July 2007. It takes about 10 minutes at a Clear registration booth at the airport plus two to four weeks approval time by the Transportation Security Administration for the initial sign up, Brill said. The service allows members to avoid long lines at security areas where non-members are often required to remove coats and wallets (68).

Biometric recognition technology could also be used to verify employees trying to log in remotely into protected systems while telecommuting.

Challenges/Drawbacks: Fingerprint and retina are highly accurate; while Face recognition is not very accurate. In terms of ease of use, face and voice recognition are best suited; fingerprint and retina have low user acceptance; Iris recognition is expensive.

According to Mike Thieme, Director of Special Projects for the International Biometric Group, "In environments such as airports and open public spaces, there are three challenges: finding faces, matching faces against a database, and manually resolving 'matches' returned by the facial-scan system." Each of these steps takes time, in particular the 3rd step. "In many environments there may not be adequate time to resolve the number of false matches likely to occur in a surveillance or screening application". (69)

Concerning retinal scan devices, the cost of the proprietary hardware as well as the inability to evolve easily with new technology makes them a bad fit for most situations. It also has the stigma of consumer's thinking it is potentially harmful to the eye, and in general not easy to use. (64)

Energy and Environment Technologies

Natural Gas and Propane

Description and Features: Propane, also known as liquefied petroleum gas (LPG or LP-gas), or autogas in Europe, is a three-carbon alkane gas (C3H8). Stored under pressure inside a tank, propane turns into a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used for combustion. Propane has several advantages including (70, 71)

- Excellent properties for spark-ignited internal combustion engines.
- An exceptionally safe fuel.
- Non-toxic and presents no threat to soil, surface water, or groundwater.
- Compared with vehicles fueled by conventional diesel and gasoline, propane vehicles can produce significantly lower amounts of some harmful emissions and the greenhouse gas carbon dioxide.

Natural gas is a mixture of hydrocarbons, predominantly methane (CH4). As delivered through the pipeline system, it also contains hydrocarbons such as ethane and propane and other gases such as nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor (72, 73). Advantages of natural gas are similar to propane mentioned above. Natural gas (74, 75) is domestically produced alternative fuel. It has a high octane rating and excellent properties for spark-ignited internal combustion engines. It provides fueling convenience. It is safe, non-toxic, non-corrosive, and non-carcinogenic. It presents no threat to soil, surface water, or groundwater. Natural gas vehicles are cleaner than most fuels. NGVs produce about 15 percent less greenhouse gases than comparable diesel vehicles, and 20 percent less than comparable gasoline vehicles.

Home Refueling Unit "Phill"
Courtesy of FuelMaker Corporation

Commercial vehicles are the primary on-road consumers of diesel fuel, the use of which the Energy Information Agency (EIA) forecasts will reach over 50 billion gallons per year by 2017. Ethanol is not expected to be able to displace any of this diesel fuel, and biodiesel will be able to displace at most 2 billion gallons per year. Depending on the level of government support, use of domestic natural gas to power the nation's trucks and buses could displace 3, 5, 7 or over 10 billion gallons per year by 2017.

There are over 5 million NGVs on the road worldwide. Argentina is the world's leader with over 1.5 million NGVs (20 percent of all Argentine vehicles). According to the U.S. Energy Information Administration, the U.S. has only about 130,000 NGVs on the road in 2006. The number of diesel fueled vehicles that must switch to natural gas in order to achieve the above scenarios is modest – ranging from just 808,000 for 3 billion gallon of displacement to 2,756,000 for the 10 billion gallon displacement. The 10 billion-plus gasoline-gallon-equivalent shown in the scenario above would represent only 6.2 percent of the natural gas consumed in the U.S. in 2006. Using EIA's forecast, it would represent only 5.2 percent of the natural gas consumed in the U.S. in 2017 (82).

Finally, in the longer term, natural gas may be obtained from methane hydrates (82). Methane hydrates are ice formations consisting of methane and water. They can be found in Arctic areas and in the ocean floor at water depths greater than 1,000 feet. Methane hydrates are found throughout the world – including off all U.S. coasts. The U.S. Geological Survey conservatively estimates that energy contained in the world's methane hydrates is twice the energy contained in all known fossil fuels on earth, i.e., twice that in all the world's estimated natural gas, petroleum and coal combined. Research is being carried out today to determine how to produce methane from hydrates economically. Officials in Japan, for example, have indicated that that country plans to have the technology needed to turn methane hydrates into commercial gas by 2016.

Timeline: Both propane and natural gas are available in the country. However propane's lower efficiency and the need for compressed storage of natural gas on-board the vehicle make them inconvenient personal vehicle fuel choices. However home refueling units such as the one shown above could allow more individuals to choose natural gas for fuel.

Until an area develops an adequate natural gas fueling station infrastructure (as has already developed in Southern California), NGVs are most practical for fleets.

Costs: The latest Alternative Fuel Price Report show the price of propane per gallon is less than regular gasoline. (76)

Compressed natural gas is the least expensive alternative fuel (except electricity) when you compare equal amounts of fuel energy. (77)

Southern California Gas estimates CNG currently costs about 40 percent less than gasoline (81). As of July 2005, PG&E charges approximately $1.40 per therm, equivalent to about $1.78 per gasoline gallon, for CNG used as a motor fuel.

Biogas

Description and Features: Biogas is the gaseous product of the anaerobic digestion (decomposition without oxygen) of organic matter. It is a mixture of methane, carbon dioxide, and traces of gases such as hydrogen, carbon monoxide, and nitrogen. Advantages of biogas as an alternative fuel include (78):

- Domestic, renewable resource
- Directly reduces greenhouse gas emissions by preventing methane release into the atmosphere.
- Anaerobic digestion systems (non-landfill) treat waste naturally, require less land area than aerobic composting, reduce the amount of material that must be land filled, reduce waste odors, and produce sanitized compost and nutrient-rich liquid fertilizer.

Biogas is produced naturally in landfills, and from the processing of animal waste, sewage, crop waste, and cellulosic and non-cellulosic crops. Biomethane is a pipeline-quality natural gas-substitute produced by purifying biogas. Landfills, animal waste "lagoons," and sewage processing plants are major sources of biogas, a major component of which is methane. A U.S. Department of Energy study concluded that a feasible biomethane potential from these sources is 10 billion gasoline-gallon-equivalents per year.

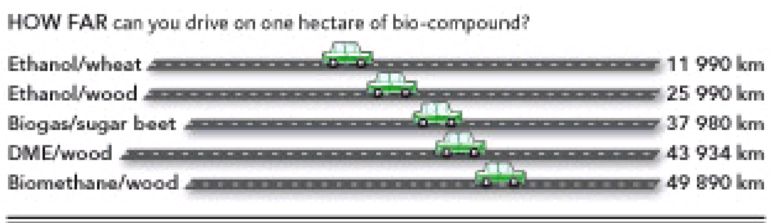
As a CO_2-neutral source of energy it will be increasingly used to meet the Kyoto Protocol commitments and to benefit from the CO_2-emission trade. Biogas is a flexible form of renewable energy that can produce heat, electricity and serve as a vehicle fuel.

When used as automotive fuel, biogas is cleaned to a level of 97% methane. One cubic meter clean biogas is approximately the same as one litre gasoline. Biogas is the most environmentally friendly automotive fuel commercially available today. A person driving 15 000 kilometers per year contributes to a reduction of fossil carbon dioxide of 3600 kg per year (83).

Sweden and Switzerland are the only countries where pure biogas is available as transport fuel. The utilization of biogas as vehicle fuel uses the same engine and vehicle configuration as natural gas. Worldwide there are more than 3 million natural gas vehicles and about 10,000 biogas driven cars and buses, demonstrating that the vehicle configuration is not a problem for use of biogas as vehicle fuel. However, the gas quality demands are strict so the raw biogas from a digester or a landfill has to be upgraded (84).

Timeline: A 2007 (79, 80) report estimated that 12,000 vehicles are being fueled with upgraded biogas worldwide, with 70,000 biogas-fueled vehicles predicted by 2010. Europe has most of these vehicles. Sweden alone reports that more than half of the gas used in its 11,500 natural gas vehicles is biogas. Germany and Austria have established targets of 20% biogas in natural gas vehicle fuel.

In the United States, biogas vehicle activities have been on a smaller scale. Examples include a landfill in Whittier, California, that fuels vehicles with CNG derived from the landfill and an Orange County, California, landfill that produces LNG for use in transit buses (78).



Source: http://www.businessregiongoteborg.com/huvudmeny/clusters/businessenvironment/biogaswest/

Challenges/Drawbacks: Research and development are focusing on reducing the costs of biogas production and purification, producing higher-quality natural gas from biogas, and evaluating the performance of biogas-fueled vehicles.

Bio-diesel and Ethanol

Description and Features: Ethanol (CH3CH2OH) is a renewable transportation fuel primarily made from starch crops, such as corn. It is also made from sugar beets and cane or cellulosic materials, such as fast-growing trees and grasses. Nearly one-third of U.S. gasoline contains ethanol in a low-level blend to reduce air pollution. (85, 86)

Ethanol is:

1. Produced from domestic crops, increasing Energy Security.
2. Fueling the Economy. Ethanol production is a new industry that is creating jobs in rural areas where employment opportunities are strongly needed.
3. Reduces Greenhouse Gas

Biodiesel is a liquid fuel made up of fatty acid alkyl esters, fatty acid methyl esters (FAME), or long-chain mono alkyl esters. It is produced from a variety of natural crops including rapeseed, soybean, mustard, flax, sunflower, canola, palm oil, hemp, jatropha and waste vegetable oils (87, 88). This fuel source is

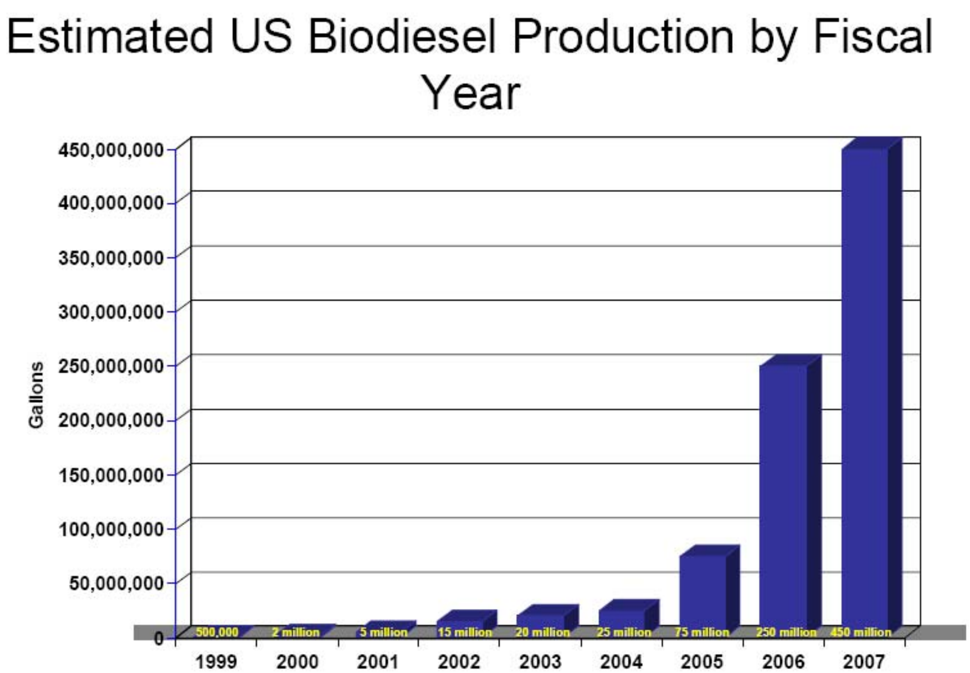
1. Clean-burning;

2. Domestically produced, Renewable substitute for petroleum diesel;
3. Nontoxic and biodegradable;
4. Capable of reducing engine wear.

Moreover, biodiesel has a positive energy balance. For every unit of energy needed to produce a gallon of biodiesel, 3.24 units of energy are gained. (89)

Since 2001, ethanol production has quadrupled from 1.6 billion gallons in 2000 to an estimated 6.4 billion gallons in 2007, with the vast majority coming from corn. In 2005, the United States became the world's leading ethanol producer, and last year, the U.S. accounted for nearly half of worldwide ethanol production. (90)

Last year, the U.S. produced about 450 million gallons of biodiesel – up 80 percent from 2006. Today, there are more that 650 biodiesel fueling stations, and hundreds of fleet operators use biodiesel to fuel their trucks. (90)



Source: http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf

The US Energy Independence and Security Act of 2007 (EISA) mandates, among its many components, an aggressive ramp-up in the use of renewable fuels, culminating in a 36 billion gallon renewable fuel standard (RFS) by 2022. Of that, corn ethanol production is capped at 15 billion gallons per year starting in 2015; the remainder is expected to be provided by "advanced biofuels", the majority of which are cellulosic biofuels. (91)

Renewable Energy's Office of Vehicle Technologies is funding efforts on two paths to increase ethanol consumption (91):

- Path A is to saturate the E10 markets and to significantly expand E85 markets at a greatly accelerated pace relative to today through the optimization of E85 use. The current E85 pathway won't deliver the consumption result—there are too few vehicles, and not enough fueling stations.
- Path B is to verify intermediate blends of gasoline to use up to 15% or 20% ethanol (E15, E20) and to let market forces drive supply distribution. Currently, the EPA does not register any ethanol fuel blend above E10 or below E85.

Biofuels has also emerged as an important alternative fuel in the European Union. However, recently the plans have been scaled down due to increasing concerns regarding food security (92).

Costs: E85 (85% ethanol, 15% gasoline) typically costs about the same or slightly less than gasoline on a gallon-for-gallon basis (85). The cost of Biodiesel is competitive with diesel. (89)

When evaluating the total costs associated with other alternative fuel systems, many fleet managers have determined biodiesel is their least-cost strategy to comply with state and federal regulations. Use of biodiesel does not require major engine modifications. That means operators keep their fleets, their spare parts inventories, their refueling stations, and their skilled mechanics. (93)

America's biodiesel industry will add $24 billion to the U.S. economy between 2005 and 2015, assuming biodiesel growth reaches 650 million gallons of annual production by 2015. Biodiesel production will create a projected 39,102 new jobs in all sectors of the economy. It will keep $13.6 billion in America that would otherwise be spent on foreign oil (94).

Table 1. Overall Average Fuel Prices

	Nationwide Average Price for Fuel This Report	*Nationwide Average Price for Fuel Last Report*	*Change in Price This Report vs. Last Report*	*Units of Measurement*
Gasoline (Regular)	$2.76	$3.03	($0.27)	per gallon
Diesel	$3.11	$2.96	$0.15	per gallon
CNG	$1.77	$2.09	($0.32)	per GGE
Ethanol (E85)	$2.40	$2.63	($0.23)	per gallon
Propane	$2.75	$2.58	$0.17	per gallon
Biodiesel (B20)	$3.08	$2.96	$0.12	per gallon
Biodiesel (B2-B5)	$2.99	$2.84	$0.15	per gallon
Biodiesel (B99-B100)	$3.38	$3.27	$0.11	per gallon

Table 2. October 2007 Overall Average Fuel Prices on Energy-Equivalent Basis

	Nationwide Average Price in Gasoline Gallon Equivalents	*Nationwide Average Price in Diesel Gallon Equivalents*	*Nationwide Average Price in Dollars per Million Btu*
Gasoline	$2.76	$3.08	$23.95
Diesel	$2.79	$3.11	$24.13
CNG	$1.77	$1.98	$15.37
Ethanol (E85)	$3.39	$3.78	$29.40
Propane	$3.80	$4.23	$32.90
Biodiesel (B20)	$2.81	$3.14	$24.39
Biodiesel (B2-B5)	$2.68	$2.99	$23.26
Biodiesel (B99-B100)	$3.33	$3.72	$28.87

Source: http://www.eere.energy.gov/afdc/pdfs/afpr_oct_07.pdf

Transportation Applications: E85 (85% ethanol, 15% gasoline) is considered an alternative fuel. It is used to fuel E85-capable flexible fuel vehicles (FFVs), which are available in a variety of models from U.S. and foreign automakers. (85)

At the production level, biodiesel fuel is a clean and affordable fuel for trucks, buses, farm equipment and other forms of heavy transportation (87). Biodiesel can be used in conventional diesel engines, directly substituting for or extending supplies of traditional petroleum diesel (95). Modern diesel engine technology has taken the advantages of biofuel usage.

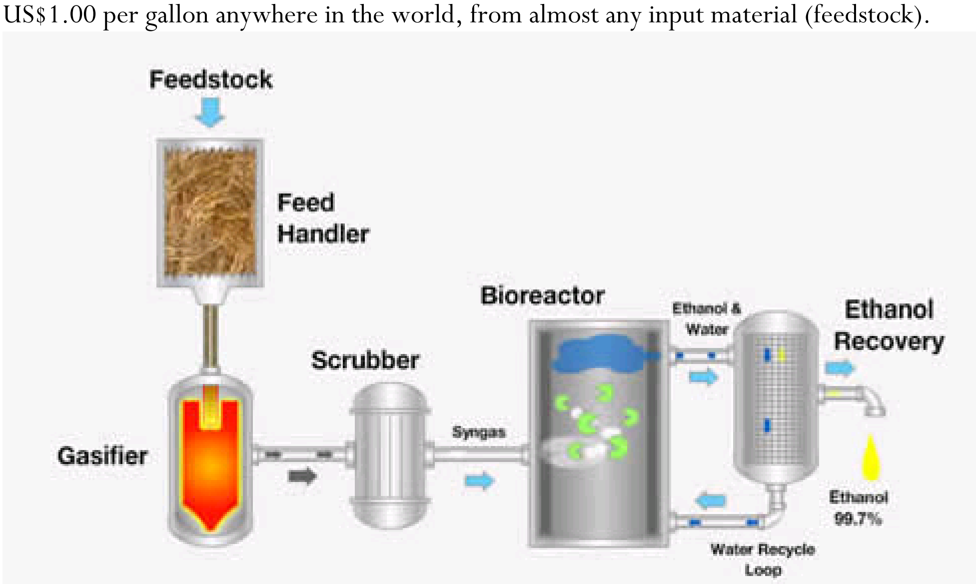
Challenges/Drawbacks: It is generally opined that ethanol requires more energy to produce than what it provides. However, recent study by Argonne National Laboratory (a U.S. Department of Energy Laboratory), indicates a 38% gain in the overall energy input/output equation for the corn-to-ethanol process. (95)

However import of biofuels can have negative social impacts since it increases the cost of food in places such as Mexico by re-directing corn produce for fuel production (96).

Biodiesel is not currently widely available, even though there production-scale plants, such as NOPEC, do exist (91). Biodiesel (B100) has about 8 percent less energy per gallon than petroleum diesel, so more gallons of biodiesel are needed to power a vehicle than a comparable volume of petroleum diesel (97). E85 has about 27% less energy per gallon than gasoline.

Implementation or Commercial Examples: By 2012, 50 percent of GM cars will be "Flex Fuel" models that run on up to 85 percent ethanol, because that fuel source has the most potential in the short term (98).

Coskata, Inc. is a biology-based renewable energy company, with technology for the production of liquid fuels. Using proprietary microorganisms and transformative bioreactor designs, the company will produce ethanol for under US$1.00 per gallon anywhere in the world, from almost any input material (feedstock).



Source: Coskata Inc.

Electric-driven and Hybrid vehicles

Description and Features: Electricity used to power vehicles is generally provided by the electricity grid and stored in the vehicle's batteries. There are no tailpipe emissions. But the emissions can be generated in the electricity production process. There are concerns whether this could lead to overall increase in pollution (131).

Multiple technologies feed into developing hybrid vehicles including: Electric propulsion systems, Electrical energy storage systems (e.g., batteries, power capacitors), on-board data acquisition and control system. While several hybrid vehicles are available in passenger vehicle market, research is on-going to adopt hybrid technology for heavy-vehicles (99).

Timeline: The world hybrid-vehicle market, estimated at 384,000 vehicles in 2006, is projected to reach 1.1 million units in 2010 and 2 million units by 2015 (100).

Despite rapid growth in hybrid-electric vehicle sales forecasted over the next few years, hybrid market share is expected to top out at 3 percent of the U.S. automotive market by 2010, according to the J.D. Power-LMC Automotive Forecasting Services Hybrid-Electric Vehicle Outlook (101).

Costs: Electricity fueling costs for electric vehicles are reasonable compared to gasoline.
$0.05 per mile for vehicles with direct current (DC) electric systems and $0.03 cents per mile for vehicles with alternating current (AC) systems.

Transportation Applications: Electricity can be used to power electric and plug-in hybrid electric vehicles directly from the power grid (102). Hybrid Electric Vehicles (HEVs) are becoming widely available for a variety of applications (103, 104).

Challenges/Drawbacks: Several barriers are preventing widespread commercialization of plug-in hybrid electric vehicles (PHEVs), including the following:

1. Hybrid component mass, volume, cost, reliability, and safety
2. Lack of domestic sources for batteries
3. Consumer behavior and expectations
4. Robust operation in range of environmental conditions.
5. Cost of battery
6. Energy storage density / vehicle range,
7. Refueling facility (for pure electric vehicles) (105)

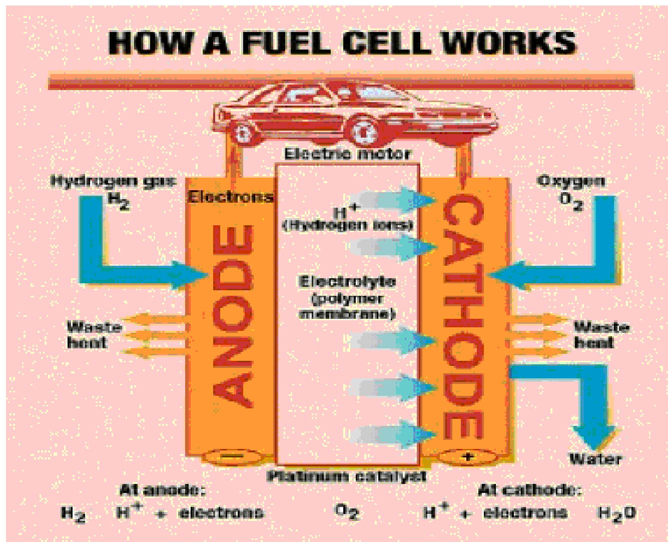
Implementation or Commercial Examples: Research efforts include DoE's FreedomCAR and Vehicle Technologies (FCVT) Program evaluating PHEV (106, 107), National Renewable Energy Laboratory's Advanced Vehicle and Fuels research program on HEV (108). Commercial players including Toyota (109), Honda (110), Ford (111), General Motors (112) are developing PHEV. The Ann Arbor Transportation Authority is operating several Hybrid buses (113). Cadillac Provoq, which runs on Lithium-Ion batteries and hydrogen fuel cells and GMs Volt are expected to be in the market within the next 5 years.

GMs volt has a very powerful all-electric 161-horsepower 45KW (53 KW peak) motor that is the only engine to power the car at all times. This engine should be capable of moving the car from 0 to 60 in 8.5 seconds, and have a top speed of at least 100 mph. Another very important feature of the Volt is that it will still have an on-board gasoline/E85 combustion engine. This engine is the smaller one, and has only one task, it charges the battery pack when the stored power gets low. The motor is not connected to the wheels, it is only a generator. The brilliance of this feature is that you will have an overall driving range of 600-700 miles, greater than most gas cars now. The efficiency of this motor amounts to about 50mpg, for each gallon you use to charge the batteries.

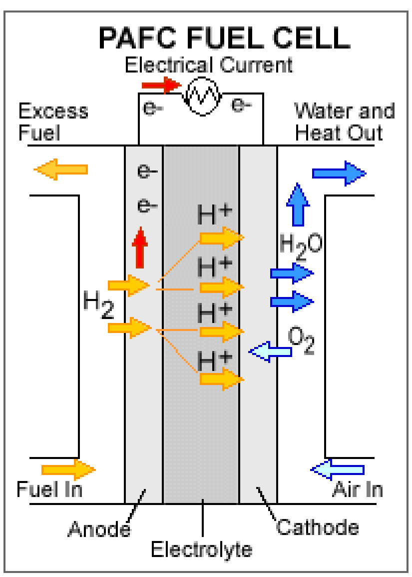
Hydrogen Fuel

Description and Features: Hydrogen fuel is

1. Clean-burning;
2. High potential for domestic production;
3. A fuel with high efficiency. The energy in 2.2 lb (1 kg) of hydrogen gas is about the same as the energy in 1 gallon of gasoline. (114, 115)



Hydrogen can be produced using diverse, domestic resources including nuclear; natural gas and coal; and biomass and other renewable including solar, wind, hydroelectric, or geothermal energy. This diversity of domestic energy sources makes hydrogen a promising energy carrier and important to our nation's energy security. It is expected and desirable for hydrogen to be produced using a variety of resources and process technologies (or pathways). DOE focuses on hydrogen production technologies that result in near-zero net greenhouse gas emissions and use renewable energy sources, nuclear energy, and coal (when combined with carbon sequestration). To ensure sufficient clean energy for our overall energy needs, energy efficiency is also important. Hydrogen can be produced via various process technologies, including thermal (natural gas reforming, renewable liquid and bio-oil processing, and biomass and coal gasification), electrolytic (water splitting using a variety of energy resources), and photolytic (splitting water using sunlight via biological and electrochemical materials). Hydrogen can be produced in large, central facilities (50-300 miles from point of use), smaller semi-central (located within 25-100 miles of use) and distributed (near or at point of use). In order for hydrogen to be successful in the market place, it must be cost competitive with the available alternatives. In the light duty vehicle transportation market, this means that hydrogen needs to be available at $2-$3/gge (untaxed). This would result in hydrogen fuel cell vehicles having the same cost to the consumer on a cost per mile driven basis as a comparable conventional internal combustion engine or hybrid vehicle. DOE is engaged in research and development of a variety of hydrogen production technologies. Some are further along in development than others — some can be cost competitive for the transition period (beginning in 2015), while others are considered long-term technologies (cost-competitive after 2030) (116).



The major conclusions from a recent study (117) on Hydrogen fuel are:

- Greenhouse gas reductions: the hydrogen-powered fuel cell vehicle is the only option that can achieve the goal of reducing GHGs by 60% or more below 1990 levels in the transportation sector; the second-best option, cellulosic ethanol PHEVs, could at best achieve a 20% reduction, and even then not until 2090.
- Urban air pollution: the hydrogen-powered fuel cell vehicle is the only option that would virtually eliminate urban air pollution from the transportation sector by 2100; all other vehicle/fuel options including both gasoline and ethanol PHEVs would produce essentially the same or greater urban air pollution as the existing car fleet due to increased vehicle miles traveled.
- Petroleum consumption: the hydrogen-powered fuel cell vehicle is the only option that could achieve energy "quasi-independence" reaching that milestone by mid-century; the second-best option, ethanol PHEVs would still consume over 5 million barrels oil per day by the end of the century.
- Societal cost savings: hydrogen-powered fuel cell vehicles will provide greater societal cost savings than any other alternative: each FCV sold will cut societal costs by a factor of 7.6 relative to conventional gasoline cars in the near-term (now to 2020), by a factor of 9.5 in the mid-term (2021 to 2050) and by a factor of 15.5 in the long-term (2051 to 2100); second-best option is the hydrogen-powered ICE HEV (reduction factors of 5.0, 6.2, 11.7); third-best the battery EV (4.2, 4.6, 10.6); fourth-best the ethanol plug-in hybrid (3.8, 4.8, 6.8) and fifth-best the gasoline plug-in hybrid (1.7, 2.1, 2.9).

Phosphoric Acid Fuel Cells (PAFC) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram to the right. The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than Polymer Electrolyte Membrane (PEM) cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell (118).

Timeline: Ford currently has a fleet of 30 hydrogen-powered Focus fuel cell vehicles on the road as part of a worldwide, seven-city program to conduct real-world testing of fuel cell technology. The fleet has accumulated more than 300,000 miles since its inception. (119)

Costs: Hydrogen is currently very expensive because it's difficult to generate, handle, and store (7). This total cost is \$3.0 to \$7.4/kg of H_2, or \$1.12 to \$3.20/gallon of displaced gasoline/diesel, which compares with the actual costs of U.S. gasoline and diesel in mid-March 2005 of \$2.06 and \$2.19, respectively. Adding the reduction in health and mortality costs from wind HFCVs of \$0.29 to \$1.80/gallon, which is the externality cost of gasoline, gives a direct cost plus externality cost of U.S. gasoline/diesel of \$2.35 to \$3.99/gallon, which exceeds the mean cost of hydrogen from wind (\$2.16/gallon) even if retail hydrogen is marked up. (120)

The cost of fuel cell stacks has decreased tenfold in just three years. GM's latest fuel cell concept vehicle, the Sequel, has a lower-cost fuel cell stack than the earlier Hy-wire concept vehicle. But the price is still too high to make a vehicle that costs the same as today's vehicles. (121)

Today, compressed hydrogen can be shipped in tube trailers at pressures up to 3,000 psi (about 200 bar). This method is expensive, however, and it is cost-prohibitive for distances greater than about 200 miles. Researchers are investigating technology that might permit tube trailers to operate at higher pressures (up to 10,000 psi), which would reduce costs and extend the utility of this delivery option. (118)

Using today's technology, liquefaction consumes more than 30% of the energy content of the hydrogen and is expensive. In addition, some amount of stored hydrogen will be lost through evaporation, or "boil off" of liquefied hydrogen, especially when using small tanks with large surface-to-volume ratios. Research to improve liquefaction technology, as well as improved economies of scale, could help lower costs (today's liquefaction units are small to meet minimal demand). (118)

A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate. (118)

Based on a 2001 survey of leading stationary fuel cell manufacturers, the installed cost of fuel cells is expected to fall from an average of $4,500/kW in 2002 to about $1,000/kW by 2010. This price drop is associated with an expected increase in sales, subsequent adoption of mass production, and discounts for large orders. (122)

Transportation Applications: Fuel cell vehicles, powered by Hydrogen, have the potential to revolutionize our transportation system. They are more efficient than conventional internal combustion engine vehicles and produce no harmful tailpipe exhaust—their only emission is water. (123)

BMW Hydrogen 7 powered by liquid hydrogen and gasoline bi-fuel vehicle is an industrial application case in USA (124). Hydrogen Fuel Cell Bicycles developed in China (125). Hydrogen is currently available only as an industrial or scientific chemical product, not as a bulk fuel. (126)

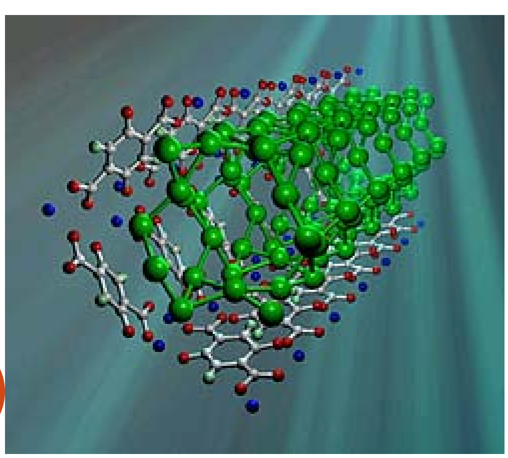
Hydrogen Hybrid-Electric Vehicle: A hybrid-electric vehicle avoids the currently high cost of fuel cells while achieving high fuel efficiency. The equivalent energy efficiency is 80-mpg, with a range of 300 miles. It would require onboard storage of 3.75 kg, which could be increased to provide a longer driving range.

Fuel Cell Electric Vehicle: A fuel cell effective vehicle would be three times as efficient as the current internal combustion engine. The vehicle would achieve the equivalent of 90-mpg and have equal fuel costs at a hydrogen cost of $3.75 per gallon, or $30/GJ. When fuel cells become less costly, they would become the ideal choice for hydrogen-powered vehicles. (127)

Ford Edge with HySeries Drive^{tm} is the world's first drivable fuel cell hybrid electric plug-in that combines an onboard hydrogen fuel cell generator with lithium-ion batteries to deliver more than 41 mpg with zero emissions.

The plug-in hybrid is powered by a 336-volt lithium-ion battery pack at all times. The vehicle drives the first 25 miles each day on stored electricity alone, after which the fuel cell begins operating to keep the battery pack charged. This provides another 200 miles of range for a total of 225 miles with zero emissions. (119)

Wind hydrogen fuel cell vehicles (HFCV) may save 2300 to 4000 lives/year and $32 billion to $180 billion/year in the United States relative to hybrids, and that wind or natural gas HFCVs may save 3700 to 6400 lives/year and reduce asthma by 1 million to 3 million cases/year relative to current fossil-fuel onroad vehicles. Because wind HFCVs result in the greatest health-plus-climate benefit among all cases, examining the cost to the U.S. economy of producing hydrogen from wind is warranted.



Challenges/Drawbacks:

1. Storage Technologies. Hydrogen has a low volumetric energy density. Therefore, to store the same amount of energy, hydrogen needs larger storage tank than gasoline. (114, 115, 128)

2. The primary challenge for hydrogen production is reducing the cost of production technologies to make the resulting hydrogen cost competitive with conventional transportation fuels. (114, 115)
Source: NIST

One of the key engineering challenges to building a clean, efficient, hydrogen-powered car is how to design the fuel tank. Storing enough raw hydrogen for a reasonable driving range would require either impractically high pressures for gaseous hydrogen or extremely low temperatures for liquid hydrogen. In a new paper* researchers at the National Institute of Standards and Technology's Center for Neutron Research (NCNR) have demonstrated that a novel class of materials could enable a practical hydrogen fuel tank.

MOF-74 resembles a series of tightly packed straws comprised mostly of carbon atoms (white balls) with columns of zinc ions (blue balls) running down the walls. Heavy hydrogen molecules (green balls) adsorbed in MOF-74 pack into the tubes more densely than they would in solid form.

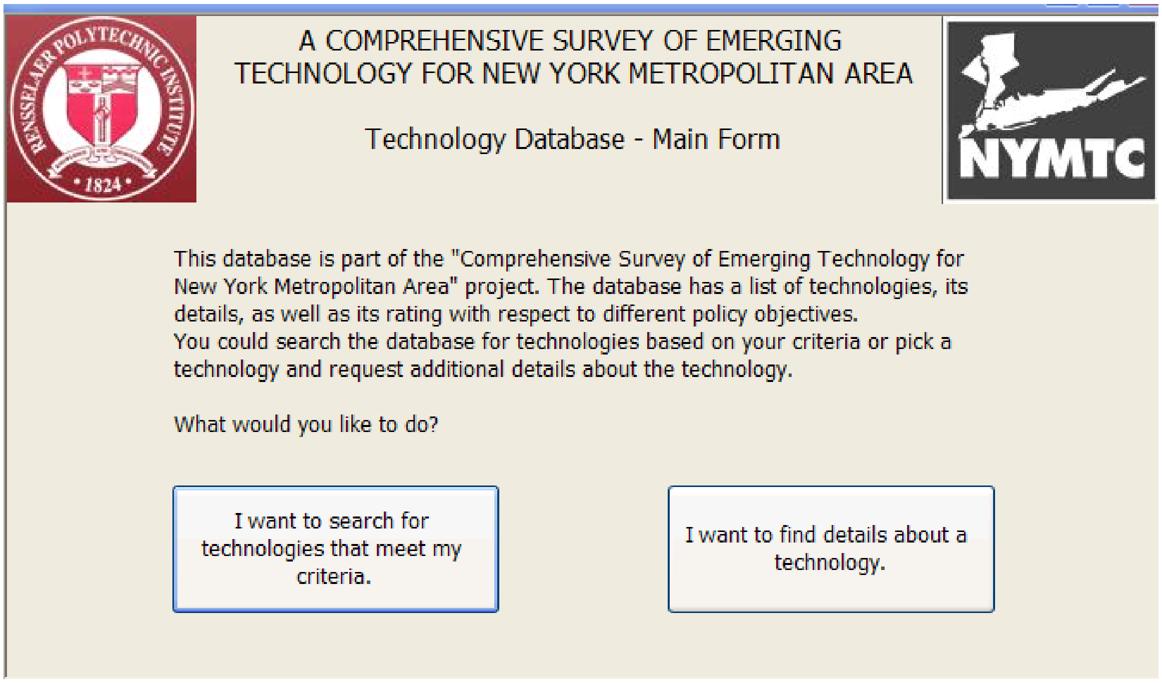
Implementation or Commercial Examples:

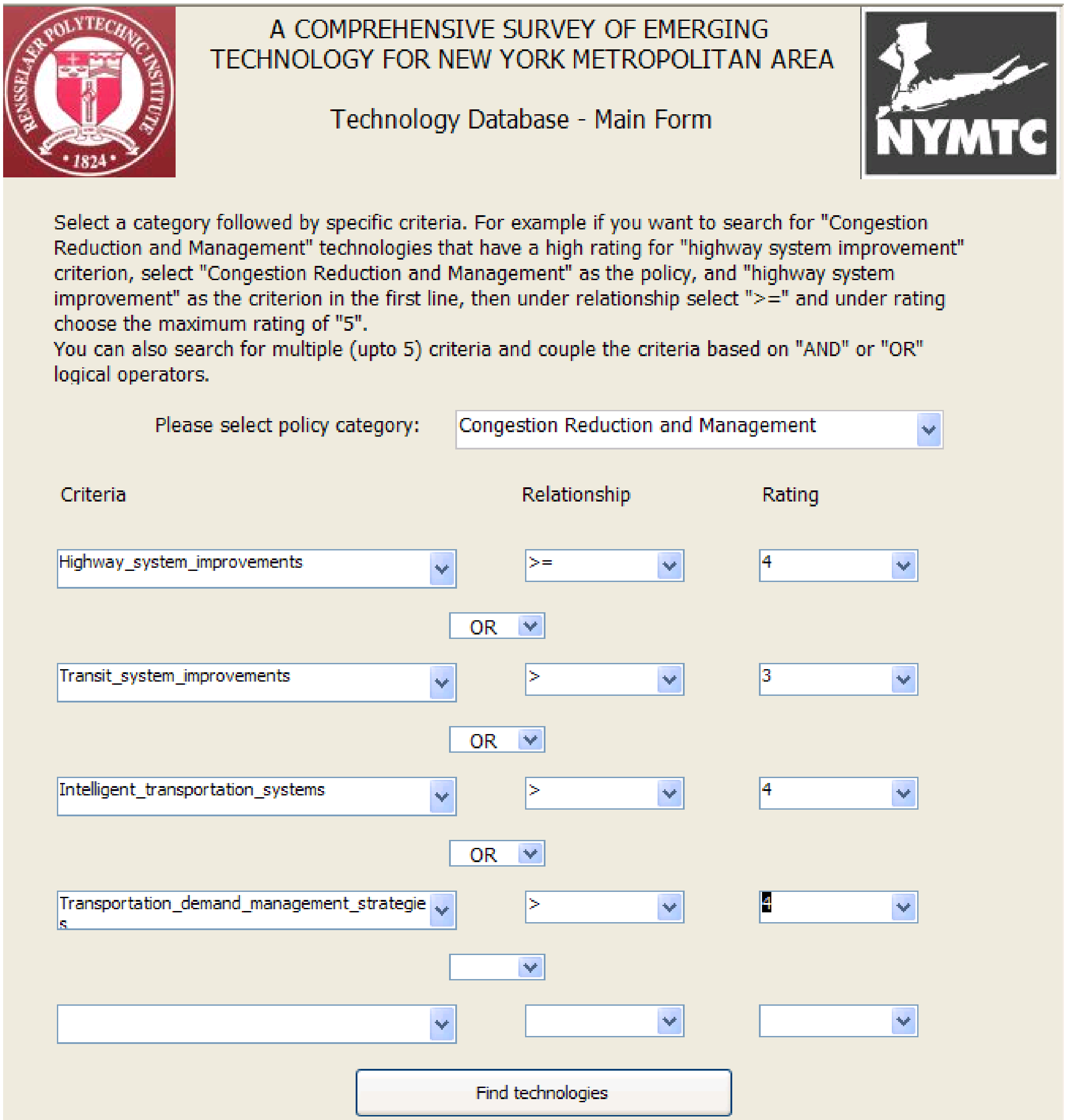
Nissan aims to introduce a new fuel-cell vehicle using an improved fuel stack developed in-house after 2010 that will offer performance on par with gasoline-power automobiles. (129)

The Chevy Equinox Fuel Cell contains General Motor's fourth generation fuel cell propulsion system including a 93 kw fuel cell, 73 kw front-wheel drive 3-phase asynchronous electric motor and 35 kw nickel metal hydride battery pack. The Equinox Fuel Cell uses 3 carbon fiber fuel tanks, pressurized to 10,000 psi and has a range of 200 miles before refueling. With a top speed of 100 mph, the Chevrolet Equinox Fuel Cell accelerates from 0 - 60 mph in 12 seconds. The 5-door, 4-seat vehicle is expected to meet all 2007 U.S. Federal Motor Vehicle Safety Standards. (130)

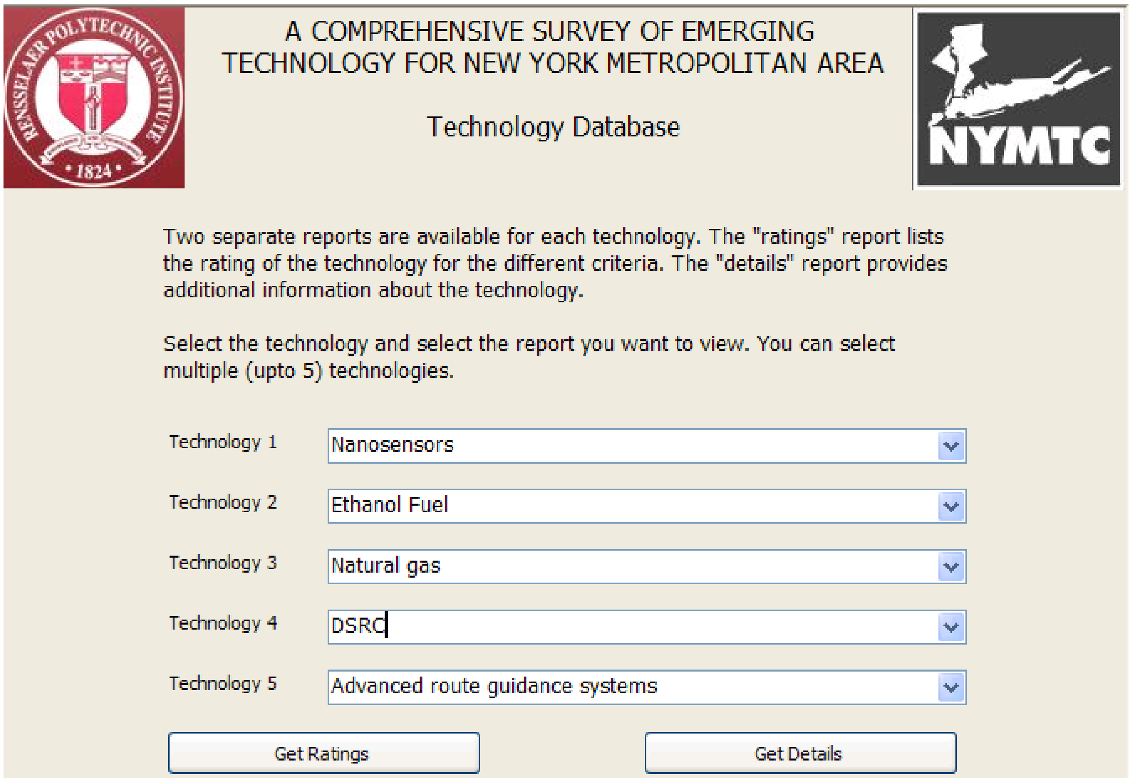
Description of Database

The database allows easy access to the information and allows the user to organize the information in convenient formats. The details for each technology include: features, timeline, costs, applications to transportation, and challenges. The features field describes


A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA
Technology Database - Main Form
NYMTC
This database is part of the "Comprehensive Survey of Emerging Technology for New York Metropolitan Area" project. The database has a list of technologies, its details, as well as its rating with respect to different policy objectives.
You could search the database for technologies based on your criteria or pick a technology and request additional details about the technology.
What would you like to do?
I want to search for technologies that meet my criteria.
I want to find details about a technology.



the technology in detail including the components and capabilities of the technology. The timeline provides a subjective estimate of the level of maturity of the technology and the time to implementation. Costs provide estimates of the implementation and operational cost and economic benefits from the technology. Given the uncertainty involved and the fact that these technologies are still under development, in most cases the costs are rough estimates. The next field identifies the potential application of the technology to transportation domain. What are the different benefits arising from the technology in terms of congestion reduction and management, air quality improvement, safety and security etc. is also discussed in the database. Finally, the field corresponding to 'challenges' lists the main hurdles to the development of the technology. In addition to these details the database has additional information with regard to how effective the technology is towards meeting specific policies or goals. This is a rating carried out as part of task 4 in order to short-list the technologies. The figures below demonstrate screenshots of the user-friendly forms available in the database.


A COMPREHENSIVE SURVEY OF EMERGING
TECHNOLOGY FOR NEW YORK METROPOLITAN AREA
Technology Database
Two separate reports are available for each technology. The "ratings" report lists the rating of the technology for the different criteria. The "details" report provides additional information about the technology.
Select the technology and select the report you want to view. You can select multiple (upto 5) technologies.
Technology 1
Nanosensors
Technology 2
Ethanol Fuel
Technology 3
Natural gas
Technology 4
DSRC
Technology 5
Advanced route guidance systems
Get Ratings
Get Details

Chapter 6: Assessment of Shortlisted Technologies

Task 5 assessed the shortlisted technologies by the consultants with input from several experts. A brief summary of the work conducted in previous tasks is: In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan (RTP) committee members. An important result from the first survey is the ranking of the different policy sub-categories. The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be explored for implementation in the NY metropolitan area.

The methodology for short-listing technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. A weighted sum method was used to obtain the rankings of the technologies. Since the focus on technologies have always been toward meeting the three broad goals of NYMTC, i.e., congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals was prepared.

Based on the ranking of the technologies and the project team's reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

The shortlisted technologies include:

Congestion Reduction and Management

Geographic Positioning Systems and Personal Travel Assistants
Adaptive Ramp Metering
Smart Cards and RFID
Personalized Rapid Transit
Collaborative Technologies

Safety and Security

Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication (DSRC, RFID, VANETs)
Machine Vision
MEMS and Nanosensors
Automated Vehicles
Biometric Identification

Energy and Environment

Natural Gas and Propane
Biogas
Bio-diesel and Ethanol
Electric-driven and Hybrid vehicles
Hydrogen Fuel

Assessment of Technologies

In Task 5, the focus of this report, technologies in each of the broad categories – congestion reduction and management, safety and security, energy and environment – are assessed using the weights obtained from pair wise comparison process described in section 3.1. Input is obtained from several experts to assist in the assessment process. Assessment is based on two criteria including the contribution of each technology towards the listed goals and the likely acceptance/growth of the technology in the NY metropolitan region.

Below we present the methodology adopted to obtain the rankings. We then describe the survey questionnaire used to obtain input from the different experts.

Weights from Ratio Comparisons

Given a set of m alternatives, each having a weight of w_i, the ratio comparison between two alternatives i and k, is given as w_i / w_k. That is alternative i is w_i / w_k times better than alternative k. However, it is often difficult to obtain the weights of the alternatives directly.

The inverse problem, which is the focus here, deals with obtaining the ratio comparison of two alternatives at a time. Having thus obtained the ratio comparison of each pair of alternatives, we obtain the ratio comparison matrix, **A**. The weights are subsequently obtained using the methodologies described below. Matrix **A** is a reciprocal matrix, i.e. the ratio comparison between alternative i and k is a_{ik} and the ratio between k and i is $1/ a_{ik}$. Consequently the diagonal elements of matrix **A** are 1.

The eigen decomposition theorem states that any square matrix can be decomposed into eigenvalues and eigenvectors[17]. It can be shown[18] that if **W** is the vector of weights, and n is the eigenvalue of matrix **A**, then:

$$\mathbf{A}\ \mathbf{W} = n\ \mathbf{W}$$

The above holds only if the ratio comparisons are perfect, i.e. $a_{ik} = w_i / w_k$. However if the ratio comparisons are not perfect, one has to find the eigenvector that corresponds to the maximum eigenvalue n_{max}.

$\mathbf{A}\ \mathbf{W} = n_{max}\ \mathbf{W}$ where, $n_{max} > n$.

This approach to finding the weights is referred to as the eigenvalue approach. However, the approach is accepted as consistent only when the ratio:

$CI = (n_{max} – n) / (n - 1)$
is 10% or less.

A second method to obtain the weights from an imperfect ratio comparison matrix is by determining the weight vector **W** that provides the least error deviation. This can be obtained by solving for w_i's in the optimization problem below:

Minimize $$\sum_{i=1}^{n}\sum_{k=i}^{n}\left(a_{ij} - \frac{w_i}{w_j}\right)^2$$

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[17] http://mathworld.wolfram.com/Eigenvector.html

[18] Evangelos Triantaphyllou, Multi-Criteria Decision Making Methods: A Comparative Study, Kluwer Academic Publishers, 2000.

s.t. $\sum_{i=1}^{n} w_i = 1$ and $w_i > 0$ for $i = 1, 2, \dots n$.

Survey Questionnaire

In order to obtain ratio comparison values a survey questionnaire was developed. Experts were requested to complete the questionnaire online. The questionnaire was divided into five sections. Two sections each related to congestion reduction and management, and safety and security technologies, and one section dealing with energy and environment technologies. The first section in each of the technology categories included questions on pair wise comparison (Figure 1) of the technologies with respect to the effectiveness of the technology towards meeting the broad category goal. The remaining two sections obtained input on the degree of likely penetration of the technology (Figure 2) and the likelihood of implementation of less developed in the future (Figure 3).

Section 1. Assume all of the above technologies are in place and are performing to their best potential. How do you rate the technologies with respect to their impact on congestion reduction? In the table below, each row represents a separate pair-wise comparison. First choose which of the two technologies is better and then tell us how much better you consider it to be: 1-Equally, 3-Moderately, 5-Strongly, 7-Very strongly, and 9-Absolutely. The even numbers in between suggest intermediate importance values.

Technology 1	Technology 2	Equally		Moderately		Strongly		Very Strongly		Absolutely
		1	2	3	4	5	6	7	8	9
Personal Rapid Transit	Collaborative Technologies									
GPS and Personal Travel Assistant	Adaptive Ramp Metering									
Personal Rapid Transit	Adaptive Ramp Metering									
GPS and Personal Travel Assistant	Smartcards and RFID									
Personal Rapid Transit	Smartcards and RFID									

Fig 1. Survey: Pair wise comparison of technologies

Section 2. In the following questions, we are interested in your opinion on the likely degree of penetration (% of individuals using the technology) for these technologies.

Geographic Positioning Systems and Personal Travel Assistants

	Likely degree of penetration
Next 10 years	%
Next 20 years	%
Smart Cards and RFID	
Next 10 years	%
Next 20 years	%
Collaborative Technologies	
Next 10 years	%
Next 20 years	%

Fig 2. Survey: Likely degree of penetration of technology

	Highly Unlikely		Unlikely		Neither		Likely		Highly Likely
	-4	-3	-2	-1	0	1	2	3	4
What is the likelihood of a Personal Rapid Transit being implemented in a major metropolitan region in the next 20 years?	○	○	○	○	○	○	○	○	○
What is the likelihood of Webinars and Video Conferencing becoming the preferred method of conducting business meetings in the next 20 years?	○	○	○	○	○	○	○	○	○

Fig 3. Survey: Likelihood of implementation of less developed technology

The ratio comparisons provided the input to determine the weights used for ranking the technologies in terms of their effectiveness towards contributing to the major goal. The complete questionnaire may be accessed at: http://transp.rpi.edu/~gita/assess.htm

Results

The survey questionnaire was completed by 22 respondents including seven university professors, nine practitioners (including private industry), and six government/DOT officials. Four respondents were New York residents while three respondents were international experts. The response rate for the survey was approximately 30 percent.

The main results from the responses are presented below. The actual response for the ratio comparison questions are presented in the Appendix. We have used the minimization of sum of squares of error methodology to estimate the weights since the CI index when applying the eigenvalue method was consistently over 10% in most of the cases.

Congestion Reduction and Management Technologies

The five congestion reduction and management technologies compared and their weights are presented in Figure 4 and the table below. The respondents compared the technologies pairwise. The criterion for comparison was the technologies "impact on congestion reduction". On the overall, GPS and Personal Travel Assistant was ranked the most effective (average weight of 0.27), followed by Smartcards and RFID (0.24), Collaborative technologies (0.22), adaptive ramp metering (0.21), and personal rapid transit (0.07). The last column in Table 1 lists the coefficient of variation (COV). COV is the normalized measure of dispersion of a value. While standard deviation provides an absolute measure, the COV given by the ratio of standard deviation to the mean provides a normalized measure that provides additional insight into the degree of dispersion relative to the mean value. Personal rapid transit was consistently ranked the least effective (COV = 0.44). The maximum spread (COV = 0.66) was observed for adaptive ramp metering which also had the highest maximum individual weight; this is perhaps indicating a mixed-response from the experts in terms of the actual effectiveness of adaptive ramp metering. Adaptive ramp metering success and failure are significantly dependent on the particular location and traffic characteristics of the transport network. The number one rank for GPS and personal travel assistants is also in keeping with recent trends of increasing patronage of such devices by travelers. However, no single technology has emerged as a clear winner; this is according to the expectation that several varied technologies all have an interdependent role to play towards reducing congestion.

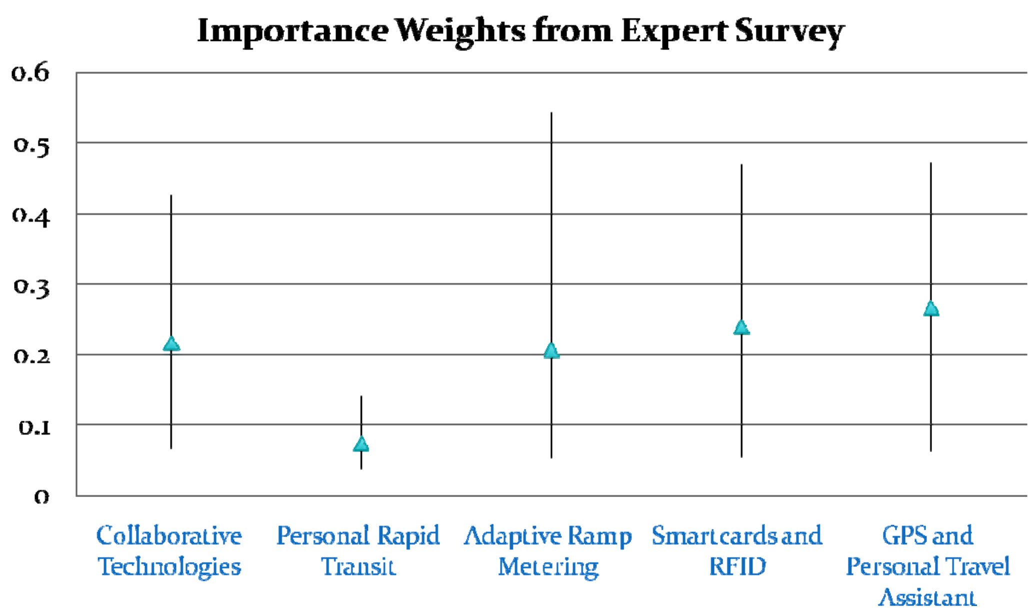


Fig 4. Weights of Congestion Reduction and Management Technologies

Table 1. Weights of CRM Technologies

	Min	Max	Average	Std Dev	C.O.V
Collaborative Technologies	0.0657	0.4254	0.2163	0.11	0.52
Personal Rapid Transit	0.0379	0.1404	0.0730	0.03	0.44
Adaptive Ramp Metering	0.0545	0.5429	0.2061	0.14	0.66
Smartcards and RFID	0.0549	0.4688	0.2391	0.13	0.56
GPS and Personal Travel Assistant	0.0632	0.4712	0.2655	0.13	0.47

The second part of the survey queried experts on the likelihood of implementation of the different technologies. Personal rapid transit was widely perceived as an "unlikely" technology even in the next 20 years. On the other hand, the experts collectively regard webinars and video conferencing as the "likely to highly likely" method for business meeting in 20 years.

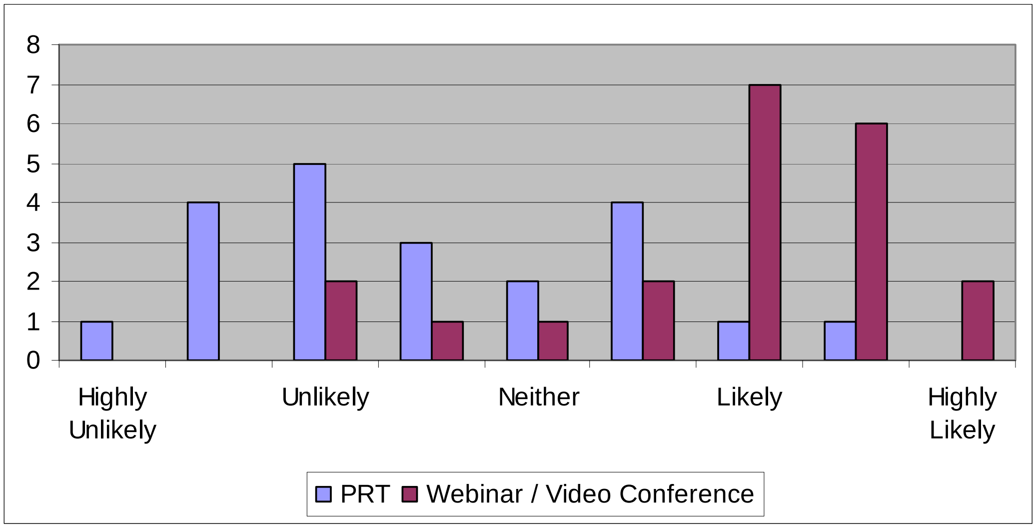
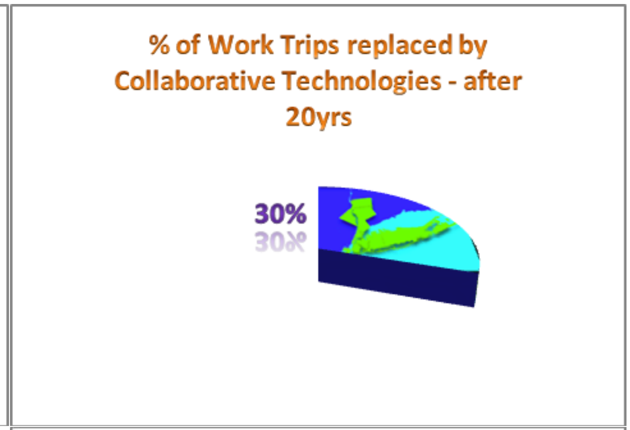


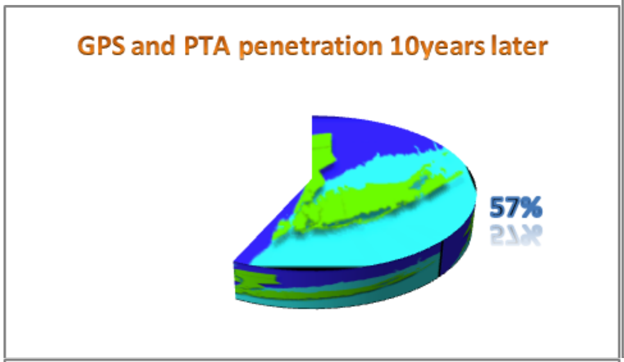
Fig 5. Likelihood of implementation

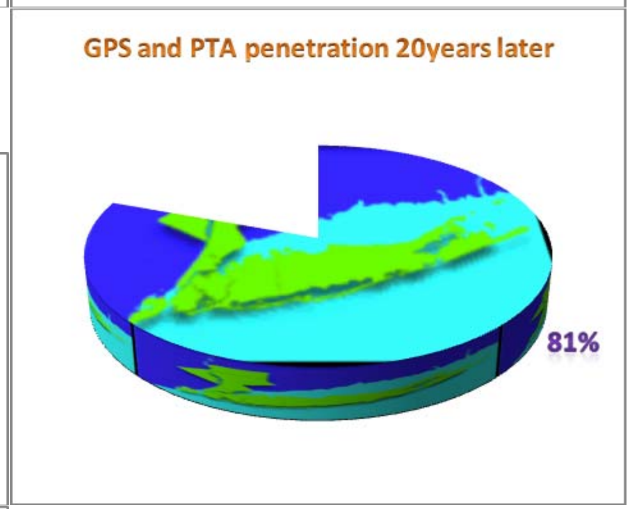
Table 2. Likely degree of penetration (% of individuals using the technology)

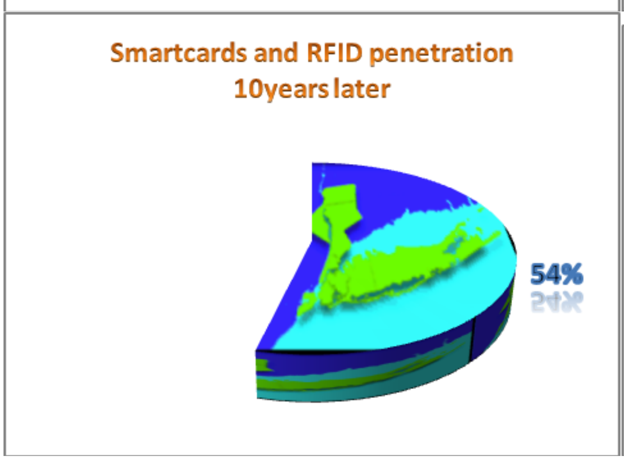
	Min	Max	Average
GPS and Personal Travel Assistants			
10 years later	20%	95%	56.6%
20 years later	50%	100%	80.6%
Smartcards and RFID			
10 years later	5%	99%	53.7%
20 years later	10%	100%	76.1%
Collaborative Technologies			
10 years later	10%	95%	52.1%
20 years later	20%	99%	71.5%
% of Work Trips replaced by Collaborative Technologies			
10 years later	2%	50%	18.7%
20 years later	3%	60%	30.1%

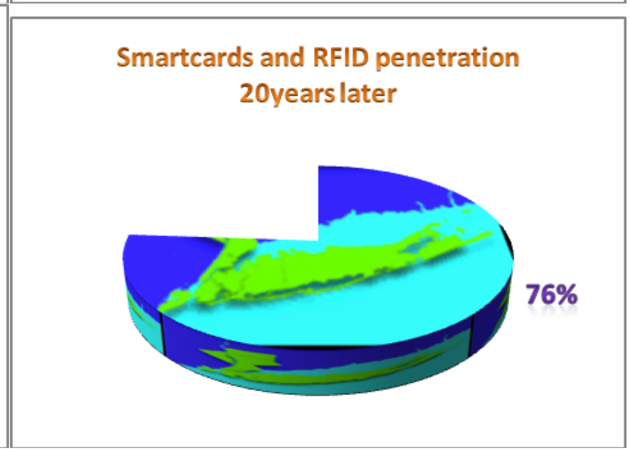
In terms of the degree of penetration, GPS and personal travel assistants are likely to be used by 56.6% and 80.6% percent of individuals after 10 and 20 years respectively. Smartcards and RFID as well as Collaborative technologies are also likely to be widely used with over 70% estimated on average after 20 years. Given their potential to impact congestion, such high penetration could significantly help mitigate congestion over the next two decades. A related question on the percentage of work trips that are likely to be replaced by collaborative technologies, the average response was over 30% after 20 years. On the overall, the shortlisted technologies appear to be highly favored by the experts in terms of their potential to reduce congestion.











Overall general comments from experts:

"These technologies can not work by themselves solely. For example, technologies for traveler information such as GPS have to be combined with better system management technologies such as adaptive ramp metering. Otherwise, the technologies may do harm. I strongly believe in the emergence of tolling schemes, whatever the technology to implement them - SmartCards, license plate recognition etc."

"The next generation of system user is technology savvy and is already immersed in collaborative technology. Technologies like Adaptive ramp metering and PRT are, to some extent, management technologies, as opposed to enabling technologies. GPS, RFID,

and collaborative technologies provide more information and more options to individuals for transportation and other services and will be more fully integrated into other aspects of their lives. PRT and Adaptive Ramp Metering are specialized technologies that address transportation issues alone. They may be important in specific situation but will not enjoy the broadbased adoption that these other technologies already experience."

Safety and Security Technologies

The weights obtained from the minimization of error methodology for safety and security technologies are shown in Figure 6 and Table 3. The comparison was restricted to only the three technologies listed since automated vehicles were considered to be a superset of these three technologies. Also, biometric identification was treated as security technology and was not included in the comparison below. The overall response rating for the question "which technology is likely to improve safety to a greater extent?" yielded the greatest average weight for Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication technology, followed by MEMS and Nanosensors, followed by Machine Vision. Given the significant spread in the weights of all three technologies (COV > 0.6) it is likely that a mixture of all three technologies could evolve into the future indicating no single technology will dominate the other.

Table 3. Weights of Safety and Security Technologies

	min	max	ave	Std Dev	C.O.V
Machine Vision	0.0769	0.7596	0.2722	0.18	0.66
V2V and V2I Communication	0.0882	0.7636	0.3977	0.24	0.59
MEMS and Nanosensors	0.0738	0.7769	0.3302	0.21	0.63

In terms of the degree of penetration (Table 4), MEMS devices had the greatest degree of penetration (34.3% after 10 years and 61.7% after 20 years). Over half-the-vehicles are likely to be equipped with V2V and V2I capabilities 20 years hence. Further, over a third of the vehicles 20 years hence are likely to be automated vehicles. Such high degree of penetration can have significant impacts towards improving road safety.

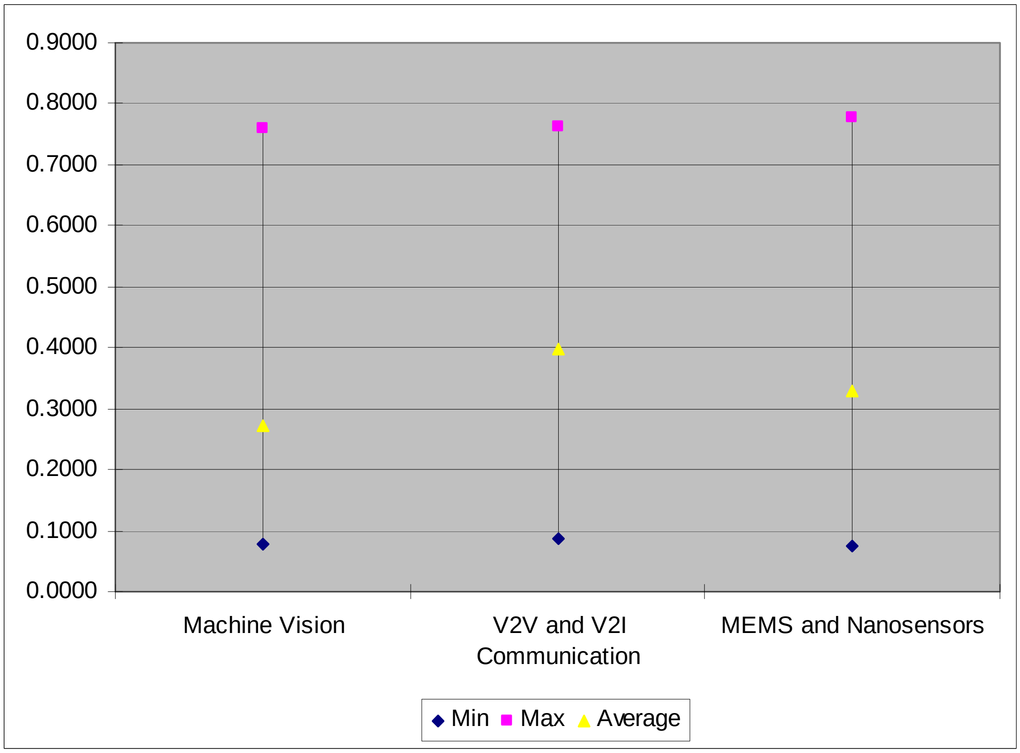


Fig 6. Weights of Safety and Security Technologies

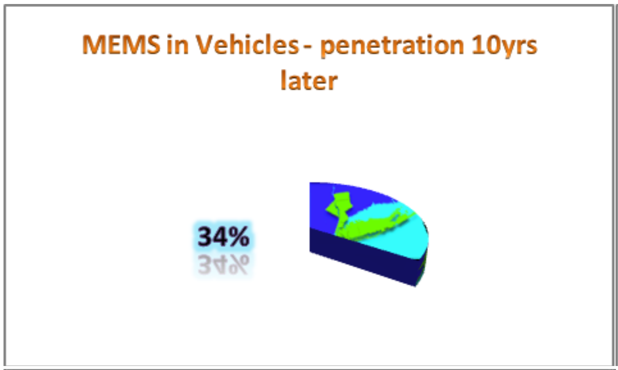
Table 4. Likely degree of penetration (% of individuals using the technology)

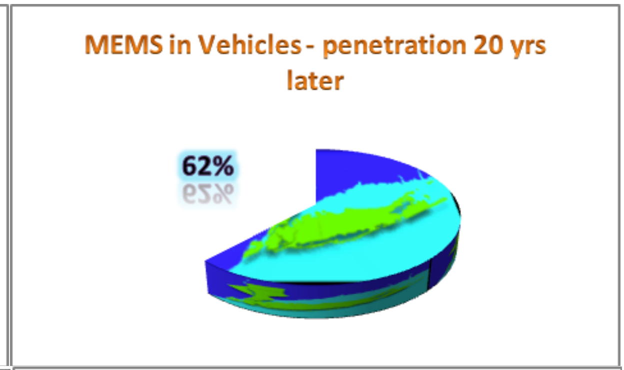
	Min	Max	Average
MEMS			
10 years later	5%	90%	34.3%
20 years later	15%	19%	61.7%
Machine Vision			
10 years later	5%	60%	21.6%
20 years later	5%	80%	42.3%
Automated Vehicles			
10 years later	0%	70%	20.7%
20 years later	0%	90%	37.3%
V2V and V2I communication			
10 years later	0%	66%	26.4%
20 years later	5%	90%	51.4%

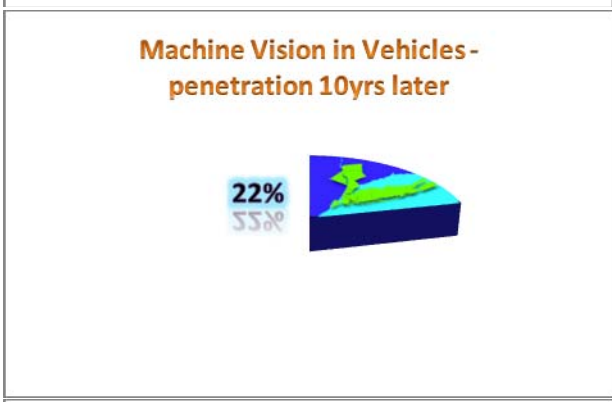
In terms of the likelihood of implementing biometric identification for fare payment as a security measure, the overall average response remained neutral. However, 55% of respondents indicated a positive likelihood of such a technology being implemented.

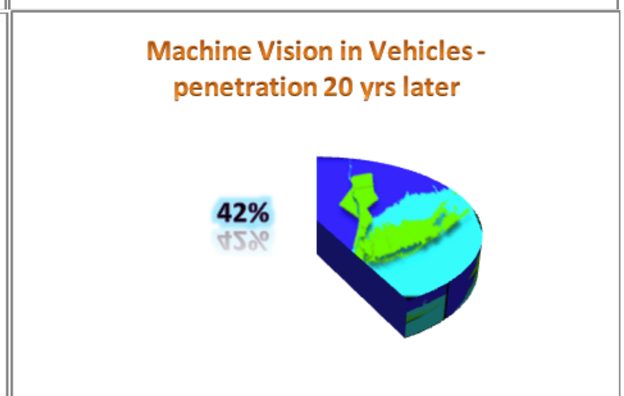
Overall general comments from experts:
"I suspect that safety and security technologies will continue to expand as regulatory agencies and OEM identify high payoff technologies that will become standard in new vehicles - perhaps beginning with commercial vehicles. V2V and V2I communications may become standard as well since they can be passive technologies and serve as a mesh network for communicating in sparsely

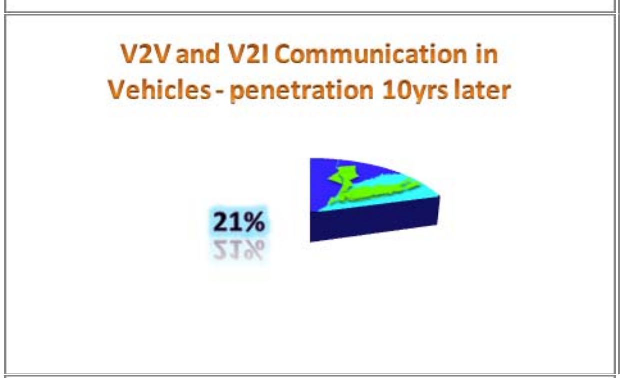
populated areas and in "urban canyons" where line-of-sight communications may be difficult. Biometrics may become popular for convenience and security reasons. Automated vehicles and machine vision will be possible but may be either limited to specific applications e.g., major freeways or specific technologies e.g., detecting obstacles and warning drivers - but may not be widely deployed."

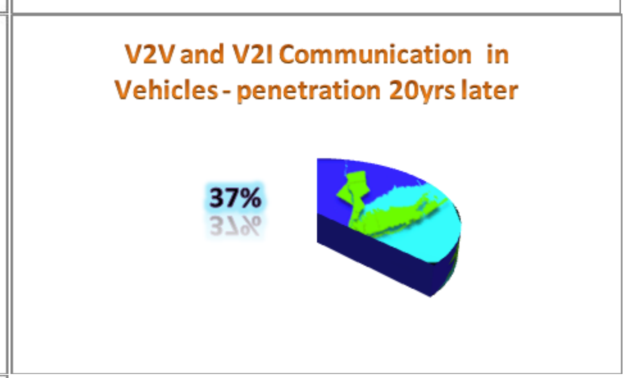


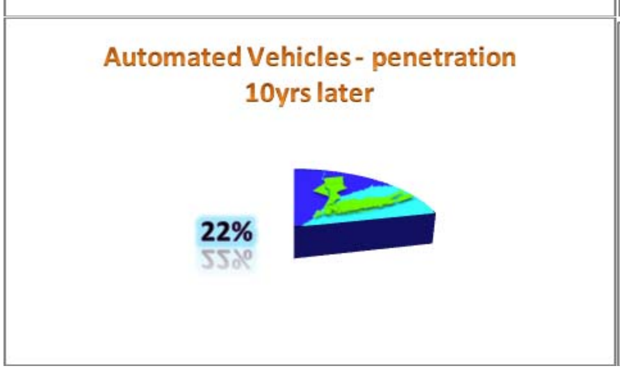


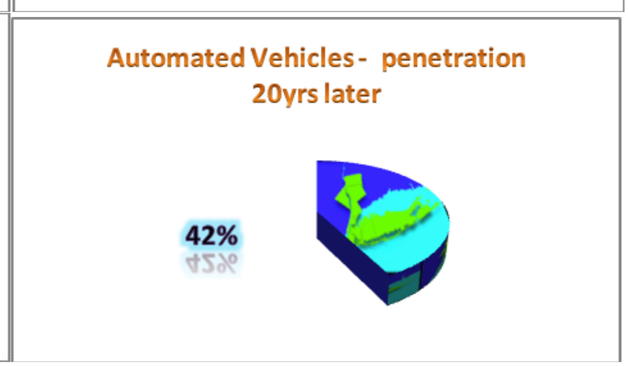












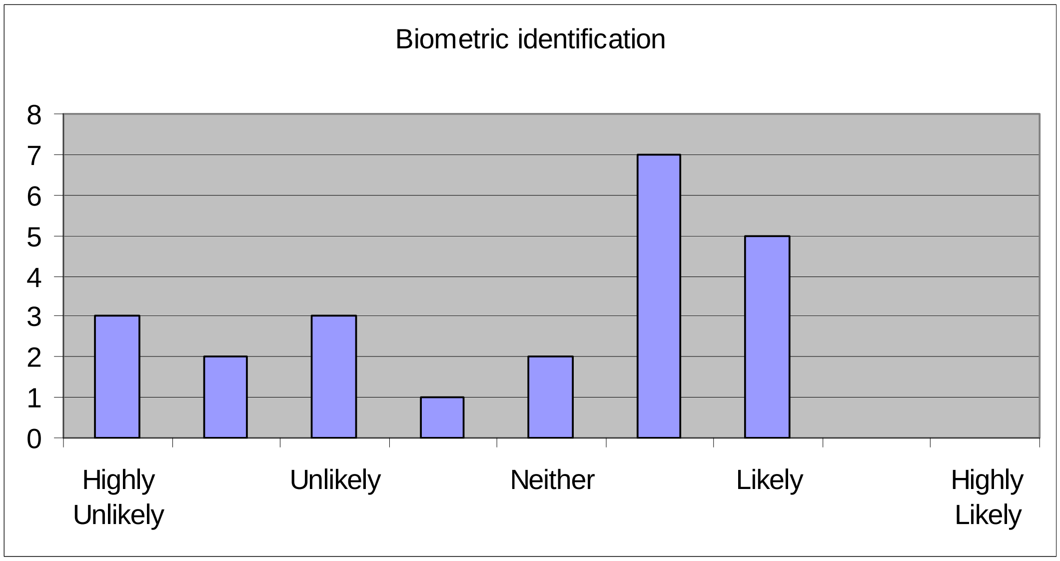


Fig 7. Likelihood of Biometric Technologies for fare payment (Security measure)

Energy and Environment Technologies

The energy and environment technology weights are presented in Figure 8 and Table 4. The question posed to the experts was:

"A key determinant of future energy sources is the set of policies adopted by governments and corporations involved in energy production. In terms of these policy decisions over the next 20 years which fuel types are more likely to be developed and promoted?"

As expected, electric and hybrid fuel vehicles are collectively (COV = 0.27) ranked the highest (weight = 0.44). Unlike the previous two categories, electric and hybrid vehicles appear to be significantly more important than the next important fuel technology: Natural Gas and Propane (0.18). Surprisingly, Biodiesel and Ethanol has a lower weight than Natural Gas and Propane – perhaps indicative of growing concerns regarding food security. Hydrogen fuel (ranked 4th) has a high coefficient of variation (COV = 1.15) – this is perhaps because of the limited success of the so far. At the same time, the immense promise of hydrogen as a transportation fuel must have triggered few of the respondents to rank it highly.

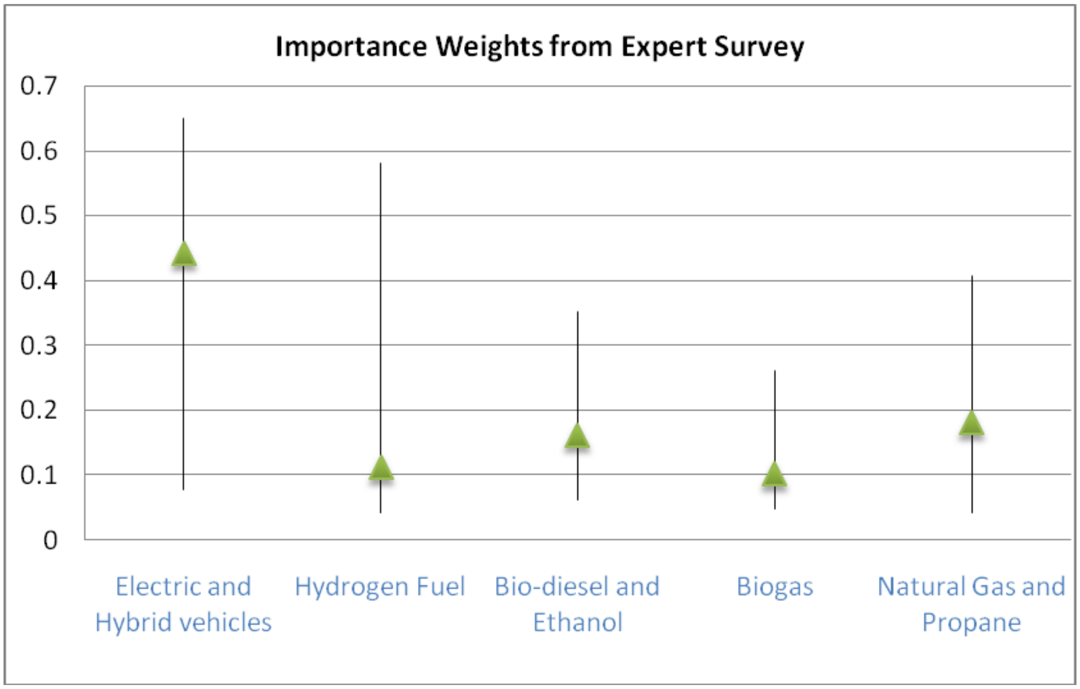


Fig 8. Weights of Energy and Environment Technologies

Table 4. Weights of Energy and Environment Technologies

	Min	Max	Average	Std Dev	C.O.V
Electric and Hybrid vehicles	0.0771	0.6511	0.4429	0.12	0.27
Hydrogen Fuel	0.0417	0.5810	0.1116	0.13	1.15
Bio-diesel and Ethanol	0.0616	0.3533	0.1623	0.09	0.58
Biogas	0.0475	0.2606	0.1025	0.05	0.50
Natural Gas and Propane	0.0424	0.4071	0.1807	0.12	0.65

Overall general comments from experts:
"A variety of fuels would give us resilience. Different fuels will likely be promoted for Different vehicles and applications - auto versus bus and train for example."

"I see electric and hybrid-electric vehicles as potentially more popular assuming appropriate storage technologies batteries and related infrastructure can be developed. The advantage of electric-hybrid vehicles is that the fuel used to generate the electric power can be changed in response to markets and other constraints without changing the vehicle or the support infrastructure. As long as electrical power is delivered to the user, the vehicle can operate, regardless of the energy source used to generate the power. The trade-offs, of course deal with the generation, transmission, and distribution of electrical power versus the production and distribution of alternative fuels and associated infrastructure. Bio-diesel and ethanol has already been integrated into the infrastructure and many vehicles are dual fuel capable so we will likely see increased use of these fuels unless we see this infringing on production of food crops to the point that regulatory intervention results."

Chapter 7: Workshop Findings and Results

As part of the final task in the project, NYMTC and Rensselaer Polytechnic Institute organized a half-day workshop on September 25th 2008 to discuss preliminary findings from the project and obtain input from various stakeholders. Invited expert speakers from industry and academia presented on telecommuting technologies, congestion reduction technologies, safety technologies, and energy technologies. The workshop also included four break-out sessions in each of the above categories where participants provided critical input on the project. Over 60 participants attended the workshop. Here we summarize the main conclusions from the break-out sessions. The individual participant response forms are attached in Appendix B. The bios of the expert speakers are attached in Appendix C.

Break-out Sessions

Congestion Reduction and Management

This session was moderated by Dr. Yuko Nakanishi, Founder and Principal of NAKANISHI RESEARCH AND CONSULTING LLC. The participants reviewed each of the shortlisted technologies and provided feedback. Here we summarize the major comments.

GPS and PTA

- Should be provided in-vehicle or on cell-phones/PDA's
- They should include real time traffic as well as transit information
- Besides congestion reduction, there could be possible safety benefits
- Private sector participation could result in less cost for public sector
- Clearly is a feasible technology even in the near future
- On the downside, re-routing cars through residential neighborhood or other inappropriate locales must be avoided
- Congestion could simply be diverted from one point to another
- User costs must be determined and equity ensured – microscopic simulation may be employed to model cost
- Driver education and training is necessary – could be accomplished using virtual worlds where participants are trained on various advisories and traffic measures through simulations
- A regional cooperative may be set-up to drive the market for such services

Smartcards and RFID

- In addition to obvious benefits from better tolling and fare collection, they can be used to measure ridership, adopt service to demand, induces usage that diverts SOV demand, and smoothes overall traffic
- RFID can be used to implement HOT lanes

Personal Rapid Transit

- Can be modeled to carry upto six passengers – need to consider trade-offs between small cars and efficiency
- Has the ability to reduce VMT
- Can be viewed as similar to carpooling, where different individuals going to a common destination could share a car

Adaptive Ramp Metering

- Ramp metering has to adjust to the highway demand
- It also has to be integrated with active traffic management
- It may impact congestion – needs to be examined more closely

Collaborative technologies

- Most participants admitted that telecommuting enabled by collaborative technologies only has an upside in terms of reducing congestion; no downsides

In addition to the above shortlisted technologies, the participants identified other plausible technologies including active traffic management techniques such as speed control, warning signs, use of shoulder lanes etc. On the downside, there could be significant costs of installation. On a related note, the use of technologies for traffic enforcement was also mentioned. Other technologies that were discussed include bicycle-oriented transportation, bus rapid transit, and managed lanes.

Safety and Security

Mr. Richard Wallace, Senior Project Manager with the Center for Automotive Research (CAR) was the moderator for the break-out session on Safety and Security. The primary issues raised by participants in this session were:

- The need to map the safety and security technologies to multi-modal transportation systems
- Need to study security concerns under terrorist attacks – for example trucks to construction sites
- Also, automated controls for safety must have built in redundancy back-up in case of electronic system failure
- In terms of financing the safety technologies, it was mentioned that public relations angle to revenue collection need to be explored
- Another participant raised the issue of shared cars – such as Zipcar or borrowing of vehicle from another person – what would happen to the safety features in such a case since the driver is not likely to be familiar with the safety system in the car
- Artificial Intelligence techniques may be built into the security systems
- Another participant raised a related issue to safety: emergency vehicle management and priority

Overall, the participants considered the shortlisted technologies to hold immense promise and were optimistic about the potential to improve safety using these technologies.

Energy and Environment

This break-out session was moderated by Dr. John Sullivan, Research Scientist and Head for Sustainable Transportation Systems at University of Michigan Transportation Research Institute. Four major topics were raised in this break-out session:

- When it comes to reducing environmental impact, we ought to be looking for ways to achieve system-wide multi-modal optimization in terms of reducing emissions and costs for moving both people and goods.
- On a related note to multi-modal issues, a participant raised the importance of considering ferries and other water-based modes.
- A participant raised the important issue of infrastructure of recharging plug-in vehicles. It was felt that municipality, utility providers, and consumers will have to share the cost; another participant raised the possibility of utilizing parking lots such as those belonging to Zipcar.
- Plug-in hybrids for heavy vehicles was also discussed. It was felt that given the significant stop and go pattern in city traffic for dump trucks, delivery trucks, and buses, PHEV options can be immensely beneficial.

Telecommuting

The telecommuting break-out session was chaired by Mr. Chuck Wilsker, President and CEO of the Telework Coalition (TelCoa), a not for profit association headquartered in Washington, DC. This session raised several important issues including those related policy, management, and legal issues related to telecommuting.

- The importance of managerial concerns such as project management and accountability in telecommuting implementation was discussed. There is a need for mentality of not-trusting to change.
- Telecommuting provides a certain continuity of operations that cannot be realized in traditional offices which need to be closed on certain days and hours. Clearly there are significant cost benefits to the organization to have continuous operations.
- Telecommuting provides different benefits for different sectors – for private sectors there is a clear return on investment in terms of increased productivity and lower real-estate costs, for public sector there is a possibility to retain employees that need to work from home, hiring disabled individuals, and saving gas.
- The advances in communication technology have enabled telecommuting options. At IRS traditional land lines are being replaced with Blackberry phones. This allows for employees to report to work from anywhere any time.
- A participant said there is a need to measure productivity in both office and home before implementing teleworking.
- A related yet important issue is taxation for teleworkers – especially out-of-state teleworkers. It needs to be urgently addressed.

- A telecommute tax fairness act supported by congressman and senators is gaining traction in Washington D.C.
- On the overall, it was felt that the laws have not kept up with teleworking.

General Comments

Several participants often brought up the important topic of technology and its relationship to policy. One must remember that technology is not a panacea; it is only an enabler. Technology has to be integrated with sound policy. The right policy and incentives will allow the rise of particular technologies and determine its eventual success. At the same time certain technologies will enable the implementation of particular policies. It is important to have appropriate modeling and evaluation techniques to understand the complex inter-linkage between policy and technology. An overall structure of such interdependency is shown in the figure below.

Chapter 8: Summary

The goal of this project is to conduct a comprehensive survey and assessment of the emerging and promising technology that are likely to impact the transportation performance in the NYMTC region. This final report could serve as a 'one-stop shop' for information on emerging technology that may impact transportation in the New York Metropolitan region in the next 15-20 years. However, these are not recommendations but plausible technologies that will likely impact the New York metropolitan region.

A comprehensive literature review was conducted and covered three broad NYMTC goals of (i) congestion reduction and management, (ii) safety and security systems, and (iii) air quality improvement and environmental impact mitigation. Both national as well as international studies have been included. The studies have been classified into sub-categories under each of the above broad categories.

The most important technologies from the literature review are summarized under each category below.

Congestion reduction and management:

1. Current major trends include congestion pricing and the use of ATIS.
2. However significant scope for improvement exists in these technologies including distance-based pricing and active travel guidance systems using vehicle-to-vehicle communication and VII systems.
3. Other congestion reduction and management strategies include telecommuting, ramp metering, and improved transit service (bus signal priority, information, etc.).

Safety and Security:

1. Among safety systems crash avoidance systems hold immense promise. These systems will utilize sensors to detect vehicle, environment, and driver characteristics and determine crash possibilities using intelligent algorithms.
2. Pedestrian safety systems that alert driver of presence of pedestrians in their path or pedestrian detection systems at pedestrian crossing.
3. Biometric identification

Air Quality Improvement:

1. Use of bio-fuels and hybrid vehicles are recommended in the short-term;
2. In the longer term hydrogen fuel vehicles may offer better benefits. However currently the operational costs and lack of institutional support hinder the use of hydrogen fuel on a large scale.

The above systems for achieving different goals are enabled because of developments in diverse technologies. These technologies include wireless communication systems, advanced sensors, electronic payment, and biometric identification among others.

A comprehensive, initial list of emerging technologies to improve transportation systems was then developed. The project team undertook a visioning process. The visioning process was done in two steps. First, it was recognized that technology advancements in several fields are likely to impact transportation and travel. Therefore in the first step, these broad technological domains and their general trends were identified. The broad technology domains studied include:

a) Nanotechnology
b) Energy and Fuel technology
c) Communication technology
d) Computing and Internet technology
e) Transportation, Vehicular and Automotive technology
f) Sensors
g) Freight technology

The second step of the visioning process involved identifying the potential impacts of the technological developments on transportation in general and transportation technology in particular. Further, fact-sheets of each technology were prepared which include details on features, timeline/costs, transportation applications, and challenges.

Subsequently the emerging technologies were screened and a total of forty-six technologies were identified. In order to obtain a better understanding of the forty-six technologies listed above, a survey of existing studies was carried out. Information was gleaned from these existing studies and a database was constructed to store the information. The decision making process for screening the technologies was done in two stages. In the first stage the most appropriate goals or policies that are relevant to NYMTC was screened, and in the second stage the economic and technical feasibility of technologies useful for achieving the goals was assessed. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members. An important result from the survey is the ranking of the different policy sub-categories. Energy consumption is the highest ranked policy sub-category followed by transit-system improvements. Highway system improvements, transportation demand management strategies (including telecommuting), ITS, and highway safety are ranked next. These rankings will be used as weights to rank each of the specific technologies from the comprehensive list to obtain a shortlist for task 4.

The feasibility assessment questionnaire was completed by 7 respondents including two outside experts. Feasibility assessment included both technical and economic feasibility. We present the average rating for the technical and economic feasibility and also provide a joint weighted measure. The technologies are ranked based on this weighted measure. The top 5 technologies in terms of the joint feasibility measure are GPS, HD video conferencing, machine vision, ultra-low sulfur diesel, and biodiesel fuel.

Based on the input above, a final shortlist of technologies was identified. A weighted sum method was used to obtain the rankings of the technologies. Since the focus on technologies have always been toward meeting the three broad goals of congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals were prepared.

Based on the ranking of the technologies and the project team's reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

The shortlisted technologies include:

Congestion Reduction and Management

Geographic Positioning Systems and Personal Travel Assistants
Adaptive Ramp Metering
Smart Cards and RFID
Personalized Rapid Transit
Collaborative Technologies

Safety and Security

Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication
Machine Vision
MEMS and Nanosensors
Automated Vehicles
Biometric Identification

Energy and Environment

Natural Gas and Propane
Biogas
Bio-diesel and Ethanol
Electric-driven and Hybrid vehicles
Hydrogen Fuel

In Task 5, technologies in each of the broad categories – congestion reduction and management (CRM), safety and security (S&S), energy and environment (E&E) – were ranked using the weights obtained from pair wise comparison process. Input is obtained from several experts to assist in the assessment process. Assessment is based on two criteria including the contribution of each technology towards the listed goals and the likely acceptance/growth of the technology in the NY metropolitan region.

The criterion for comparison of the CRM technologies was "impact on congestion reduction". On the overall, GPS and Personal Travel Assistant was ranked the most effective (average weight of 0.27), followed by Smartcards and RFID (0.24), Collaborative technologies (0.22), adaptive ramp metering (0.21), and personal rapid transit (0.07). However, no single technology has emerged as a clear winner; this is according to the expectation that several varied technologies all have an interdependent role to play towards reducing congestion. In terms of the likelihood of implementation of the different technologies, personal rapid transit was widely perceived as an "unlikely" technology even in the next 20 years. On the other hand, the experts collectively regard webinars and video conferencing as the "likely to highly likely" method for business meeting in 20 years. In terms of the degree of penetration, GPS and personal travel assistants are likely to be used by 56.6% and 80.6% percent of individuals after 10 and 20 years respectively. Smartcards and RFID as well as Collaborative technologies are also likely to be widely used with over 70% estimated on average after 20 years. Given their potential to impact congestion, such high penetration could significantly help mitigate congestion over the next two decades. A related question on the percentage of work trips that are likely to be replaced by collaborative technologies, the average response was over 30% after 20 years.

The comparison in the S&S category was restricted to only the three technologies listed since automated vehicles were considered to be a superset of these three technologies. Also, biometric identification was treated as security technology and was not included in the comparison below. The overall response rating for the question "which technology is likely to improve safety to a greater extent?" yielded the greatest average weight for Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication technology, followed by MEMS and Nanosensors, followed by Machine Vision. In terms of the degree of penetration, MEMS devices had the greatest degree of penetration (34.3% after 10 years and 61.7% after 20 years). Over half-the-vehicles are likely to be equipped with V2V and V2I capabilities 20 years hence. Further, over a third of the vehicles 20 years hence are likely to be automated vehicles. Such high degree of penetration can have significant impacts towards improving road safety. In terms of the likelihood of implementing biometric identification for fare payment as a security measure, the overall average response remained neutral. However, 55% of respondents indicated a positive likelihood of such a technology being implemented.

The question posed to the experts evaluating the E&E category of technologies was:

"A key determinant of future energy sources is the set of policies adopted by governments and corporations involved in energy production. In terms of these policy decisions over the next 20 years which fuel types are more likely to be developed and promoted?"

As expected, electric and hybrid fuel vehicles were collectively ranked the highest (weight = 0.44). Unlike the previous two categories, electric and hybrid vehicles appear to be significantly more important than the next important fuel technology: Natural Gas and Propane (0.18). Surprisingly, Biodiesel and Ethanol has a lower weight than Natural Gas and Propane – perhaps indicative of growing concerns regarding food security. Hydrogen fuel is ranked 4th and had a high coefficient of variation – this is perhaps because of the limited success of the so far. At the same time, the immense promise of hydrogen as a transportation fuel must have triggered few of the respondents to rank it highly.

Appendix A: Technology Fact-Sheets

Nanotechnology

Nano-fuel

Technology	Nano-sized batteries (1) Nano Fuelsaver (2,3,6) Fuel-cell Catalyst (4,5,7)
Features	Nano-sized battery fuel cell measuring just 200 nanometers across that potentially can be integrated on-chip to supply power from a hydrogen reservoir for decades. Nano Fuelsaver uses revolutionary nano-technology to treat petrol or diesel entering the engine in order to enhance the combustion process, saving 10-20% fuel/diesel in cars, trucks, boats, motorbikes. Nano fuel-cell catalyst could lead to cheaper catalysts for making and using alternative fuels.
Timeline / Costs	"It will be 5 to 10 years before the technology (fuel cell catalyst) is ready to use in practical applications, according to the researchers." (5) Nano fuel-saver – already in commercial testing stage
Transportation Applications	Nano-batteries can be used to power remote sensors for its entire life time (CRM, SS) Fuel-cell catalysts could improve the efficiency of fuel-cells and bring down the costs making it inexpensive for use in vehicles (AQEM)
Challenges	Nano-sized batteries: commercialization is not feasible yet (1)

References:

1. http://www.fuelcellsworks.com/Supppage4589.html
2. http://www.nanovip.com/node/2359
3. http://www.newscientist.com/article/dn4271.html
4. http://www.technologyreview.com/Nanotech/18669/
5. http://www.trnmag.com/Stories/2005/050405/Nano_pyramids_boost_fuel_cells_Brief_050405.html
6. http://www.nanotechnology.net.nz/
7. http://www.iom3.org/materialsworld/feature-pdfs/jun05/Model%20behaviour.pdf

Nanosensors

Technology	To track bio-terror agents (1, 2) To track stress in materials (6) To detect polluting agents.
Features	Tiny detectors that could instantly screen for hundreds of toxins or pathogens Gaining increasing attention – special issue call for papers dedicated to the topic in IEEE journal of Sensors (3) The Golden Gate Bridge now has an experimental sensor network of approximately 200 small Motes, each with an accelerometer that measures movement such as traffic, wind, or seismic loads (5).
Timeline / Costs	"I work on a lot of things that I'll never see in my lifetime, this will happen in my lifetime." (1)
Transportation Applications	Nanosensors could be used in transportation to monitor pavement conditions, bridge conditions, pollution deduction, bio-terror agent detection, air quality monitor etc. The feasibility of "Cyberliths", or Smart Aggregates, as wireless sensors embedded in concrete or soil is being studied. (4) Researchers at Johns Hopkins University's Applied Physics Laboratory have developed a robust wireless embedded sensor, suitable for long term field monitoring of corrosion in rebar, particularly in bridge decks.
Challenges	Nanowire sensor devices have proven difficult to mass-produce, economic costs are high, regulatory hurdles, legal challenges (2)

References:

1. http://www.technologyreview.com/Nanotech/18127/
2. http://www.rpitechnology.com/files/article_nanosensors.pdf
3. http://ewh.ieee.org/tc/sensors/SJ/CallForPapers/NanosensorTechnologyCFP.pdf
4. http://concreteproducts.com/mag/concrete_fhwa_research_zeroes/
5. http://www.cs.berkeley.edu/~binetude/ggb/
6. http://www.ceam.ucsd.edu/papers/sensors.html

Nano-material

Technology	Carbon-based fibers Nanocoating of metallic surfaces Nanoparticle-reinforced materials Nanomaterials in pavements (2) Automatic healing materials (2)
Features	Carbon-based fibers are 100x stronger than steel and yet lighter Nanocoating of metallic surfaces help achieve super-hardening, low friction, and enhanced corrosion protection nanoparticle-reinforced materials that replace metallic components in cars Nanomaterials in pavements (2) Automatic healing of materials (2)
Timeline / Costs	The researchers surveyed predicted that many advances would arrive within five years (2011). (5)
Transportation Applications	Autonomic (spontaneous) healing research in structural polymers, could lead the way to guardrails that heal themselves, or concrete or asphalt that heal their own cracking. Coatings which mimic the surface of the lotus leaf — to which nothing adheres — likely will lead to signage and work zone barricades which shed dirt and grime and never need to be washed, enhancing safety and lowering labor costs. They can also be used on windshields to keep them clear of dirt and water. (4) Nanoparticle-reinforced materials can replace metallic components in cars Two nano-sized particles that stand out in their application to construction materials are titanium dioxide (TiO_2) and carbon nanotubes (CNT's). The former is being used for its ability to break down dirt or pollution and then allow it to be washed off by rain water on everything from concrete to glass and the latter is being used to strengthen and monitor concrete. (5)
Challenges	Cost and the relatively small number of practical applications, for now, hold back much of the prospects for nanotechnology. (5)

References:

1. http://tti.tamu.edu/documents/0-5239-1.pdf
2. T. Kuennen. "Small Science Will Bring Big Changes To Road." Better Roads, 2004, http://www.betterroads.com/
3. http://www.smt.sandvik.com/nanoflex
4. http://ieeexplore.ieee.org/iel5/7182/19339/00893798.pdf
5. http://www.innovationsgesellschaft.ch/images/fremde_publikationen/nov06_nanoforum.pdf

Energy

Hydrogen Fuel

Technology

Hydrogen is the simplest and most abundant element in the universe. At Earth surface temperatures and pressures, it is a colorless, odorless gas (H2), but very little hydrogen gas is present in Earth's atmosphere. Instead, it is usually bonded with other elements. For example, Hydrogen is locked up in enormous quantities in water (H2O), hydrocarbons (such as methane, CH4), and other organic matter. (1)

Features/benefits

1. Clean-burning;
2. High potential for domestic production;
3. A fuel with high efficiency. The energy in 2.2 lb (1 kg) of hydrogen gas is about the same as the energy in 1 gallon of gasoline. (1, 5)

Timeline / Costs

Hydrogen is currently very expensive, not because it is rare (it's the most common element in the universe!) but because it's difficult to generate, handle, and store. (7)
You can get average costs for hydrogen fuels through the Alternative Fuel Price Report. (8)

Transportation Applications

- Fuel cell vehicles, powered by Hydrogen, have the potential to revolutionize our transportation system. They are more efficient than conventional internal combustion engine vehicles and produce no harmful tailpipe exhaust—their only emission is water. Fuel.(2)
- BMW Hydrogen 7 powered by liquid hydrogen and gasoline bi-fuel vehicle is an industrial application case in USA. (3)
- Hydrogen developed in China. (4)
- Hydrogen is currently available only as an industrial or scientific chemical product, not as a bulk fuel. (7)

Challenges

1. Storage Technologies. Hydrogen has a low volumetric energy density. Therefore, to store the same amount of energy, hydrogen needs larger storage tank than gasoline. (1,5,6)
2. The primary challenge for hydrogen production is reducing the cost of production technologies to make the resulting hydrogen cost competitive with conventional transportation fuels. (1, 5)

Reference

1. http://www1.eere.energy.gov/hydrogenandfuelcells/production/basics.html
2. http://www.eere.energy.gov/afdc/vehicles/fuel_cell.html
3. http://www.hydrogencarsnow.com/blog/hydrogencars.html
4. http://www.alternative-energy-news.info/hydrogen-fuel-cell-bikes/
5. http://ec.europa.eu/research/energy/pdf/hlg_vision_report_en.pdf
6. http://www.sciencedaily.com/releases/2007/10/071003100601.htm
7. http://www.altfuels.org/backgrnd/altftype/hydrogen.html
8. http://www.eere.energy.gov/afdc/price_report.html

Biodiesel Fuel

Technology	**Biodiesel** is a liquid fuel made up of fatty acid alkyl esters, fatty acid methyl esters (FAME), or long-chain mono alkyl esters. It is produced from a variety of natural crops including rapeseed, soybean, mustard, flax, sunflower, canola, palm oil, hemp, jatropha and waste vegetable oils. (1, 2)
Features/benefits	This fuel source is 1. Clean-burning; 2. Domestically produced, Renewable substitute for petroleum diesel; 3. Nontoxic and biodegradable; 4. Capable of reducing engine wear. (1, 2)
Timeline / Costs	The cost of Biodiesel is competitive with diesel. (7) You can get average costs for Biodiesel through the Alternative Fuel Price Report (5).
Transportation Applications	• At the production level, biodiesel fuel is a clean and affordable fuel for trucks, buses, farm equipment and other forms of heavy transportation. (4) • Biodiesel can be used in conventional diesel engines, directly substituting for or extending supplies of traditional petroleum diesel. (3) Modern diesel engine technology has taken the advantages of biofuel usage. Biodiesel is not currently widely available, even though there production-scale plants, such as NOPEC, do exist. (6)
Challenges	None

Reference:

1. http://www.eere.energy.gov/afdc/fuels/biodiesel.html
2. http://www.alternative-energy-news.info/technology/biofuels/biodiesel-fuel/
3. http://www.eere.energy.gov/afdc/vehicles/diesel.html
4. http://www.alternative-energy-news.info/advantages-biodiesel-fuel-transportation/
5. http://www.eere.energy.gov/afdc/price_report.html
6. http://www.altfuels.org/backgrnd/altftype/b20.html
7. http://www.biodiesel.com/theFuel.htm

Ethanol Fuel

Technology	Ethanol (CH3CH2OH) is a renewable transportation fuel primarily made from starch crops, such as corn. It is also made from sugar beets and cane or cellulosic materials, such as fast-growing trees and grasses. Nearly one-third of U.S. gasoline contains ethanol in a low-level blend to reduce air pollution. (1, 2)
Features/ benefits	1. Produced from domestic crops, increasing Energy Security. 2. Fueling the Economy. Ethanol production is a new industry that is creating jobs in rural areas where employment opportunities are strongly needed. 3. Reducing Greenhouse Gas
Timeline / Costs	E85 (85% ethanol, 15% gasoline) typically costs about the same or slightly less than gasoline on a gallon-for-gallon basis. (1)
Transportation Applications	E85 (85% ethanol, 15% gasoline) is considered an alternative fuel. It is used to fuel E85-capable flexible fuel vehicles (FFVs), which are available in a variety of models from U.S. and foreign automakers. (1) For more details about flexible fuel vehicles refer to (5).
Challenges	Requires more energy to produce than what it provides Can have negative social impacts since it increases the cost of food in places such as Mexico by re-directing corn produce for fuel production

Reference:

1. http://www.eere.energy.gov/afdc/fuels/ethanol_what_is.html
2. http://freeenergynews.com/Directory/Ethanol
3. http://www.iastate.edu/~nscentral/news/2006/may/mold.shtml
4. http://www.newswise.com/articles/view/511547/?sc=dwhp
5. http://www.eere.energy.gov/afdc/vehicles/flexible_fuel.html

Methanol Fuel

Technology	Methanol (CH_3OH), known as wood alcohol, is an alternative liquid engine fuel. Usually it is produced by natural gas, coal, or, woody biomass. (1)
Features/benefits	1. Methanol is domestically produced, sometimes from renewable resources. 2. Protecting Public Health and the Environment. When compared to reformulated gasoline, M85 emitted fewer (and less reactive) ozone forming pollutants, hydrocarbons, and potency-weighted toxics (including acetaldehyde, benzene, 1,3-butadiene.) However, it also emitted more NOx and formaldehyde.
Timeline / Costs	M85 is the least distinguishable from gasoline in how you buy and use. In California, M85 costs about the same per mile as mid-grade gasoline.(3)
Transportation Applications	• Methanol has been seen as a possible large volume motor fuel substitute at various times during gasoline shortages. (2) • Methanol can be used for mostly Heavy-duty buses.(1) • The flexible-fuel vehicles currently being manufactured by General Motors, Ford and Chrysler can run on any combination of ethanol, methanol and/or gasoline. (2)
Challenges	• Methanol is extremely toxic. Exposure can occur through inhalation of vapors or through skin contact. Special lubricants must be used as directed by the supplier and M-85-compatible replacement parts must be used. Therefore, Methanol remains a qualified alternative fuel as defined by EPAct, but it is not commonly used or easily available.(1) • Methanol's energy density is about half that of gasoline, reducing the range a vehicle can travel on an equivalent tank of fuel. (2) • The availability of 85 percent methanol is limited. (3)

Reference:
1. http://www.eere.energy.gov/afdc/fuels/ethanol_what_is.html
2. http://www.ethanol-gec.org/clean/cf05.htm
3. http://www.altfuels.org/backgrnd/altftype/m85.html

Natural gas

Technology	**Natural gas** is a mixture of hydrocarbons, predominantly methane (CH_4). As delivered through the pipeline system, it also contains hydrocarbons such as ethane and propane and other gases such as nitrogen, helium, carbon dioxide, hydrogen sulfide, and water vapor. (4,7) "Most natural gas is extracted from gas and oil wells. Much smaller amounts are derived from supplemental sources such as synthetic gas, landfill gas and other biogas resources, and coal-derived gas." (1,7)
Features/benefits	1. A domestically produced alternative fuel. (1) 2. A high octane rating and excellent properties for spark-ignited internal combustion engines. (1) It provides fueling convenience. (5) 3. It is safe, non-toxic, non-corrosive, and non-carcinogenic. It presents no threat to soil, surface water, or groundwater. (1,5) 4. Natural gas vehicles are cleaner than most fuels. (5)
Timeline / Costs	Compressed natural gas is the least expensive alternative fuel (except electricity) when you compare equal amounts of fuel energy. (2) You can get average costs for natural gas through the Alternative Fuel Price Report. (3)
Transportation Applications	Approximately 22 percent of the energy consumption of the U.S. comes from natural gas.(7) A direct natural gas application on transportation is the dedicated natural gas vehicles (NGVs). (6)
Challenges	Natural gas vehicles cost more (7) Fuel availability is an issue outside of California (7)

Reference:
1. http://www.eere.energy.gov/afdc/fuels/natural_gas.html
2. http://www.altfuels.org/backgrnd/altftype/cng.html
3. http://www.eere.energy.gov/afdc/price_report.html
4. http://www.socalgas.com/business/ngv/fleets.shtml
5. http://www.eere.energy.gov/afdc/vehicles/natural_gas_what_is.html
6. http://www.eia.doe.gov/kids/energyfacts/sources/non-renewable/naturalgas.html
7. http://www.nrel.gov/docs/fy07osti/41884.pdf

Propane

Technology	"**Propane**, also known as liquefied petroleum gas (LPG or LP-gas), or autogas in Europe, is a three-carbon alkane gas (C_3H_8). Stored under pressure inside a tank, propane turns into a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used for combustion. An odorant, ethyl mercaptan, is added for leak detection." Propane is produced as a by-product of natural gas processing and crude oil refining. (1)
Features/ benefits	1. Enable excellent properties for spark-ignited internal combustion engines. (1) 2. An exceptionally safe fuel. Propane has the lowest flammability range of all alternative fuels. (1) 3. Non-toxic and presents no threat to soil, surface water, or groundwater. (1) 4. Compared with vehicles fueled by conventional diesel and gasoline, propane vehicles can produce significantly lower amounts of some harmful emissions and the greenhouse gas carbon dioxide. (3)
Timeline / Costs	Propane prices are subject to a number of influences, such as Crude Oil and Natural Gas Prices, Supply/Demand Balance. (7) The latest Alternative Fuel Price Report show the price of propane per gallon is less than regular gasoline. (6)
Transportation Applications	Propane is distributed nationwide. It is the most commonly used alternative transportation fuel and the third most used vehicle fuel, behind gasoline and diesel. Dedicated propane vehicles (2) have been used in delivery vehicles, school buses, utility vehicles, shuttle buses, and beverage vehicles. (4, 5)
Challenges	No information at this time.

Reference:

1. http://www.eere.energy.gov/afdc/fuels/propane_what_is.html
2. http://www.eere.energy.gov/afdc/vehicles/propane.html
3. http://www.propanecouncil.org/newsroom/press_releaseDetail.cfv?id=434
4. http://www.propaneshuttlebus.com/pressroom.htm
5. http://www.propaneshuttlebus.com/
6. http://www.eere.energy.gov/afdc/price_report.html
7. http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/propane_prices_brochure/propbro.html

Biogas Fuels

Technology	Biogas is the gaseous product of the anaerobic digestion (decomposition without oxygen) of organic matter. It is a mixture of methane, carbon dioxide, and traces of gases such as hydrogen, carbon monoxide, and nitrogen. (1, 4) For an overview of biogas and its uses, see the International Energy Agency's Biogas Production and Utilization. (2)
Features/benefits	1. Domestic, renewable resource. 2. Directly reduces greenhouse gas emissions by preventing methane release into the atmosphere. 3. Anaerobic digestion systems (non-landfill) treat waste naturally, require less land area than aerobic composting, reduce the amount of material that must be land filled, reduce waste odors, and produce sanitized compost and nutrient-rich liquid fertilizer.
Timeline / Costs	Emerging Fuels
Transportation Applications	Biogas-fueled vehicles: • A 2007 report estimated that 12,000 vehicles are being fueled with upgraded biogas worldwide, with 70,000 biogas-fueled vehicles predicted by 2010. Europe has most of these vehicles. United States only has a smaller scale of biogas vehicle.(2) • A biogas-fueled passenger train carriage, the world's first to run solely on biogas, was presented in Sweden, 2005. (3)
Challenges	Research and development are focusing on reducing the costs of biogas production and purification, producing higher-quality natural gas from biogas, and evaluating the performance of biogas-fueled vehicles. (1)

Reference:

1. http://www.eere.energy.gov/afdc/fuels/emerging_biogas_what_is.html
2. http://www.iea-biogas.net/Dokumente/Brochure%20final.pdf
3. http://findarticles.com/p/articles/mi_m0FZX/is_11_71/ai_n15892440
4. http://www.humboldt.edu/~serc/biogas.html

Biobutanol Fuels

Technology	Butanol is a 4-carbon alcohol. Biobutanol is butanol produced from biomass feedstock. Currently, butanol's primary use is as an industrial solvent in products such as lacquers and enamels." (1, 2)
Features/ benefits	1. It can be produced domestically from a variety of homegrown feedstock. 2. Greenhouse gas emissions are reduced. 3. It is easily blended with gasoline which is used in today's gasoline-powered vehicles. 4. Its energy density is only 10 to 20% lower than gasoline's. 5. It is compatible with the current gasoline distribution infrastructure so it does not need new facility for delivery and storage. 6. It can be produced using existing ethanol production facilities with relatively minor modifications.
Timeline / Costs	Emerging Fuels. Biobutanol research and development by government and industry groups is ongoing. (1)
Transportation Applications	Biobutanol proponents claim that today's vehicles can be fueled with high concentrations of biobutanol—up to 100%—with minor or no vehicle modifications, but tests for this claim are insufficient. (1)
Challenges	No infrastructure for fueling vehicles with biobutanol currently exists. However, biobutanol would be able to be distributed through the existing gasoline infrastructure, including pipeline transport since biobutanol does not cause corrosion or water contamination issues. (1)

Reference:

1. http://www.eere.energy.gov/afdc/fuels/emerging_biobutanol_what_is.html.
2. http://www.lightparty.com/Energy/Butanol.html

Hydrogenation-Derived Renewable Diesel

Technology	Hydrogenation-derived renewable diesel (HDRD), also called second-generation biodiesel, is the product of fats or vegetable oils—alone or blended with petroleum—that have been refined in an oil refinery.(1)
Features/Benefits	1. It can be produced domestically from a variety of homegrown feedstock. (1) 2. Greenhouse gas emissions are reduced. (1) 3. It should be compatible with the current diesel distribution infrastructure. (1) 4. It can be produced using existing oil refinery capacity and does not require extensive new production facilities. (1) 5. Its ultra-low sulfur content should enable use of advanced emission control devices.
Timeline / Costs	Emerging Fuels. Hydrogenation-derived renewable diesel (HDRD) is close to full commercialization. (1)
Transportation Applications	It should be able to be used directly in today's diesel-powered vehicles. Its fuel properties, especially its high octane number, suggest it will provide similar or better vehicle performance than conventional diesel. (1)

Reference:

1. http://www.eere.energy.gov/afdc/fuels/emerging_green_what_is.html.

P-Series

Technology	P-Series fuel is a blend of natural gas liquids (pentanes plus), ethanol, and the biomass-derived co-solvent methyltetrahydrofuran (MeTHF). (1)
Features/Benefits	1. Produced from domestic sources. (1) 2. More than 60% of energy contents is derived from renewable sources. (3) 3. Less greenhouse gas emissions.(1,3) 4. Reducing fossil fuel use. (3)
Timeline / Costs	Emerging Fuels. Currently, P-Series is not being produced in large quantities and is not widely used. (1, 2)
Transportation Applications	P-Series fuel can be used alone or freely mixed with gasoline in any proportion inside a flexible fuel vehicles fuel tank. (1, 2)
Challenges	No related information at this time.

Reference:

1. http://www.eere.energy.gov/afdc/fuels/emerging_pseries.html
2. http://www.iags.org/pseries.htm
3. http://books.google.com/books?id=U4TBoJB2zgsC&pg=PA680&lpg=PA680&dq=benefit+of+%22p+series%22+fuel&source=web&ots=MTSPRnPKom&sig=5kIHv9J7yDPwTGY4M57A3BGj3qc#PPA680,M1

Ultra-low sulfur diesel

Technology	Ultra-low sulfur diesel (ULSD) is diesel fuel with 15 parts per million (ppm) or lower sulfur content. (1, 3)
Features/Benefits	1. Ultra-low sulfur diesel enables use of advanced emission control technologies on light-duty and heavy-duty diesel vehicles.(1) 2. Diesel engines are 20-40% more efficient than comparable gasoline engines. (1) 3. Ultra-low sulfur diesel uses the existing fueling infrastructure, engine and vehicle technologies. (1)
Timeline / Costs	Emerging Fuels.
Transportation Applications	Ultra-low sulfur fuel (ULSD) is now nationwide available. It will be the primary highway diesel fuel produced, but EPA does not require service stations and truck stops to sell ULSD fuel. (2)
Challenges	Currently, the vast majority of ULSD is produced from petroleum. It cannot meet the demand requirement. However, biodiesel; biomass-to-liquids, coal-to-liquids, and gas-to-liquids diesel; and hydrogenation-derived renewable diesel are inherently ultra-low sulfur fuels and could help the insufficiency of ULSD in the future. Most ULSD fuels produced from non-petroleum and renewable sources are considered alternative fuels. (1, 3)

Reference:
1. http://www.eere.energy.gov/afdc/fuels/emerging_sulfur_diesel_what_is.html
2. http://www.clean-diesel.org/highway.html
3. http://www.dieselforum.org/meet-clean-diesel/what-is-clean-diesel/new-technologies/ultra-low-sulfur-diesel/

Electricity

Technology	"Electricity used to power vehicles is generally provided by the electricity grid and stored in the vehicle's batteries. Fuel cells are being explored as a way to use electricity generated on board the vehicle to power electric motors. Unlike batteries, fuel cells convert chemical energy from hydrogen into electricity." (4, 5)
Features/Benefits	1. No tailpipe emissions. But the emissions can be generated in the electricity production process. 2. Easy to recharge.
Timeline / Costs	Electricity fueling costs for electric vehicles are reasonable compared to gasoline. $0.05 per mile for vehicles with direct current (DC) electric systems and $0.03 cents per mile for vehicles with alternating current (AC) systems.
Transportation Applications	Electricity can be used to power electric and plug-in hybrid electric vehicles directly from the power grid. (3) Hybrid Electric Vehicles (HEVs) are becoming widely available for a variety of applications. (1.2)
Challenges	Several barriers are preventing widespread commercialization of plug-in hybrid electric vehicles (PHEVs), including the following: 1. Hybrid component mass, volume, cost, reliability, and safety 2. Lack of domestic sources for batteries 3. Consumer behavior and expectations 4. Robust operation in range of environmental conditions.

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Communication

DSRC

Technology

Dedicated Short Range Communications (DSRC) is a block of spectrum in the 5.850 to 5.925 GHz band allocated by US FCC to enhance the safety and productivity of the transportation system. (1)
DSRC technology will provide secure, reliable communication links between vehicles and infrastructure safety subsystems that can increase highway safety. (5)

Features

DSRC applications now in use include electronic toll collection, and electronic credentialing and monitoring of commercial vehicle operations (CVO) (6)
The promise of DRSC is to deliver a far greater data rate and range to wireless highway applications. "Compared with existing RFID toll applications, DRSC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters," says Richard Schnacke, vice president of industry relations for TransCore (7)
The DSRC system supports communication links in the following parameters (5):
Vehicle speed (up to 120 mph), Communication range (up to 1000 meters for special vehicles; nominal is 300 meters), System Latency (< 50 ms), Data rate (default is 6 Mbps; up to 27 Mbps), Single transaction size (up to 20K bytes)

Timeline / Costs

Government and vehicle manufacturers plan to make a collaborative decision on deployment of DSRC in the year 2008 that could signal the beginning of the deployment process in the auto industry and public agencies. (9)
DSRC is the technology for the 2010 decade and beyond. (5)
No cost estimates are available, but they will clearly be a lot more expensive than today's standard toll tags, let alone the new sticker tags (9)

Transportation Applications

Active safety systems communication on-board the vehicle (2)
Allows vehicle-vehicle and roadside-vehicle communications (1)
Roadside-vehicle wireless communications for Intersection Decision Support (4)
Cooperative Adaptive Cruise Control (CACC) system and its impact at highway merge junctions (3)
Traffic Flow (Speed & Volume), Lane Occupancy, Priority Signal Preemption, Toll Collection, Freight Tracking, Roadway Conditions (5)
Intersection collision avoidance, Approaching emergency vehicle warning, Vehicle safety inspection, Transit or emergency vehicle signal priority, Electronic parking payments, Commercial vehicle clearance and safety inspections, In-vehicle signing, Rollover warning, Probe data collection, Highway-rail intersection warning. (7)

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Wide area wireless communication

Technology	Wide area wireless communication includes WiMax, Mobile WiMax, Ultra Mobile Broadband (UMB) and UMTS.
Features	WiMAX provides large coverage distances of up to 50 kilometers under line of sight (LOS) conditions and typical cell radii of up to 5 miles/8 km under Non-LOS conditions. (2) Mobile WiMAX can provide tens of megabits per second of capacity. The high data throughput enables efficient data multiplexing and low data latency. Attributes essential to enable broadband data services including data, streaming video and VoIP with high quality of service (QoS). (1) Universal Mobile Telecommunications System (UMTS) is the European standard for 3G mobile communication systems which provide an enhanced range of multimedia services. UMTS supports up to 1920 kbit/s data transfer rates (5) "…known commercially as Ultra Mobile Broadband (UMB). Soon, people will be sending data through the air at speeds of up to 280 Mbps in a mobile environment." (6)
Timeline / Costs	Intel is bringing add-in cards in 2007 and embedded modules in 2008 for WiMax (3). Yankee Group Research Inc. has a somewhat conservative forecast for WiMax growth, predicting about 27 million subscribers in 2011, with about 7 million to 8 million in the U.S. (4)
Transportation Applications	In-vehicle communication, Inter-vehicle communication Anytime, anywhere connectivity allows for personalized real-time information dissemination. Encourages telecommuting and provides greater work flexibility. Allows for anytime, anywhere video conferencing.

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Ultra high-speed Internet

Technology	Next generation optical networks, Dense Wave Division Multiplexing (DWDM) transmission technology
Features	Next generation optical networks will transfer data at the rate of 10 gigabits per second to 100 gbps (1-5)
Timeline / Costs	“the Internet2 community seeks to put these new technologies in the hands of businesses and consumers over the next 5 to 10 years.” (4)
Transportation Applications	“…the network of the future will support a whole new set of applications -- immersive collaboration environments, resource-sharing, real-time computation-intensive simulations, HDTV-quality video on demand” (4) Advanced telecommuting options, advanced traveler information systems and traffic management, drastic changes in life-style affecting travel demand.

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VANETs

Technology	“A **Vehicular Ad-Hoc Network**, or **VANET**, is a form of Mobile ad-hoc network, to provide communications among nearby vehicles and between vehicles and nearby fixed equipment, usually described as roadside equipment.” (1)
Features/Benefits	Benefits: Infrastructure light. Fully take advantage of online traffic information. Reduce congestion. Improve traffic productivity. Improve traffic safety. (2)
Transportation Applications	VANET is a technology that could significantly increase traffic productivity in the future. For safety purposes, police and fire vehicles are estimated to be instrumented first so that vehicles can communicate with each other (2). VANET related application can be categorized into safety and non-safety groups. (6) Prototype system in research: StreetSmart (7), TrafficView (8).
Challenges	Application of VANET faces several research challenges as below: The high vehicular mobility makes VANET subject to frequent fragment and low connectivity. (4,6) The varying traffic flow characteristics in the transportation network could possibly lead to different VANET in a single trip. (5) The possibility of malicious messages and the accessibility of any traveler's origin-destination information can pose a serious security and privacy problem.(3) All nodes sharing the same medium access channel will lead to congestion in very dense networks. (3,4,5, 6)

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Computing and Internet Technology

Collaboration software

Technology	Software that enables coordinated remote work. Examples include Microsoft Office Groove (1), Adobe Acrobat Connect (2), Webex (3), OfficeScape (4), Documentum (5), IBM collaboration platform (6)
Features	Collaborative Management software provides audio, video, data, and desktop sharing features in a single package. There are more than 100 collaboration tools on the market, with about 25 geared to small businesses. (7)
Timeline / Costs	Already available in market.
Transportation Applications	Enables telecommuting

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Augmented Reality

Technology	"Augmented reality (AR) is a field of computer research which deals with the combination of real world and computer generated data." (1)
Features/Benefits	Based on both software and hardware, it is a representation technique combing real world and computer generated data. The aim of this technique is to augment human perception by adding to it information not normally detectable by the human senses.
Timeline / Costs	Most of AR applications are under development and not in commercial use since for now, the technology is still too complicated and expensive for most companies. This situation will change as smaller and less expensive computer hardware is available. (5)
Transportation Applications	A main part of recent AR research focus on using live video imagery which is digitally processed and "augmented" by the addition of computer generated graphics. (1) AR technology is used in transportation simulation. It can offer a very realistic environment for driving enhancement as well as driving performance testing under different scenarios. (3) AR technology used in traffic tracking, for example "Augmented reality traffic control center" which combines data from a plurality of sensors to display real-time, information about traffic control objects, such as airplanes. (4)

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Personal travel assistant

Technology	Provides individuals, in vehicle and on foot, with location based information services.
Features	Brings together several features including navigation, traffic information, as well as utility and entertainment through stand-alone GPS or mobile phones. Initially, network-based location technologies from cellular service providers relied on triangulation using cell-tower signals to determine individual location; This method is increasingly giving way to leveraging built-in GPS chips in each handset, mostly because these chips have become dramatically more cost-effective and less power consumptive while improving location availability over the last several years. (6)
Timeline / Costs	Several models are available in the market including Garmin nuvi (1), TomTom (2) Of the $118 million in revenue that downloadable mobile applications such as location based services (LBS), weather applications, chat/community, and personal organization tools generated during Q2 2007, LBS represented 51 percent. (5) Today, Verizon Wireless (>50 million users), Sprint-Nextel (>50 million users), and Alltel (>10 million users) use GPS technology to provide E-911 services. (6)
Transportation Applications	Real-time information on traffic delays, enables personalized public transit information system, advanced route guidance capabilities Multi-modal information applications: Personalized multimodal trip planning, continuous on-trip information to multimodal travelers, information on transfers, assist travelers in finding their way to the destination address once they get off at the last stop provided by public transport. (3)
Challenges	While hardware technology is available, it is expensive and the corresponding software technology to provide real-time information content is lagging.

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HD video conferencing

Technology	Hi-def video conferencing service providers include: Cisco TelePresence (6), HP Halo Collaboration Studio (7), LifeSize (1), Polycom (10), Tandberg (4), UltraGrid (5), Teleris (8), Aethra (9), Sony (12)
Features	Also referred to as TelePresence, the system includes hi-definition cameras, monitors, bridges, and network equipment that allow two-way and multi-way video conferencing.
Timeline / Costs	LifeSize costs $8,000 to $12,000 (2, 3) The basic TelePresence 1000 model, designed for one-on-one meetings, is priced at $79,000 per station. TelePresence 3000, for larger meetings, is listed at $299,000 per station.
Transportation Applications	The main application industry is telemedicine. However with increasing availability, faster internet connections hi-def video conferencing will become more common. It can encourage telecommuting and offer alternate ways for individuals to socialize.
Challenges	High definition requires a large amount of bandwidth.

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Advanced route guidance systems

Technology	Examples include Mopar navigation (1)
Features	Advances in modeling route guidance (3,4) are enabling the implementation of next generation route guidance. With the introduction of European satellites for navigation – called GALILEO (2) - the accuracy in urban areas of GPS is likely to improve further.
Transportation Applications	-trip coordination (3), En-route guidance, incorporate real-time information about dynamic tolls Real-time feedback route guidance can help alleviate and dissolve heavy non-recurrent traffic congestion, and establish dynamic user equilibrium (6)
Challenges	Personalization of route guidance by incorporating user preferences is one of the most desired features (to ensure consistency) (7).

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Adaptive ramp metering

Technology	Algorithms that ensure efficient traffic flow. Examples include: ALINEA (1), stratified zone-metering (2), and their combinations (3).
Features	Ramp metering algorithms are either local or coordinated. ALINEA is a local feedback-control algorithm. Several studies compare the different ramp metering strategies (3,4)
Timeline / Costs	Ramp metering have been implemented over the past 30 years in several states and countries. But the availability of new and improved algorithms coupled with more accurate deduction and communication technologies, have improved the benefits of adopting ramp metering algorithms.
Transportation Applications	Congestion reduction and management technique; better flow also helps realize air quality improvement objectives. Smoother traffic flow will result in lesser accidents.

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Small wheeled transport

Technology	Small-Wheeled Transport includes travel involving wheeled luggage, walkers, skates, skateboards, push scooter, motorized scooter, wheelchairs, Segway, handcarts and wagons. (1)
Features	They are a category of Nonmotorized Transportation. Future implementations are likely to be electric with a range of options (2, 3) Segway (4) is a two-wheeled, self-balancing, electric transportation device - versatile, agile, short-range devices that utilize the patented dynamic stabilization technology and advanced alternative-power systems.
/ Timeline Costs	Several of these are available in the market but have seen only limited use.
Transportation Applications	Shifts automobile travel to alternative modes, Improves access to public transit, faster and efficient movement of pedestrians. Provides mobility for people who are physically and economically disadvantaged.
Challenges	Create conflicts when used on nonmotorized facilities. There are no clear policy measures outlined for the use of such devices. (5)

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Hybrid vehicles

Technology	Hybrid electric vehicles (HEV) comprising battery + ICE and plug-in hybrid electric vehicles (PHEV) Several (Toyota (1), Honda (2), Ford (3), General Motors (4)) commercially available Research efforts include DoE's FreedomCAR and Vehicle Technologies (FCVT) Program evaluating PHEV (5, 6), National Renewable Energy Laboratory's Advanced Vehicle and Fuels research program on HEV (7).
Features	Multiple technologies feed into developing hybrid vehicles including: Electric propulsion systems, Electrical energy storage systems (e.g., batteries, power capacitors), on-board data acquisition and control system. While several hybrid vehicles are available in passenger vehicle market, research is on-going to adopt hybrid technology for heavy-vehicles (8)
Timeline / Costs	The world hybrid-vehicle market, estimated at 384,000 vehicles in 2006, is projected to reach 1.1 million units in 2010 and 2 million units by 2015 (10) Despite rapid growth in hybrid-electric vehicle sales forecasted over the next few years, hybrid market share is expected to top out at 3 percent of the U.S. automotive market by 2010, according to the J.D. Power-LMC Automotive Forecasting Services Hybrid-Electric Vehicle Outlook (11) vehicle models utilizing a hybrid-electric powertrain still will remain a small portion of the market, growing from 1.3 percent of U.S. light-vehicle sales in 2005 to 4.2 percent market share by 2012. (12) Europe will see considerable growth in the number of HEVs with introduction of models such as Audi Q7, Porsche Cayene, Volkswagen Touran, BMW X3, Mercedes M&S Class in the years ahead, with volumes projected to be over 1.3 million vehicles in 2012. (1`3)
Challenges	Cost of battery, Energy storage density / vehicle range, Refueling facility (for pure electric vehicles) (9)

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Personalized rapid transit

Technology	Automated vehicles, reserved guideway, algorithms to control vehicle motions and match system capacity to demand
Features	PRT system includes fully automated vehicles capable of operation without human drivers over a reserved guideway. The vehicles are available on-demand, direct origin to destination service for an individual or a small group - typically 1 to 6 passengers. (1)
Timeline / Costs	Capital costs per mile are estimated at $5,458,013 while annual operating costs are $8,927,723. (3)
Challenges	Engineering and planning expertise, proprietary designs and vendor exclusivity, lack of standards are few of the challenges (2)

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Automated vehicles

Technology	Adaptive cruise control (5), lane departure warning, collision avoidance (7, 8) are all part of intelligent or automated vehicles (9, 11). Sensors to detect vehicles and obstacles, and intelligent algorithms (4) to enable these technologies.
Features	Automated vehicles were originally envisaged to be a part of automated highway systems (1, 2). However, lack of financial support as well as advances in vehicle-based technology led to automated vehicles not relying on highway-based technology. Vehicle based technology includes adaptive cruise control, lane departure warning, and collision warning devices. These have already been successfully demonstrated. Adaptive cruise control maintains a desired speed taking into account the vehicles in the front and back. Lane departure warning control vehicle's linear orientation and collision warning identifies and warns drivers of impending collision. These technologies together with advanced navigation systems will enable completely automated vehicle in the future.
Timeline / Costs	Technology has been demonstrated; May require more time before it becomes accepted and widely used.
Transportation Applications	Has significant impact on throughput (reduced congestion) and safety (no accidents). Adaptive cruise control breaks backward shockwave propagation. At an average speed of 67 miles per hour, if only one in five vehicles used adaptive cruise control, no traffic jams would form and traffic would generally flow freely. (6)
Challenges	Application of technology in mixed traffic where only a fraction of the vehicles have the technology (3); lacks wide spread tests in real situations. Understand human-factors in using the technology (10) When real-world factors such as inclement weather, difficult terrain, or limited visibility due to dust or nightfall are introduced, the problem of vehicle control at military-relevant speeds can quickly become intractable. (12)

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Flying cars

Technology	Hybrid of car and light aircraft; Examples include Moller's Skycar (3), Terrafugia's transition (4). NASA has been actively supporting the development of Personal Air Vehicles (PAVs) (6). What is making aircars a more imaginable possibility is information technology. Thanks to highly sophisticated and compact computers, GPS and other advanced navigational technologies, and aerial collision-avoidance systems, it is possible to build aircraft that, through a combination of on-board guidance systems and ground control, would fly themselves. (2)
Features	Capabilities may include vertical-take-off-and-landing,
Timeline / Costs	Though several prototypes have been demonstrated, wide spread use of Flying cars may be 25 years or more away (5). Vehicles may become available in the market as early as 2009 (1). Initial costs range from $150000 (4) to $1 Million (2). But in the longer term costs could come down to $50000 (2).
Transportation Applications	Flying cars could significantly reduce congestion; vehicles can travel through the three dimensional space and fly straight to destinations instead of having to follow flat guided pathways.
Challenges	The greatest nontechnical challenge is meeting the regulatory requirements of both the FAA and the National Highway and Traffic Safety Administration (NHTSA). To satisfy FAA regulations for the category of light sports aircraft, the vehicle must have a maximum level speed of 138 miles per hour, a one- or two-person occupancy, and fixed landing gear, among other things. For the NHTSA, the Transition must be able to pass the same requirements that a regular car would. (1) Technical challenges include safety – how to ensure flying cars do not get in the way of each other, and how to deal with emergency issues.

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GPS

Technology	Augmentations to GPS will enable more accurate location. These include (1): Nationwide Differential GPS System (NDGPS), Wide Area Augmentation System (WAAS), Continuously Operating Reference Station (CORS), Global Differential GPS (GDGPS), International GNSS Service (IGS).
Features	Accuracy of GPS has been improving with enhancements (2). Targets include 5 -10 m: by 2009 and 1- 5 m: by 2013. Further the enhancements will improve reception near tall buildings, canyons, etc. It also will allow devices to reduce the amount of power they need to expend to receive a GPS signal. This will make putting accurate GPS receivers into mobile phones, watches, etc easier. (3) Introduction of Galileo system will further enhance the capabilities of GPS receivers (4). GALILEO will be fully operable in 2008 .
Transportation Applications	More accurate GPS enables better navigation systems and the potential for use of these systems in flying cars. Mobile and wearable GPS allows for better personal navigation and quicker emergency response. GPS may also aid in collecting travel behavior data (7) that could be used in building models for planning and operations.
Challenges	Shared use of frequency bands between GPS and Galileo systems. The future for the navigation receiver user should be seen in the combined GPS / GALILEO receiver that will be capable of computing signals from both constellations (GPS + Galileo). This will provide for the best possible performance, accuracy and reliability. In the short-term the challenge is to develop GPS-denied location technologies. (5)

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Radio Frequency Identification (RFID)

Technology	Passive, active, or semi-passive transponder devices with memory for data storage, small battery, and antenna for capturing and transmitting radio signals. (1)
Features	An RFID tag is an object that can be applied to or incorporated into a product, animal, or person for the purpose of identification using radio waves. Passive tags have practical read distances ranging from about 10 cm (4 in.) up to a few meters. Active tags typically have much longer range (approximately 500 m/1500 feet) and larger memories than passive tags. Uses of RFID tags include in passports, tracking goods, animals, and people, automotive control etc. Future RFID tags will shrink in size (example HP's memory spot 6, 7) to few millimeters, have greater storage capacity, faster transfer rates, and longer transfer range.
Timeline / Costs	RFID market will swell from $2.8 billion in 2006 to $8.1 billion by 2010 (2) the price of RFID tags has fallen, from around $2 each in 1999 to around $0.10-0.15 today [2007] (2) SmartCode, an Israeli RFID systems provider, is offering UHF [RFID] inlays for 5 cents apiece in volumes of 100 million or more (3) the value of the market, including hardware, systems and services, is expected to be multiplied by 10 between 2006 and 2016. The number of tags delivered in 10 years will be over 450 times the number actually to be delivered this year. (4)
Transportation Applications	Business applications that use RFID, such as transport and logistics, access control, real time location, supply chain management, manufacturing and processing, agriculture, medicine and pharmaceuticals, should continue to grow strongly. But RFID devices will also pervade the Government sector (e.g. eGovernment, national defense and security) and the consumer field (e.g. personal safety, sports and leisure, smart homes and smart cities). (4) Public transport cards, the biometric passport, micro-payment systems, office ID tokens, customer loyalty cards, etcetera. (5) Applications range from e-payment that will enable pricing on road and transit systems to security – where RFID will be used for goods and possibly individual identification.
Challenges	Identity theft, fear of being overseen all the time. (5) Cost is still an issue for large scale implementations – active tags, the ones that are most likely to be used in Transportation still cost over a dollar each.

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MEMS sensors

Technology	Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. (1) MEMS technology have been applied to motion-based approach to navigation within and between pages in PDAs or MP3 players, in game controllers, MEMS sensors allow the player to play just moving the controller/pad (2)
Features	Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose. (1)
Timeline / Costs	Air bag accelerometers that detects the beginning of the car's sudden impact by measuring the movement of an impossibly small (.10 microgram) "mass," which then causes the air bag to fire have been in use for about 10 years (4) “The first step in development is to imagine a need and an application. The most obvious would be an application in which one would take a macro sensor or control system and miniaturize it. But one must also consider applications where no macro device has ever existed. Because of their size and low cost, MEMS could make measurement and control strategies that were not possible with macro or discrete devices now feasible. MEMS have the problem of a high initial development cost. But once developed, MEMS can be mass-produced for a relatively low per-unit cost: $5 to $50 each.” (5)
Transportation Applications	MEMS can be used in Advanced Driver Assistance Systems, Crash Detection, Electronic Stability Control, LED Taillight Driver, Navigation (3) MEMS can be used in both monitoring and testing of transportation infrastructure (5) In transportation air-quality studies, MEMS “smart dust” has the potential to collect data for both analysis and forecasting the air-quality. (5) The majority of the potential MEMS applications in transportation infrastructure will act as sensors. These include sensors used in monitoring temperature, crack measurements and monitoring, corrosion testing and monitoring, alkali-silica reaction (ASR) and other related reactions in concrete, and reliability of welding units in structural steel. (5) MEMS thermal accelerometers in navigation systems with maps and global positioning satellite capabilities, MEMS-based display can overlay automobile diagnostics and repair instructions directly to the technician, seat-based MEMS for occupant deduction (6)
Challenges	To begin with, one drawback to extensive MEMS application is that MEMS products are application specific rather than generic. The vast majority of applications require solutions that necessitate the funding and completion of an evaluation or development program. In addition, the environment in which the MEMS devices has to operate and the possible effect of the environment on the performance of the MEMS device has to be assessed. Protection of the MEMS device against damage from installation or construction procedures as well as from contact with materials is paramount. (5)

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Smart Cards

Techno-logy	Smart cards are pocket sized cards with embedded integrated circuits which can process information. Examples in transportation: Oyster card in London, Octopus card in Hong Kong
Features	Use in public transit ticketing ensures: Reduce passenger/staff fraud levels, Reduce delays at entry gates, Improve cash handling procedures, Reduce staff handling costs and improve staff utilization, Flexibility in fare policies. (3)
Timeline / Costs	Typical costs range from $2.00 to $10.00.
Transportation Applications	Secure identification (e-passport) (4), security personnel identification at ports (11) In transit (10) and parking systems (5), can be coupled with other financial transactions (6)
Challen-ges	Smart card system security (1,2) A major impediment to the widespread use of smart cards has been interoperability (7, 8)

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Machine Vision

Technology	Machine vision involves the digitization, manipulation, and analysis of images, usually within a computer. (1)
Features	Machine vision has been applied in Industrial image processing for quality control, identify swimmers who are drowning (2), fire alert system (3), and many more (6)
Timeline / Costs	Most machine vision systems have already been tested and implemented. However it has been applied in only limited context in transportation
Transportation Applications	Machine vision has applications in traffic monitoring, navigation, and transport safety (4) Can deduct detecting lane markings, vehicles, pedestrians, road signs, traffic conditions, traffic incidents, and even driver drowsiness. (5) Road/Railroad Structure Analysis, Seaport Monitoring, vehicle License/Number Plate Analysis (6) Machine vision provides more accurate classification capabilities (7) compared to other sensor types.
Challenges	Challenges include making machine-vision systems less expensive, more compact, and more robust in various weather and traffic conditions. (5)

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Biometric Identification

Technology	Biometrics is the science of identifying people using physiological features. Biometric identification includes finger-print, face, DNA, hand geometry, voice, retina and Iris identification. (1)
Features	Important characteristics of a biometric identification technology are accuracy, ease of use, user acceptance, ease of implementation, and cost (1)
Transportation Applications	Security Fare-payment Access restriction
Challenges	Fingerprint and retina are highly accurate; while Iris and Face are not very accurate. In terms of ease of use, face and voice recognition are best suited; fingerprint and retina have low user acceptance; Iris recognition is expensive.

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Appendix B: Workshop Participant Comments

Responses from Participants

Question 1. Your comments on the project reports and study findings:

Question 2. Your comments on the project conference/workshop:

Question 3. Your comments on any other technologies or general comments:

Response:

Ken Diamondstone
Bklyu Solid Waste Advisory Board

1. Study findings and reports were useful on the subjects covered. However very little focus was given to previous issues associated with high tech innovations.
2. The subject matter covered exhibited NYMTC blind commitment to automobiles and trucks – any "comprehensive survey of emerging technology Affecting Transportation for the NY Metro Area" should have addressed rail freight, shipping, use of barges, use of water ferries and water taxi can become part of an intermodal solution and what technologies have been on integration of these significantly reduced carbon footprint systems.

Robert Matson
The Innovation Works, Inc.

2. Excellent – great choice of panelists.
3. The neglect of addressing bicycles as a low-tech solution to congestion issues was unfortunate.

Corey B. Bearak
Keep NYC Congestion Tax Free

1. All reports indicated measures to address transp. + transit needs + ability to implement. There is a need to focus more on the costs of implementation of each mode, alternative.
2. I expected more discussion on various "value pricing" measures. The focus on measures seemed less focused on urban areas but mobility between urban areas.

Leonard Kosliv
PANYNJ

1. Include more information on the security & counter-terrorism technology also for parking management technology.
2. Very well organized and informative.

Irene Seo
Columbia Edu

1. Need more information about transit technology. Cost-benefit analysis could be useful.
2. Nice facility and coordination

Sarah Kaufman
NYC Transit

1. Interesting report with useful information.
2. Needed more focus on transit, bikes + pedestrians, the primary modes of transport in the NYC region.
3. There are many technologies emerging for subways, but none were discussed. I'd like to see this conference again, but transit-focused. Also: Products like ZipCar are influential in the NYC region.

Michael Chiume
NYCMTC

1. Very useful, informative and shows intensive research in new technology application to transportation aspect.
2. Conference/Workshop well managed with highly knowledgeable speakers.

Angela Bigelow
PLANTRONICS

1. Excellent, great update on initiative + efforts to support funding.
2. Excellent again – Break out session was very informative – speakers were great – engaged audience with funding and national as well as regional issues.
3. Overall, great job – It would have been nice to meet each break – out session as opposed to just one, but still very good.

Chris Roltner
Ecology + Environment, Inc.

1. TDM-T its technology provides information but dies it really change behavior and trip change?
2. Nice job – thanks for information.
3. Focus on more intermodal work. Focus on increasing load of existing facilities. Focus on temporal expansions of system.

Nicole Belson Goluboff
Nicole Belson Goluboff, Esq.
31 Lawrence Road
Scarsdale, NY 10583
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found the workshop very informative. I learned a lot about technologies and/or applications of technologies with which I was unfamiliar.

I was impressed by the considerable interest in telecommuting. I hope the final report will emphasize the benefits of this strategy for relieving traffic congestion, conserving fuel and reducing greenhouse gas emissions.

The topics of how to overcome managerial resistance to telecommuting and how to address the legal implications of telecommuting generated significant discussion in the breakout session on telecommuting.

Because managerial resistance to telecommuting often stems, in part, from concerns about data security, readers of the final report might benefit from a discussion of the technologies that help assure such security.

I believe readers would also benefit from a discussion of some of the current legal impediments to the growth of this transportation strategy, including, New York State's practice of double taxing nonresidents who work for New York employers and sometimes telecommute. If the technologies that facilitate telework are to do their job, the legal environment must be hospitable to the practice of telework.

Thank you for the opportunity to participate in this workshop.

Walter C. Houston
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Thanks for a fascinating and enlightening workshop. As our region, state, and in my case, city begins to look toward the future, mobility and sustainability are at the forefront of planning efforts; and the Bronx is no different, as Gerry Bogacz can attest to. As we implement and further plan the South Bronx Initiative along with other urban renewal projects, transportation and mobility are key factors in the design and care of our neighborhood's quality of life. Many of the processes outlined at your workshop has application potential in communities like the South Bronx and I hope NYMTC and partners keep the LDC of the West Bronx abreast of further study and mobility models.

As for direct feedback of the workshop in the categories mentioned, I shall attempt to describe my thoughts as best possible; however, these are just thoughts of a lay community worker not well versed in the theoretical principles of transportation:

1. Reports & Study Findings

All the studies were intriguing. However, strategies on Congestion Reduction Management made the deepest impact for me. Your "Active Traffic Management" (ATM) process has distinct application potential here in the South Bronx especially in and around our Civic Center area. The Civic Center houses a new courts complex, the Bronx municipal building, the new Yankee Stadium, a new million-square-foot mega mall (the Bronx Gateway Shopping Center), and a new high school complex (4 schools at one site) that will cater to 2500 students. This area of the Southwest Bronx has long suffered with traffic congestion from the courts, Yankee Stadium (old), and commuters passing through as it is a regional gateway. ATM's Variable Speed Limits, Signal Timing, as well as Dynamic Signs and Re-Routing could have far reaching congestion reducing affects on neighborhoods of this section of the Bronx by increasing efficiency of local and regional commutes, increasing pedestrian safety and well being, promoting other means of transportation (mass transit, bikes, etc…), as well as relieving health conditions caused by traffic throughout this community.

ATM's Managed Lanes and Shoulder Management have "future" applications for the Bronx's Bruckner Expressway, Major Deegan Expressway, and Cross Bronx Expressway. These expressways serve as gateways to the region; however, these expressways surround the South Bronx and traffic jams along with gridlock are the daily norm for these expressways. As result, high respiratory conditions and stunted mental development for those who live in close proximity to these expressways prevail. NYMTC and partners' overview of ATM strategies, like Managed Lanes and Shoulder Management, could have a direct benefit on communities surrounded by these Bronx expressways and serve as a model for other like communities in the region and the nation.

2. Workshop

The workshop was quite informative. I thought there were going to be more participants, however the smaller number of folks made for a more intimate discussion. Breakout sessions were also enlightening. I always like when topics are discussed in a group context; you get to hear a variety of perspectives. All-in-all, the workshop was good and the information provided relevant and thought provoking.

Thanks again for the opportunity and information, please keep me further informed…!

Appendix C Bios of Invited Speakers

Mr. Chuck Wilsker is the President and CEO of the Telework Coalition (TelCoa), a not for profit association headquartered in Washington, DC. TelCoa works to enable the advancement of Virtual, Mobile, and Distributed Work through Research, Education, Technology, and Legislation. He is the past President of the Capitol Telecommunications Professionals, a member of the Internet Society, and deputy chair of the Telecommuting Task Force at the Northern Virginia Technology Council. He was also on the Transportation and Environment Committee of the Metropolitan Washington Board of Trade where he chaired the Telework Task Force. Recently, Chuck was invited to participate in meetings at the United Nations in New York City to help promote "Accessible and Assistive Information and Communications Technologies for Persons with Disabilities".

Mr. Richard Wallace, M.S., is a Senior Project Manager with the Center for Automotive Research (CAR). He serves as the project manager for CAR's vehicle-infrastructure integration efforts with the Michigan Department of Transportation and plays a leading role in CAR's work to establish the Connected Vehicle Proving Center (CVPC). He also serves as project manager for CAR's component of a US DOT RITA project to apply remote sensing to international border crossing operations. Mr. Wallace has 17 years of experience in designing, conducting, and managing transportation projects and research, including the evaluation of several intelligent transportation systems (ITS) field tests in the State of Michigan (including the FAST-TRAC, DIRECT, DIRECT II, and SMART and AATA advanced public transportation system tests).

Dr. John Sullivan, is the Research Scientist and Head for Sustainable Transportation Systems at University of Michigan Transportation Research Institute. Dr. Sullivan has over 30 years of industrial research experience at Ford Motor Company's Scientific Research Laboratory where he led several research projects including on Advanced Vehicle Safety, Alternative Fuels, and Transportation Sustainability. Dr. Sullivan has published over 120 papers and company reports, given over 160 presentations, and holds 4 patents with one pending. At UMTRI, Dr. Sullivan focuses on research in the areas of alternative fuels, life cycle performance of advanced vehicle systems, diffusion of advanced transportation innovation into the automotive marketplace, value of advanced vehicle technology to the consumer, and the sustainability and resilience of coupled infrastructures.

Dr. Yuko J. Nakanishi, is Founder and Principal of NAKANISHI RESEARCH AND CONSULTING LLC, based in New York City. For the last 15 years, she has been championing both technology and common sense to make transportation systems safe, secure, efficient, and accessible to all. Dr. Nakanishi is the Vice President of ITS-NY and has been actively involved in technology planning and management, security awareness efforts, public performance management, and training and education. She is also Chair of the Transportation Research Board Committee on Critical Transportation Infrastructure Protection's Subcommittee on Training, Education, and Technology Transfer and regularly participates as a panel member on Cooperative Research Program project panels. In 2006, she received the Transportation Research Board Excellence Award for Service.

Dr. Satish Ukkusuri is an Assistant Professor at the Department of Civil and Environmental Engineering at the Rensselaer Polytechnic Institute. He is the author of more than thirty articles on transportation modeling. Professor Ukkusuri received the SWUTC Robert Herman Award for outstanding research on transportation network modeling and leadership in transportation during the year 2005. He was also awarded the Blitman Career Development Chair at RPI. He is member of the Transportation Research Board (TRB) and the Institute of Operations Research and Management Science (INFORMS). He was elected as a member of the Transportation Network Modeling Committee at TRB in 2006. He is the member of the technical program committee of IEEE Vehicular Transportation Conference for 2007 in Baltimore, MD.

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